Shorter Contributions to Paleontology and Stratigraphy

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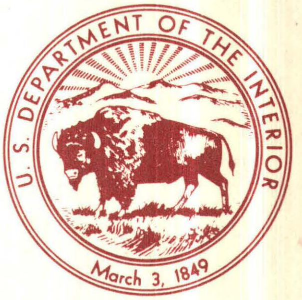

Shorter Contributions to Paleontology and Stratigraphy

Edited by WILLIAM J. SANDO

U.S. GEOLOGICAL SURVEY BULLETIN 1837

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CHAPTER A

Latest Cambrian and Earliest Ordovician Conodonts from the Conococheague and Stonehenge Limestones of Northwestern Virginia

By RANDALL C. ORNDORFF

Conodonts from two sections place the
base of the Ordovician System within
the upper Conococheague Limestone

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SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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Latest Cambrian and Earliest Ordovician Conodonts from the Conococheague and Stonehenge Limestones of Northwestern Virginia

By Randall C. Orndorff

Abstract

Conodonts from two sections in northwestern Virginia demonstrate that zonations and faunal intervals for uppermost Cambrian and lowest Ordovician strata established elsewhere in North America can be recognized in the central Appalachians. Several North American Midcontinent Province cratonic and miogeoclinal faunal units are present in the Conococheague Limestone and the overlying Stonehenge Limestone, including the *Proconodontus* and *Cordylodus proavus* Zones, and Conodont Faunas B and C. At present the Cambrian-Ordovician boundary in North America is based on trilobites and is placed at the base of the *Missisquoia* Zone. This systemic boundary can be approximated, using conodonts, as the lowest subzone of the *Cordylodus proavus* Zone. A horizon 43 m below the base of the Stonehenge Limestone yielded the lowest *Cordylodus proavus* Zone conodonts, demonstrating that in northwestern Virginia the Cambrian-Ordovician boundary, as now recognized, lies within the upper part of the Conococheague Limestone. The boundary between the *Proconodontus* and *Cordylodus proavus* Zones in many sections around the world is thought to be a eustatic event. This event may be represented in the rocks of northwestern Virginia as an unconformity above a Conococheague Limestone cycle in which the two lowest subzones of the *Cordylodus proavus* Zone either are missing or are represented by only 2 m of strata.

INTRODUCTION

The Shenandoah Valley of northwestern Virginia is along the eastern margin of the Valley and Ridge province; the valley is underlain by folded and thrust-faulted, chiefly carbonate strata of Cambrian through Middle Ordovician age (fig. 1). Although fossils from these rocks have been reported in previous geologic studies, the Cambrian-Ordovician interval has not been documented paleontologically in northwestern Virginia. Sando (1957, 1958) established the stratigraphic position of the Cambrian-Ordovician boundary in the Great Valley of Pennsylvania and western Maryland by utilizing various fossil groups, including brachiopods, mollusks, and trilobites. In these earlier studies, Hass (*in* Sando, 1958) first illustrated conodonts from Cambrian-Ordovician boundary strata in the central Appalachians. Since then, little has been added to the conodont biostratigraphic data base for the region. The objective of this investigation was to use conodonts to locate the Cambrian-Ordovician boundary in northwestern Virginia.

The sections sampled for conodonts in this study are west of the Massanutten synclinorium and east of the North Mountain fault, a structure that places Cambrian carbonate rocks of the Elbrook Formation above Devonian clastic rocks (fig. 1). These sections are 32.5 km apart and are along Narrow Passage Creek, 3 km southwest of Woodstock, Shenandoah County; and along Honey Run, 4 km northwest of Timberville, Rockingham County. Sampled strata include the upper part of the Conococheague Limestone and the lower part of the Stonehenge Limestone. Although the limestone unit above the Conococheague Limestone is mapped as Stonehenge by many Virginia mappers, it is apparent that this interval differs considerably from rocks in Pennsylvania and Maryland where the Stonehenge was first described.

Acknowledgments

This paper is part of a master's thesis completed at Old Dominion University, Norfolk, Va., under the supervision of J.E. Repetski (U.S. Geological Survey, Washington, D.C.), S.J. Culver, and C.F. Koch. Among others I wish to thank J.F. Miller, Southwest Missouri State University, for critical review of the manuscript. I also thank J.F. Taylor, E.K. Rader, and W.J. Sando for insight and discussion of the lithostratigraphic problems of this interval in northwestern Virginia.

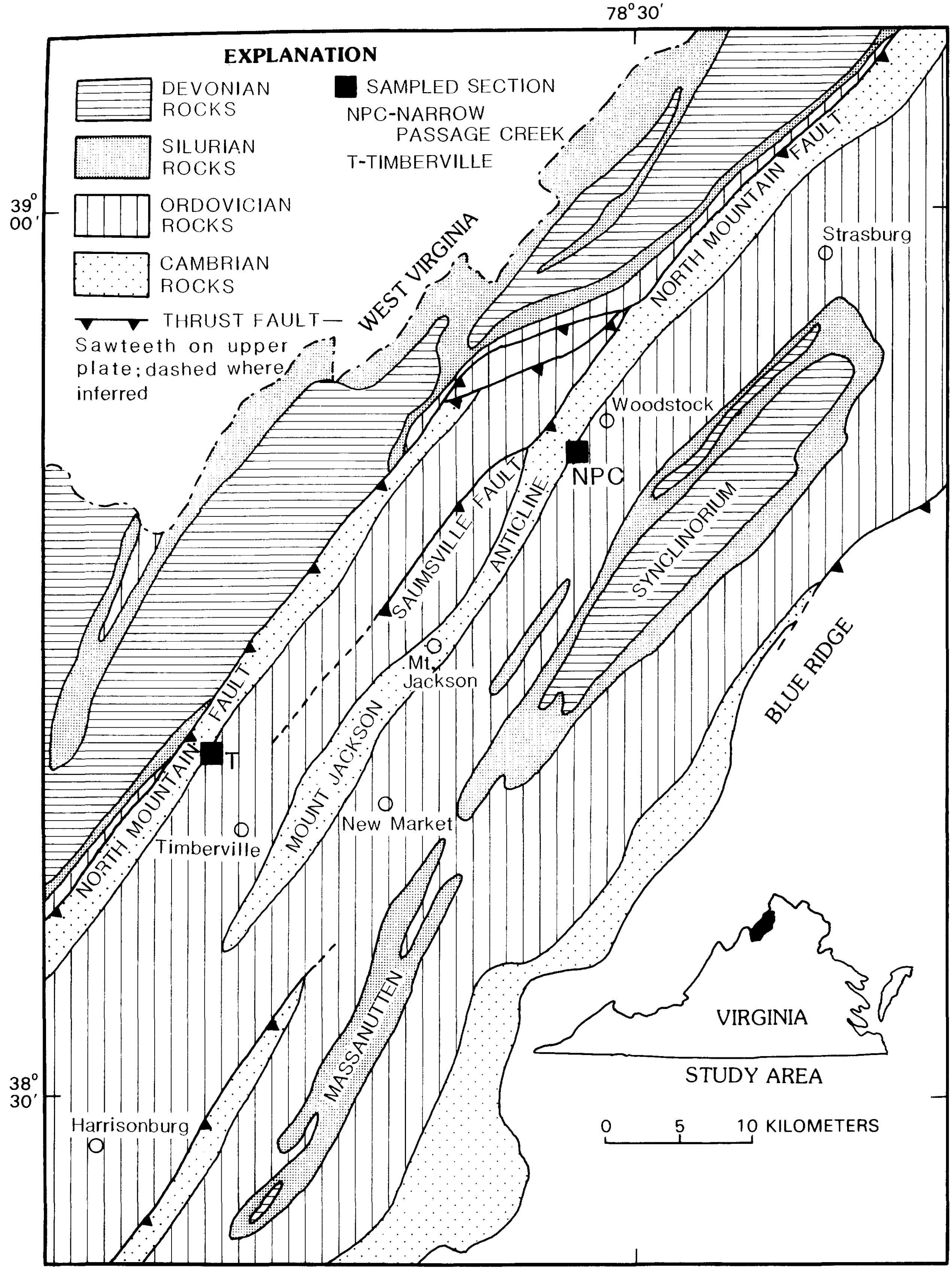

Figure 1. Generalized geologic map of part of northwestern Virginia showing locations of sampled sections (modified from Hack, 1965).

LITHOSTRATIGRAPHY

The Conococheague Limestone is 750 m thick in northwestern Virginia and is composed of limestone, dolostone, sandstone, and siltstone. These lithologies occur in 5- to 12-m-thick shallowing-upward cycles that consist of subtidal oolitic lime grainstone, intraclastic lime grainstone, and thrombolitic and stromatolitic lime boundstone in the lower part, and supratidal laminated dolostone and sandstone in the upper part. The boundary between the cycles is sharp where the peritidal carbonate cap is overlain by subtidal carbonates of the following cycle.

Overlying the Conococheague Limestone in northwestern Virginia is the Stonehenge Limestone (fig. 2), which was first described by Stose (1908) as the lowest member of the Beekmantown Formation in Franklin County, Pennsylvania, and later raised to formational rank by Sando (1956). Several typical Conococheague lithologies (mainly lime grainstones) occur within the Stonehenge Limestone. The 150 m of Stonehenge strata in northwestern Virginia includes a thick-bedded to very thick bedded gray to dark-gray limestone with crinkly siliceous laminations, minor algal bioherms, and intraclastic lime grainstone. In this study the Conococheague-Stonehenge contact is placed at the base of the lowest thick-bedded limestone with crinkly siliceous laminations, a characteristic Stonehenge lithology. The lower part of the Stonehenge in northwestern Virginia is not consistent with the lower member of the Stonehenge described by Sando (1958) for sections in Maryland. Sando (oral commun., 1986) noted a change in the lithofacies of the lower part of the unit in Virginia and believed the formation could not be mapped as Stonehenge. The major difference in the Stonehenge of Virginia from that of Maryland is that the distinctive algal unit at the base of the Stonehenge and the lower member are not recognized in northwestern Virginia. Others, however, have found it possible to map the Stonehenge in Virginia as far south as Roanoke (Henika, 1981). Young and Rader (1974) and Rader and Biggs (1976) also used the name Stonehenge for the limestone above the Conococheague Limestone in northwestern Virginia.

FAUNAL EVALUATION

Conodont biostratigraphic units recognized for the uppermost Cambrian and lowest Ordovician of northwestern Virginia are correlated with trilobite-based biostratigraphic units in figure 3. At this time the Cambrian-Ordovician boundary in North America is placed at the base of the *Missisquoia* Zone (Winston and Nicholls, 1967). However, it should be noted that the International Working Group on the Cambrian-Ordovician Boundary, part of the International Subcommission on Stratigraphy, International Union of Geological Sciences, is in the process of selecting an international standard for this systemic boundary. It may be a

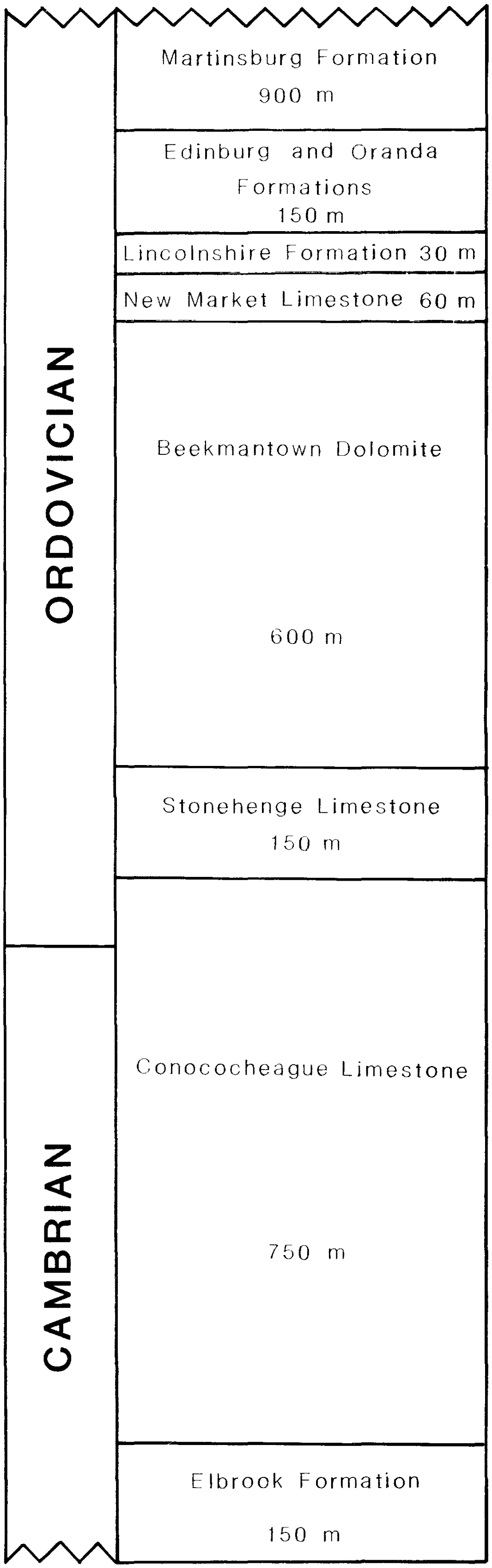

Figure 2. Cambrian and Ordovician formations, with thicknesses, in northwestern Virginia (from Young and Rader, 1974).

Series	Conodont zone or fauna	Conodont subzone or subfauna	Trilobite subzone	Trilobite zone
LOWER ORDOVICIAN	Fauna C		Bellefontia chamberlaini	Bellefontia–Xenostegium
			Bellefontia collieana	
			Xenostegium franklinense	
			Symphysurina woosteri	Symphysurina
	Fauna B	Upper part	Symphysurina bulbosa	
		Lower part	Symphysurina brevispicata	
	Cordylodus proavus	Clavohamulus hintzei		
		Hirsutodontus simplex		
		Clavohamulus elongatus	Missisquoia typicalis	Missisquoia
		Fryxellodontus inornatus		
		Hirsutodontus hirsutus	Missisquoia depressa	
UPPER CAMBRIAN			Eurekia apopsis	Saukia
	Proconodontus	Cambrooistodus minutus	Saukiella serotina	
		Eoconodontus notchpeakensis	Saukiella junia	
		Proconodontus muelleri		
			Rasettia magna	
		Proconodontus posterocostatus		

Figure 3. Conodont and trilobite zones and faunal intervals for the uppermost Cambrian and lowermost Ordovician (from Miller and others, 1982).

horizon above the *Missisquoia* Zone, possibly at the base of the conodont *Hirsutodontus simplex* Subzone of the *Cordylodus proavus* Zone (Derby, 1986). The base of the *Missisquoia* Zone falls within the lowest conodont subzone (*Hirsutodontus hirsutus* Subzone) of the *Cordylodus proavus* Zone as developed by Miller (1978, 1980). The base of this subzone serves as an approximation of the Cambrian-Ordovician boundary in this study, and it is another horizon being considered for the international standard. Ethington and Clark (1971) established five conodont faunal intervals for the Early Ordovician (Faunas A to E). Miller (1978, 1980) reevaluated the latest Cambrian and earliest Ordovician faunas and erected the *Proconodontus* Zone and the *Cordylodus proavus* Zone, the latter equivalent in part to Fauna A of Ethington and Clark.

Conodont faunas recovered from northwestern Virginia represent several North American Midcontinent Province cratonic and miogeoclinal faunal units. The Narrow Passage Creek section yielded conodonts indicative of the *Proconodontus* and *Cordylodus proavus* Zones and Conodont Faunas B and C. The Timberville section yielded conodonts from the *Cordylodus proavus* Zone and Conodont Faunas B and C.

Proconodontus Zone

The lowest productive sample from the Narrow Passage Creek section was from the upper part of the Conococheague Limestone, 5 m above the base of the sampled section, and yielded *Eoconodontus notchpeakensis* (Miller), *Proconodontus serratus* Miller, *Prooneotodus rotundatus* (Druce and Jones), and *Teridontus nakamurai* (Nogami). Specimens of *Cambrooistodus minutus* (Miller) were first recovered 53.5 m higher (fig. 4). Because *Cambrooistodus minutus* and *Proconodontus serratus* are not known to range into the overlying *Cordylodus proavus* Zone, the lower 64 m of the Narrow Passage Creek section is within the *Proconodontus* Zone.

No conodonts indicative of the *Proconodontus* Zone were recovered from the Timberville section.

Cordylodus proavus Zone

The lowest *Cordylodus proavus* Zone conodonts from the Narrow Passage Creek section occur 65 m above the base of the section. This horizon yielded *Clavohamulus elongatus*? Miller, *Cordylodus proavus* Müller, *Eoconodontus notchpeakensis* (Miller), *Fryxellodontus inornatus* Miller, *F. lineatus* Miller, *Hirsutodontus hirsutus* Miller, *Semiacontiodus nogamii* (Miller), and *Teridontus nakamurai*. The association of *Fryxellodontus inornatus* and *F. lineatus* with *Clavohamulus elongatus*? and *Semiacontiodus nogamii* suggests that this horizon lies within the *Clavohamulus elongatus* Subzone. *Clavohamulus elongatus* and *Semiacontiodus nogamii* are not known to occur below the *C. elongatus* Subzone, and both *Fryxellodontus inornatus* and *F. lineatus* may extend to the top of the *C. elongatus* Subzone. The remainder of the *Cordylodus proavus* Zone interval yielded few conodonts. However, *Utahconus utahensis* (Miller) first occurs 108 m above the base of the section, marking the base of the *Hirsutodontus simplex* Subzone.

Cordylodus proavus Zone conodonts occur at the base of the Timberville section (for example, *Hirsutodontus hirsutus*; fig. 5). Because conodonts are sparse in this interval, subzones could not be recognized. The *Cordylodus proavus* Zone extends at least to 67 m above the base of the section, and specimens of *Eoconodontus notchpeakensis*, *Teridontus nakamurai*, and *Utahconus utahensis* were recovered from this zone.

Conodont Fauna B

Fauna B of Ethington and Clark (1971) is characterized by an association of conodonts, the lower limit of which is defined by the lowest occurrence of *Cordylodus lindstromi* Druce and Jones. Miller and others (1982) divided this faunal interval into a lower part with *Cordylodus lindstromi* and an upper part with *Cordylodus angulatus*. In both the Narrow Passage Creek and Timberville sections, *Cordylodus lindstromi* was first recovered with species characteristic of Fauna C and therefore is not useful as a local approximation of Fauna B. Other conodonts characteristic of Fauna B were used to identify this interval. At Narrow Passage Creek, the lowest occurrence of *"Oistodus" triangularis* Furnish s.f. at 142 m above the base of the section was used to approximate the lower limit of Fauna B because this species is not known from the *Cordylodus proavus* Zone. The lowest occurrence of *"Oistodus" triangularis* s.f. at the Timberville section is at 90 m above the base of the section. However, *Cordylodus angulatus* Pander was recovered 3 m higher, indicating that the horizon 93 m above the base is within the upper part of Fauna B or in Fauna C. Therefore, it is difficult to recognize Fauna B in the Timberville section. Fauna B may be present in this section, but larger samples would be required to document this possibility.

Conodont Fauna C

Loxodus bransoni Furnish is a distinctive species occurring within Fauna C (Ethington and Clark, 1971); however, in this investigation as in others, it was not abundant. Repetski and Ethington (1983) suggested that *Rossodus manitouensis* Repetski and Ethington is characteristic of Fauna C. By using the lowest occurrence of this species as an approximation of the faunal interval, Fauna C can be delineated at both sections. *Rossodus manitouensis* first occurs at 169 m above the base of the Narrow Passage Creek

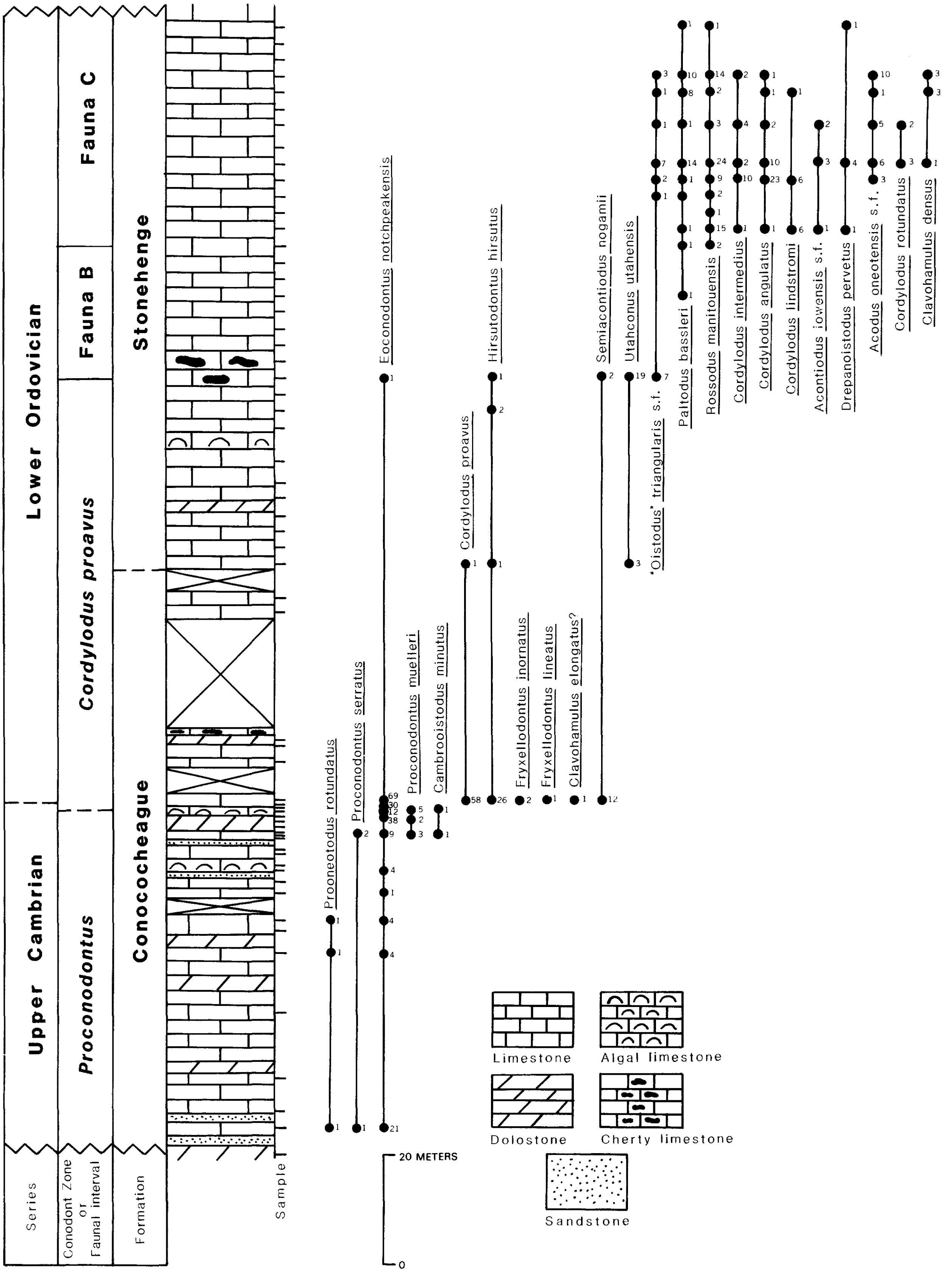

Figure 4. Distributions of selected conodont species in the Narrow Passage Creek section, along Narrow Passage Creek, 3 km southwest of Woodstock, Shenandoah County, along State Road 605, lat 38° 51.8′ N., long 78° 30.0′ W., Edinburg 7.5-minute quadrangle. Numerals next to dots represent number of specimens.

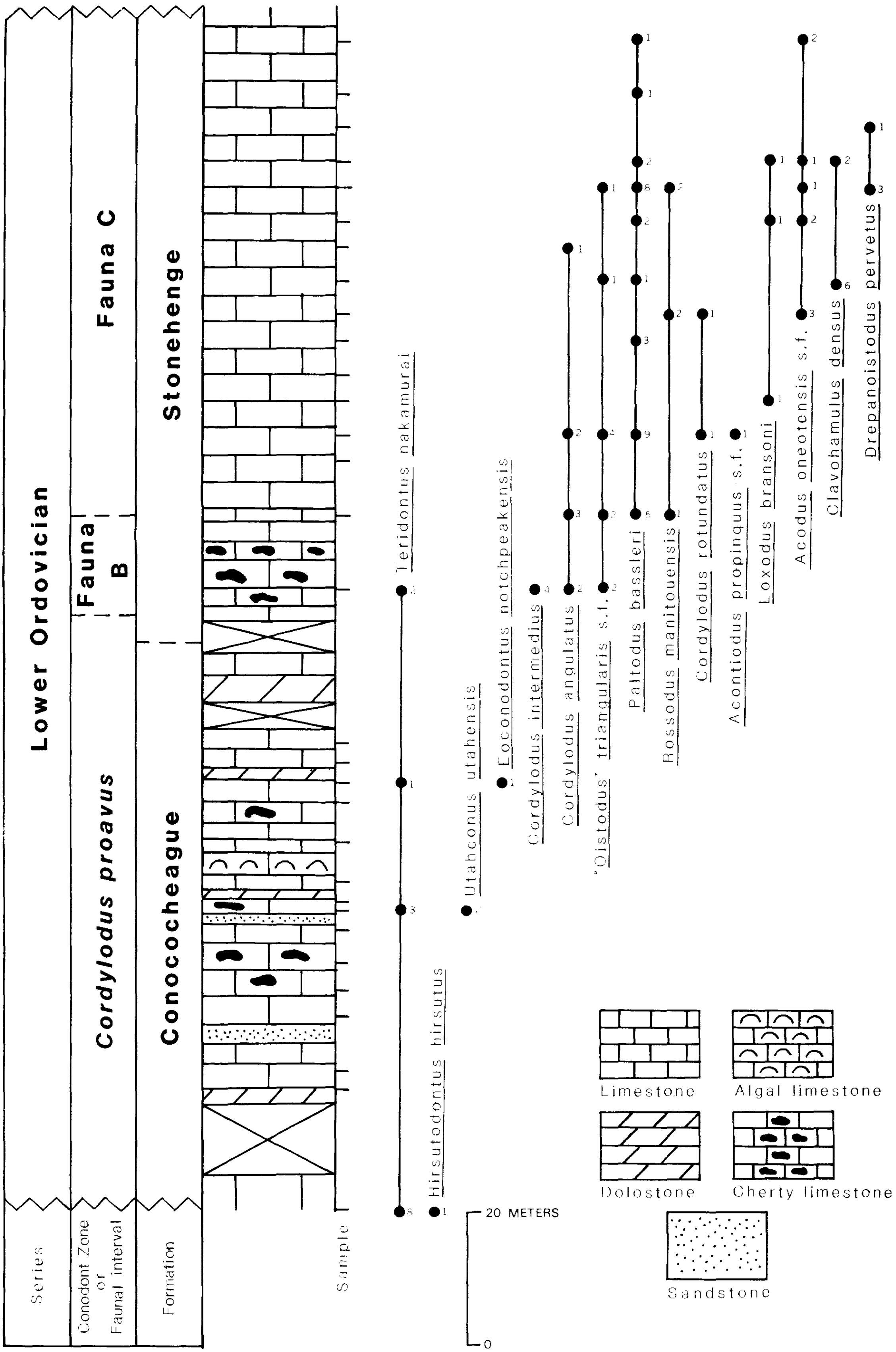

Figure 5. Distributions of selected conodont species in the Timberville section, along Honey Run, 4 km northwest of Timberville, Rockingham County, along State Road 881, lat 38° 40.3′ N., long 78° 48.5′ W., Timberville 7.5-minute quadrangle. Numerals next to dots represent number of specimens.

section and 104 m above the base of the section at Timberville. A greater diversity of conodonts appears in the interval of Fauna C; these taxa are listed in the systematics section and selected species are shown in figures 4 and 5. The uppermost beds of both sections are within the interval of Fauna C.

DISCUSSION

Conodont data from northwestern Virginia demonstrate that conodont zonal units and faunal intervals recognized elsewhere in North America are present in the central Appalachians. The faunal succession from the upper part of the *Proconodontus* Zone through the *Cordylodus proavus* Zone is similar to that described by Miller (1978, 1980) for sections in the Western United States. Although these zonal units are recognized in northwestern Virginia, conodont yields were too low to document subzonal units precisely. Faunal intervals B and C of Ethington and Clark (1971) are also present, at least in part, in the study area.

Pending a decision by the International Working Group on the Cambrian-Ordovician Boundary, the Cambrian-Ordovician boundary for North America is now placed at the base of the trilobite *Missisquoia* Zone, within the conodont *Hirsutodontus hirsutus* Subzone of the *Cordylodus proavus* Zone. Using this definition, the Cambrian-Ordovician boundary lies within the uppermost 50 m of the Conococheague Limestone in northwestern Virginia. The possible establishment of a stratigraphically higher horizon for the international standard may raise the systemic boundary close to the Conococheague-Stonehenge formational contact.

Carbonate depositional environments through the Cambrian-Ordovician boundary interval in northwestern Virginia show a progression from subtidal-to-peritidal cyclic deposition in the Conococheague Limestone through a persistent subtidal environment in the Stonehenge Limestone. Cyclic carbonate deposits of intraformational lime grainstone through laminated dolostone gradually gives way to completely subtidal lime grainstone deposits with sparse stromatolite bioherms near the Conococheague-Stonehenge boundary. Therefore, a rise in sea level may have occurred through this interval. Although the paleoenvironmental change is not drastic, the peritidal dolostone deposits become less prominent in the lower part of the strata within the *Cordylodus proavus* Zone.

Preliminary data in this investigation and by Orndorff and others (1988) for northwestern Virginia, and by Taylor (1986) for sections in western Maryland and central Pennsylvania, suggest that the paleoenvironmental changes near the Conococheague-Stonehenge contact may occur at different biostratigraphic levels along strike in the central Appalachians. Additional study throughout the central Appalachians is needed to substantiate this hypothesis.

The biostratigraphic data from the Narrow Passage Creek section show a 2-m separation between conodonts of the *Cambrooistodus minutus* Subzone and *Clavohamulus elongatus* Subzone. Therefore, the two lower subzones of the *Cordylodus proavus* Zone are either missing or are represented by only 2 m of strata. Samples from this interval were barren of conodonts. Elsewhere in North America and on other continents, these two lower subzones are represented in an interval considerably thicker than that at the Narrow Passage Creek section. In the House Range of Utah, the *Hirsutodontus hirsutus* and *Fryxellodontus inornatus* Subzones are contained in a 30-m interval while in central Texas, this same interval is 6 m (Miller and others, 1982). Miller (1984) explained the smaller interval in Texas by means of an unconformity, with part of the *Hirsutodontus hirsutus* and *Fryxellodontus inornatus* Subzones missing. Because of physical evidence of unconformities, other lithologic data (shallow-water and high-energy sediments), and paleontologic changes (disappearance of many *Proconodontus* Zone conodonts and *Saukia* Zone trilobites), Miller suggested the occurrence of a eustatic event near the Cambrian-Ordovician boundary. He named this event the Lange Ranch Eustatic Event (LREE) for the well documented Lange Ranch section in central Texas. Miller considered this event eustatic because many sections throughout the world show evidence of a sea level change near the Cambrian-Ordovician boundary. The top of the *Proconodontus* Zone in central Texas is an unconformity thought to be caused by a rapid drop in sea level. A subsequent slow rise in sea level is thought to have occurred at the beginning of *Cordylodus proavus* Zone time, as evidenced by shallow-water deposits in many parts of the world.

Even though the *Proconodontus* Zone-*Cordylodus proavus* Zone boundary occurs within the cyclic carbonates of the Conococheague Limestone in northwestern Virginia, the postulated LREE may be represented in the 2-m interval between the *Cambrooistodus minutus* Subzone and the *Clavohamulus elongatus* Subzone. The top of each carbonate cycle is an unconformity, and it is difficult to establish how much time is missing; however, the unconformity above the *Cambrooistodus minutus* Subzone at the Narrow Passage Creek section may have a considerable amount missing compared to sections in Utah and Nevada discussed by Miller and others (1982) and Miller (1984). If the LREE is represented by the top of the cycle above the last sample yielding *Cambrooistodus minutus* Subzone conodonts, then the drop in sea level is represented by the unconformity, and the subsequent transgression may be recognized by the initiation of the following cycle.

SYSTEMATIC PALEONTOLOGY

Multielement taxonomy is used for taxa that have apparatuses previously established. Species whose apparatuses are uncertain or poorly known are reported in form taxonomy (*sensu formo*; s.f.). Generally, only the rare species of the latest Cambrian and earliest Ordovician are described here; descriptions of the more common species can be found in the original diagnoses or in the cited references. Notable variations or similarities of the specimens in this study to previously described taxa are noted under remarks.

Sample numbers are coded abbreviations of the sampled section followed by meters above the base of the section. Illustrated specimens are reposited in the collections of the U.S. National Museum (USNM), Washington, D.C.

Acodus oneotensis Furnish s.f.

Plate 1, figures 1, 2

Acodus oneotensis Furnish, 1938, p. 325, pl. 42, figs. 26–29, text-fig. 1N; Ethington and Clark, 1971, p. 72, pl. 1, figs. 3, 6, 8; Ethington and Clark, 1981, p. 20, pl. 1, fig. 16; Repetski, 1982, p. 12, pl. 2, figs. 7, 8, text-fig. 4C.

Description.—The elements of *Acodus oneotensis* s.f. are erect cones with three prominent costae. These costae are arranged asymmetrically, occurring at anterolateral and posterolateral positions and extending to slightly above the basal margin. The basal cavity is moderately deep to deep. In lateral view, the basal margin is straight; the basal cross section is circular.

Remarks.—Previous workers have discussed possible multielement relationships between *Acodus oneotensis* s.f. and other form species (Sweet and Bergström, 1972; Repetski, 1982). However, these multielement relationships are uncertain. Sweet and Bergström (1972) suggested that *Acodus oneotensis* s.f. is part of an apparatus containing *Paltodus bassleri* Furnish s.f., *Paltodus variabilis* Furnish s.f., and *"Oistodus" triangularis* Furnish s.f. Ethington and Clark (1981) rejected this multielement reconstruction due to a difference in robustness between elements of *Acodus oneotensis* s.f. and *"Oistodus" triangularis* s.f. Nowlan (1985) included *Acodus oneotensis* s.f. in a taxonomic grouping *"Paltodus bassleri"* which included *P. bassleri* s.f., *P. variabilis* s.f., and *A. oneotensis* s.f. The *"Paltodus bassleri"* group was based on the co-occurrence of these form species in Canadian Arctic Island collections. Repetski (1982) suggested a relationship between *Acodus oneotensis* s.f., *Scolopodus sulcatus* Furnish s.f., and *Scolopodus sexplicatus* Jones s.f. However, these relationships cannot be determined from my material because of few specimens, and thus they are considered as form taxa.

Occurrence.—Narrow Passage Creek samples NPC-178, NPC-181, NPC-188, NPC-194, NPC-197; Timberville samples T-134, T-148, T-153, T-157, T-175.

Number of specimens.—34.

Figured specimens.—NPC-178, NPC-197.

Acontiodus iowensis Furnish s.f.

Plate 1, figure 3

Acontiodus iowensis Furnish, 1938, p. 325–326, pl. 42, figs. 16, 17, text-fig. 1L; Ethington and Clark, 1981, p. 23, pl. 1, fig. 15; Repetski, 1982, p. 14, pl. 4, figs. 1, 3, text-fig. 4G; Nowlan, 1985, p. 105, fig. 4.12.

Scolopodus iowensis (Furnish). Druce and Jones, 1971, p. 93, pl. 16, figs. 1a–7e; Jones, 1971, p. 64, pl. 6, figs. 3a–4c, pl. 9, figs. 5a–c; Landing and Barnes, 1981, p. 1614, pl. 4, figs. 7, 11–14, 16, 18–21.

Semiacontiodus iowensis (Furnish). Landing and others, 1986, p. 1942, 1943, pl. 1, figs. 4, 6, 10, text-figs. 3B, C, H.

Remarks.—Specimens from this study assigned to *Acontiodus iowensis* Furnish s.f. conform to the description of Furnish (1938). These elements contain a well-rounded and broad anterior keel and lateral keels. The posterior face of the cusp has a central carina with a large groove to either side. The base is elliptical with the long axis in the lateral direction. Rapid tapering of the cusp is characteristic of the genus. A multielement apparatus for this species was suggested by Landing and others (1986) as *Semiacontiodus iowensis*. These authors included *Acontiodus staufferi* Furnish s.f. and *Oistodus mehli* Furnish s.f. with *Acontiodus iowensis* s.f. Specimens of *Acontiodus staufferi* s.f. and *Oistodus mehli* s.f. were not recovered from Faunas B or C in northwestern Virginia, thus the form sense is maintained in this study.

Occurrence.—Narrow Passage Creek samples NPC-169, NPC-181, NPC-188.

Number of specimens.—6.

Figured specimen.—NPC-181.

Acontiodus propinquus Furnish s.f.

Plate 1, figure 4

Acontiodus propinquus Furnish, 1938, p. 326, pl. 42, figs. 13–15, text-fig. 1M; Ethington and Clark, 1971, p. 72, pl. 1, fig. 5; Repetski and Ethington, 1977, p. 95, pl. 1, fig. 8; Ethington and Clark, 1981, p. 24, pl. 1, fig. 26; Repetski, 1982, p. 14, pl. 2, fig. 13, text-fig. 4J; Nowlan, 1985, p. 107, fig. 4.11.

Remarks.—The specimen of *Acontiodus propinquus* Furnish s.f. recovered from the Timberville section is bilaterally symmetrical with a rounded anterior and a dish-shaped posterior, and conforms to the diagnosis of Furnish (1938). The basic form of this species is similar to *Acontiodus iowensis* s.f., but *A. iowensis* s.f. contains a posterior carina that is not present in *A. propinquus* s.f.

Occurrence.—Timberville sample T-116.

Number of specimens.—1.

Figured specimen.—T-116.

Cambrooistodus minutus (Miller)

Plate 1, figure 5

Oistodus minutus Miller, 1969, p. 433, pl. 66, figs. 1–4, *non* 5–7, text-fig. 5B.

Cambrooistodus minutus (Miller), 1980, p. 11, pl. 1, fig. 8, text-fig. 4F; Chen and others, 1985, p. 84, 85, pl. 26, figs. 8, 9, text-fig. 13(4).

Remarks.—Two specimens of *Cambrooistodus minutus* were recovered from the Narrow Passage Creek section. These specimens conform to Miller's (1980) description of the compressed, asymmetrical element of the genus, and are identified to the species level by the shallow basal cavity. Elements of *Cambrooistodus* contain white matter and have anterior and posterior keels along with a carina on the inner side of the base. Miller (1969, 1980) described two species, *Cambrooistodus cambricus* and *C. minutus*, that he separated by the greater depth of the basal cavity and the robustness of *C. cambricus*.

Occurrence.—Narrow Passage Creek samples NPC-58.5, NPC-63.

Number of specimens.—2.

Figured specimen.—NPC-63.

Clavohamulus densus Furnish

Plate 1, figure 6

Clavohamulus densus Furnish, 1938, p. 327, pl. 42, figs. 18–21; Ethington and Clark, 1971, p. 72, pl. 1, fig. 13; Ethington and Clark, 1981, p. 30, pl. 2, fig. 26; Repetski, 1982, p. 15, pl. 4, fig. 6.

Remarks.—The diagnosis of this species by Furnish (1938) agrees well with specimens recovered from the Narrow Passage Creek and Timberville sections. Most of the specimens in this study have a shallow pit or an attachment surface. The specimen described by Furnish (1938) possessed a bladelike cusp; however, specimens from this study have a cylindrical cusp.

Occurrence.—Narrow Passage Creek samples NPC-181, NPC-194, NPC-197; Timberville samples T-139, T-157.

Number of specimens.—15.

Figured specimen.—NPC-197.

Clavohamulus elongatus? Miller

Plate 1, figure 7

?*Clavohamulus elongatus* Miller, 1969, p. 442, pl. 64, figs. 13–18; Ethington and Clark, 1981, p. 30, pl. 2, fig. 23.

?*Clavohamulus primitus* Miller, 1969, p. 423, pl. 64, figs. 7–12; Ethington and Clark, 1981, p. 30, pl. 2, fig. 20.

Description.—The specimen from Narrow Passage Creek tentatively assigned to *Clavohamulus elongatus*? is a bulbous, bilaterally symmetrical element that is elongated antero-posteriorly and has a short cusp on the posterior. Nodes are present on the upper surface, and only a small basal depression exists.

Remarks.—This element resembles the oldest *Clavohamulus* species, *C. elongatus*. Lindström (1973) discussed the synonymy of *Clavohamulus primitus* s.f. Miller with *C. elongatus* s.f. and concluded that *C. primitus* may approach radial symmetry and therefore could be a synonym of *C. elongatus*. This synonymy was later accepted by Miller (1980).

Occurrence.—Narrow Passage Creek sample NPC-65.

Number of specimens.—1.

Figured specimen.—NPC-65.

Cordylodus angulatus Pander

Plate 1, figures 8, 9

Cordylodus angulatus Pander, 1856, p. 33, pl. 2, figs. 27–31, pl. 3, fig. 10; Müller, 1973, p. 27, pl. 11, figs. 1–5, ?6, 7, text-figs. 2G, 3; Miller, 1980, p. 13–16, pl. 1, figs. 22, 23, text-figs. 4Q, ?R; Landing and Barnes, 1981, p. 1614, pl. 3, fig. 11, text-fig. 3(4); Repetski, 1982, p. 16, pl. 4, fig. 9, text-fig. 4L; Nowlan, 1985, p. 108–109, fig. 4.10; Landing and others, 1986, pl. 1, fig. 18.

Cordylodus prion Lindström, 1955, p. 522, pl. 5, figs. 14–16; Druce and Jones, 1971, p. 70, pl. 2, figs. 1–7, text-figs. 23i, k, o; Müller, 1973, p. 33, pl. 10, fig. 4, text-figs. 2E, 8.

Cyrtoniodus prion (Lindström). Ethington and Clark, 1971, pl. 1, fig. 21; Miller, 1971, (in part) p. 79, pl. 1, figs. 14–16.

Cordylodus sp. A Druce and Jones, 1971, p. 72, pl. 8, fig. 10, text-fig. 23U.

Remarks.—Miller (1980) reassigned many species of *Cordylodus* from previous investigations to *Cordylodus angulatus* mainly based on the shape of the basal cavity. He recognized the basal cavity as the distinctive feature in designating species of *Cordylodus*. All *Cordylodus* specimens in this study are identified to species level by their basal cavity following Miller's (1980) descriptions. He noted a possible evolution from *Cordylodus intermedius* Furnish, which has an anteriorly concave or straight anterior edge of the basal cavity of the rounded element, to *Cordylodus angulatus* whose basal cavity profile is strongly concave anteriorly. Also, he noted possible transitional elements between the two species. The apparatus is interpreted to contain a compressed element (the form species *Cordylodus prion* Lindström). This form species has also been associated with other *Cordylodus* apparatuses such as *Cordylodus rotundatus* Pander, *C. intermedius*, and *C. drucei*. Miller suggested that elements conforming to this morphotype of the form species *C. prion* were part of all of these apparatuses.

Occurrence.—Narrow Passage Creek samples NPC-169, NPC-178, NPC-181, NPC-188, NPC-194, NPC-197; Timberville samples T-93, T-104, T-116, T-144.

Number of specimens.—46.

Figured specimens.—NPC-169, NPC-181.

Cordylodus intermedius Furnish

Plate 1, figure 10

Cordylodus intermedius Furnish, 1938, p. 338, pl. 42, fig. 31, text-fig. 2C; Druce and Jones, 1971, p. 68, pl. 3, figs. 1–3, text-figs. 23f, g; Müller, 1973, p. 30, pl. 10, figs. 1–3, text-figs. 2C, 4; Miller, 1980, p. 17–18, pl. 1, figs. 16, ?17, text-figs. 4L, ?M; Landing and others, 1980, p. 19–20, figs. 5E, 6A, B; Fortey and others 1982, text-figs. 8D, K; Repetski, 1982, p. 17, pl. 5, fig. 2, text-fig. 4M; Nowlan, 1985, p. 109, figs. 4.1, 4.2; Landing and others, 1986, pl. 1, fig. 13, text-fig. 3F.

Cordylodus cf. *C. angulatus* Pander. Druce and Jones, 1971, p. 67, text-fig. 23c.

Cordylodus caseyi Druce and Jones, 1971, p. 67, pl. 2, figs. 9–12, text-figs. 23d, e.

Cordylodus lenzi Müller, 1973, p. 31, pl. 10, figs. 5–9, text-figs. 2F, 5.

Cordylodus oklahomensis Müller. Druce and Jones, 1971, p. 69, pl. 5, figs. 6, 7, text-fig. 23j.

Cordylodus proavus Müller. Druce and Jones, 1971, p. 70, pl. 1, fig. 1, text-fig. 23p.

Remarks.—Druce and Jones (1971) interpreted *Cordylodus intermedius* as the evolutionary intermediate between *Cordylodus proavus*, which has a basal cavity whose tip extends well into the main cusp, and *Cordylodus angulatus*, whose basal cavity extends only as deep as the height of the posterior process. These observations were based mainly on the rounded elements. Miller (1980) included a compressed element in the apparatus, the form species of *Cordylodus* previously assigned to *C. oklahomensis* Müller and *C. prion* Lindström. These compressed elements also show, in some cases, the distinctively shaped basal cavity.

Occurrence.—Narrow Passage Creek samples NPC-169, NPC-178, NPC-181, NPC-188, NPC-197; Timberville sample T-93.

Number of specimens.—23.

Figured specimen.—NPC-181.

Cordylodus lindstromi Druce and Jones

Plate 1, figure 11

Cordylodus lindstromi Druce and Jones, 1971, p. 68, pl. 1, figs. 7–9, pl. 2, fig. 8, text-fig. 23h; Müller, 1973, p. 32, pl. 9, figs. 10, 11, text-figs. 2D, 6; Miller, 1980, p. 18–19, pl. 1, figs. 18, 19, text-figs. 4I, J; Repetski, 1982, p. 17–18, pl. 5, figs. 4, 5, text-fig. 4O; Landing and others, 1986, pl. 1, figs. 9, 14, text-figs. 3I, Q.

Cordylodus angulatus Pander. Lindström, 1955, p. 551, text-fig. 3E.

Cyrtoniodus prion (Lindström). Miller, 1971, (in part) p. 79, pl. 1, figs. 14–16, *non* 17.

Remarks.—Elements of *Cordylodus lindstromi* in this study are similar to *Cordylodus intermedius*. However, the basal cavity of *Cordylodus lindstromi* contains a secondary apex that extends into the first and in some cases the second denticle posterior to the cusp. Also, elements of *Cordylodus lindstromi* do not have lateral bulges on the posterior process, as do elements of *C. intermedius*.

Occurrence.—Narrow Passage Creek samples NPC-169, NPC-178, NPC-194.

Number of specimens.—13.

Figured specimen.—NPC-178.

Cordylodus proavus Müller

Plate 1, figures 12, 13

Cordylodus proavus Müller, 1959, p. 448, pl. 15, figs. 11, 12, 18, text-fig. 3B; Miller, 1969, p. 424, pl. 65, figs. 37–45, text-fig. 3D; Ethington and Clark, 1971, pl. 1, fig. 19; Druce and Jones, 1971, p. 70, pl. 1, figs. 2–6; Müller, 1973, p. 35, pl. 9, figs. 1–9, text-figs. 2A, 9; Fåhraeus and Nowlan, 1978, p. 453, pl. 1, figs. 8, 9; Miller, 1980, p. 19–20, pl. 1, figs. 14, 15, text-figs. 4G, H; Fortey and others, 1982, text-figs. 8F, J; Nowlan, 1985, p. 111, figs. 5.12, 5.13, 5.17–5.19; Landing and others, 1986, pl. 1, fig. 5, text-fig. 3E.

Cordylodus cf. *C. proavus* Müller. Druce and Jones, 1971, p. 71, pl. 1, figs. 10–12, text-fig. 23s.

Cordylodus oklahomensis Müller, 1959, p. 447, pl. 15, figs. 15, 16, text-fig. 3A; Miller, 1969, p. 423, pl. 65, figs. 46–53, text-fig. 3I; Ethington and Clark, 1971, pl. 1, fig. 24; Müller, 1973, p. 33, pl. 9, figs. 12, 13, text-figs. 2B, 7; Landing and others, 1980, p. 21–24, figs. 5A, D, 6C–E; Fortey and others, 1982, text-figs. 8G, O.

Remarks.—Both rounded and compressed elements are present in the Narrow Passage Creek section. The distinguishing characteristic of *Cordylodus proavus* from other species of *Cordylodus* is the convex anterior edge of the basal cavity that parallels the edge of the element. Also, the basal cavity extends well into the main cusp, above the level of the posterior process. This study follows Miller (1980) in which the compressed element, formerly *Cordylodus oklahomensis* s.f., is included in the *Cordylodus proavus* apparatus.

Occurrence.—Narrow Passage Creek samples NPC-65, NPC-108.

Number of specimens.—59.

Figured specimens.—NPC-65.

Cordylodus rotundatus Pander

Plate 1, figure 14

Cordylodus rotundatus Pander, 1856, p. 33, pl. 2, figs. 32, 33; Lindström, 1955, p. 533, pl. 5, figs. 17–20, text-fig. 3F; Druce and Jones, 1971, p. 71, pl. 3, figs. 8–10, text-fig. 23f; Ethington and Clark, 1971, pl. 1, fig. 17, text-fig. 2; Müller, 1973, p. 36, pl. 11, figs. 8–10, text-figs. 2H, 10; Miller, 1980, p. 20–21, pl. 1, fig. 24, text-fig. 4P; Repetski, 1982, p. 18, pl. 5, fig. 3, text-fig. 4N; Nowlan, 1985, p. 111–112, fig. 4.3.

Cordylodus subangulatus Furnish, 1938, p. 337, pl. 42, fig. 32, text-fig. 2D.

Cyrtoniodus prion (Lindström). Ethington and Clark, 1971, pl. 1, fig. 21.

Remarks.—Miller (1980) discussed the *Cordylodus rotundatus* apparatus as containing the form species *C. rotundatus* as the rounded element and *C. prion* s.f. as the compressed element. The distinctive basal cavity of the rounded element is recognized by the strongly concave anterior edge and recurved tip. Also, the anterobasal margin is well rounded.

Occurrence.—Narrow Passage Creek samples NPC-181, NPC 188; Timberville samples T-116, T-134.

Number of specimens.—7.

Figured specimen.—NPC-181.

Drepanodus cf. D. arcuatus Pander

Plate 1, figure 15

cf. *Drepanodus arcuatus* Pander, 1856, p. 20, pl. 1, figs. 2, 4, 5; Lindström, 1955, p. 558–560, pl. 2, figs. 30–33; Lindström, 1973, p. 67–68, pl. 1, figs. 1, 2; Fåhraeus and Nowlan, 1978, p. 458, pl. 2, figs. 1?, 2, 8; Ethington and Clark, 1981, p. 36, 37, pl. 3, figs. 4–6, 12; Repetski, 1982, p. 19, pl. 6, fig. 1; Landing and others, 1986, pl. 2, fig. 2.

cf. *Drepanodus flexuosus* Pander, 1856, p. 20, pl. 1, figs. 6–8.

cf. *Drepanodus* cf. *arcuatus* Pander. Lindström, 1955, p. 560–561, pl. 2, figs. 45, 46, text-fig. 4C.

cf. *Drepanodus sculponea* Lindström, 1955, p. 567, pl. 2, fig. 40, text-fig. 3L.

cf. *Scandodus pipa* Lindström, 1955, p. 593, pl. 4, figs. 38–42, text-fig. 3P; Ethington and Clark, 1964, p. 698, pl. 114, fig. 8.

cf. ?*Drepanodus arcuatus* Pander. Ethington and Clark, 1981, p. 36–37, pl. 3, figs. 4–6, 12.

Remarks.—This multielement apparatus was diagnosed by Lindström (1973) to include the form species *Drepanodus arcuatus* Pander s.f., *Drepanodus sculponea* Lindström s.f., and *Scandodus pipa* Lindström s.f. The specimen recovered from Narrow Passage Creek identified as *Drepanodus* cf. *D. arcuatus* resembles the arcuatiform element as illustrated by Ethington and Clark (1981).

Occurrence.—Narrow Passage Creek sample NPC-197.

Number of specimens.—1.

Figured specimen.—NPC-197.

Drepanoistodus pervetus Nowlan

Plate 1, figures 16–18

Drepanoistodus? pervetus Nowlan, 1985, p. 112, figs. 5.53–5.55, 6.1–6.3.

Oistodus suberectus Branson and Mehl, 1933, p. 111, pl. 9, fig. 7.

Drepanoistodus? n. sp. Landing and Barnes, 1981, p. 1615-1616, pl. 2, figs. 1, 2, 5, 7, 8.

Drepanoistodus suberectus subsp. A, n. sp. (Branson and Mehl), Repetski, 1982, p. 25, pl. 7, fig. 13, pl. 8, fig. 5.

Remarks.—Nowlan (1985) recognized the multielement apparatus *Drepanoistodus*? *pervetus* that included a nongeniculate oistodontiform element, a suberectiform element, and a homocurvatiform element. Characteristic of this species are the variability of the curvature between the cusp and the base, and the lack of costae. Only the suberectiform and homocurvatiform elements were recovered from Narrow Passage Creek and Timberville.

Occurrence.—Narrow Passage Creek samples NPC-169, NPC-181, NPC-206; Timberville samples T-153, T-162.

Number of specimens.—Suberectiform-6, homocurvatiform-4.

Figured specimens.—NPC-181, NPC-206, T-153.

Eoconodontus notchpeakensis (Miller)

Plate 1, figures 19, 20

Proconodontus notchpeakensis Miller, 1969, p. 438, pl. 66, figs. 21-29, text-fig. 5G; Lindström, 1973, p. 43, pl. 4, fig. 6.

Oneotodus nakamurai Nogami, 1966, (in part) p. 216, pl. 1, figs. 10, 11, text-figs. 3D, E.

Proconodontus carinatus Miller, 1969, p. 437, pl. 66, figs. 13-20, text-fig. 5I; Landing and others, 1980, p. 31-33, figs. 5C, F, 8D-H.

Eoconodontus notchpeakensis (Miller), 1980, p. 22, 23, pl. 1, figs. 10-12 [synonymy to 1980]; Landing 1983, p. 1177, text-figs. 11P, Q; Chen and others, 1985, p. 89, pl. 25, figs. 12-14, text-fig. 13(3).

Remarks.—Miller (1980) erected the genus *Eoconodontus* to include coniform elements with both oval and compressed cross sections. The compressed element of this apparatus possesses anterior and posterior keels and formerly was assigned to the form species *Proconodontus carinatus* (Miller, 1969). The rounded element is *Proconodontus notchpeakensis* s.f. The characteristic that separates *Eoconodontus* elements from those of *Proconodontus* is the occurrence of white matter in the cusp of elements of *Eoconodontus*.

Occurrence.—Narrow Passage Creek samples NPC-5, NPC-37, NPC-43, NPC-48, NPC-52, NPC-58, NPC-59, NPC-62, NPC-64, NPC-65 NPC-136; Timberville sample T-67.

Number of specimens.—183.

Figured specimens.—NPC-59.

Eucharodus cf. E. parallelus (Branson and Mehl)

Plate 1, figure 21

cf. *Drepanodus parallelus* Branson and Mehl, 1933, p. 59, pl. 4, fig. 17; Jones, 1971, p. 52-53, pl. 8, figs. 5a-c; Lee, 1975, p. 86, pl. 1, fig. 16, text-fig. 3M; Repetski, 1982, p. 21, pl. 6, figs. 9, 10.

cf. *Drepanodus simplex* Branson and Mehl, 1933, p. 58, pl. 4, fig. 2; Barnes and Tuke, 1970, p. 86, pl. 19, fig. 8, 12, 13; Müller, 1973, p. 37, pl. 5, fig. 5; Fåhraeus and Nowlan, 1978, p. 450-451, 457, pl. 2, fig. 14.

cf. *Drepanodus arcuatus* Pander. Branson and Mehl, 1933, p. 58, pl. 4, figs. 7, 8, 13.

cf. *Drepanodus subarcuatus* Furnish, 1938, p. 320, 328, pl. 41, figs. 25-30, pl. 42, figs. 2, 3; Ethington and Clark, 1971, p. 72-74, pl. 2, fig. 1, text-fig. 2.

cf. *Drepanodus tortus* Furnish, 1938, p. 329, pl. 42, fig. 6.

cf. *Eucharodus parallelus* (Branson and Mehl). Kennedy, 1980, p. 58-60, pl. 1, figs. 35-38 [synonymy].

Remarks.—Various workers have concluded that several form species, including *Drepanodus parallelus* Branson and Mehl s.f., *D. arcuatus* Pander s.f. (*sensu* Branson and Mehl, *non* Pander), *D. simplex* Branson and Mehl s.f., and *D. subarcuatus* Furnish s.f. are conspecific and that the species is variable (Kennedy, 1980; Repetski, 1982). Kennedy (1980), in his reexamination of Branson and Mehl's (1933) fauna from the Jefferson City Formation, assigned the apparatus to *Eucharodus parallelus* (Branson and Mehl). *Eucharodus parallelus* is a common species of Early Ordovician Faunas D and E. However, the ancestry is unclear and possibly occurs in the Fauna C interval. Noting the long range of this species and its wide variability in morphology, one hyaline and finely striated cone recovered from Narrow Passage Creek is assigned as being comparable to *Eucharodus parallelus*.

Occurrence.—Narrow Passage Creek sample NPC-169.

Number of specimens.—1.

Figured specimen.—NPC-169.

Fryxellodontus inornatus Miller

Plate 1, figures 22, 23

Fryxellodontus inornatus Miller, 1969, p. 426, pl. 65, figs. 1-10, 12-16, 23-24, text-figs. 4A, C-E; Miller, 1980, p. 23, text-fig. 5; Landing and others, 1980, p. 24-25, fig. 7C-G; Chen and others, 1985, p. 89, 90, pl. 25, figs. 15, 16.

Genus et sp. indet. B, Druce and Jones, 1971, p. 102, pl. 12, fig. 9, text-fig. 33.

Description.—This species consists of laterally compressed, bilaterally symmetrical and asymmetrical coniform elements with a strongly developed posterior costa extending from the tip of the cusp to the basal margin. The anterior is rounded and the basal cavity is very deep. The antero-posterior width of one element in the material at hand is only slightly less than the height; however, the other specimen is quite elongated (pl. 1, fig. 23).

Remarks.—Miller (1969) described four element types for this species, including planar, serrate, symmetrical, and intermediate elements. Both specimens from Narrow Passage Creek are of the planar type.

Occurrence.—Narrow Passage Creek sample NPC-65.

Number of specimens.—2.

Figured specimens.—NPC-65.

Fryxellodontus lineatus Miller

Plate 1, figure 24

Fryxellodontus lineatus Miller, 1969, p. 429, pl. 65, figs. 17-22, 26-29, text-figs. 4B, F.

Fryxellodontus inornatus Miller, (part) 1969, p. 426, pl. 65, fig. 11.

Description.—The specimen assigned to *Fryxellodontus lineatus* is an asymmetrical simple cone that is slightly compressed antero-posteriorly and possesses a posterior costa that extends from the tip of the cusp to the basal margin.

Also, this specimen contains linear ridges on the rounded anterior side and the basal cavity is very deep.

Remarks.—Three morphotypes were described by Miller (1969): a planar element, a symmetrical element, and an intermediate element. One intermediate element was recovered from Narrow Passage Creek.

Occurrence.—Narrow Passage Creek sample NPC-65.

Number of specimens.—1.

Figured specimen.—NPC-65.

Hirsutodontus hirsutus Miller

Plate 1, figure 25

Hirsutodontus hirsutus Miller, 1969, p. 431, pl. 64, figs. 25, 26, 29-31, text-fig. 4I; Lindström, 1973, p. 119.2, 123; Miller, 1980, p. 25, pl. 2, fig. 14; Fortey and others, 1982, text-fig. 8S.

Remarks.—Specimens of *Hirsutodontus hirsutus* recovered in this study resemble those of Miller (1969). Some specimens have only anterior nodes whereas others have nodes that extend around one side. Miller (1980) discussed the differences in the species of *Hirsutodontus*, noting a well developed cusp consisting of nodes for *H. hirsutus*, large spines on the later species *H. simplex* (Druce and Jones), and small spines with a poorly developed cusp in *H. rarus* Miller.

Occurrence.—Narrow Passage Creek samples NPC-65, NPC-108, NPC-130, NPC-136; Timberville sample T-0.

Number of specimens.—31.

Figured specimen.—NPC-65.

Loxodus bransoni Furnish

Plate 1, figure 26

Loxodus bransoni Furnish, 1938, p. 339, pl. 42, figs. 33, 34, text-fig. 2A; Ethington and Clark, 1971, p. 72-73, pl. 1, fig. 11; Abaimova, 1975, p. 112, 114, pl. 10, figs. 12, 13, 15, text-figs. 8(35, 40, 43); Ethington and Clark, 1981, p. 52-53, pl. 5, fig. 15; Repetski, 1982, p. 27-28, pl. 9, fig. 7, text-fig. 5P; Nowlan, 1985, fig. 4.29.

Description.—Specimens of this species consist of a denticulate bar with the denticles erect at the anterior and progressively reclined posteriorly. Denticles decrease in size toward the posterior. The basal cavity is narrow and moderately deep.

Remarks.—Specimens of *Loxodus bransoni* recovered from the Timberville section conform well with Furnish's (1938) description. Repetski (1982) noted an inward deflection of the basal margin in specimens of *Loxodus bransoni* from the El Paso Group of west Texas and southern New Mexico, found also in specimens from the Stonehenge Formation from south-central Pennsylvania by Sando (1958). This deflection was not shown in Furnish's specimens from the Prairie du Chien beds of the upper Mississippi Valley (Repetski, 1982), but it is present in the specimens recovered from the Timberville section.

Occurrence.—Timberville samples T-121, T-148, T-157.

Number of specimens.—3.

Figured specimen.—T-157.

"Oistodus" triangularis Furnish s.f.

Plate 2, figure 1

Oistodus? triangularis Furnish, 1938, p. 330-331, pl. 42, fig. 22, text-fig. 1P; Ethington and Clark, 1971, p. 72, pl. 1, figs. 18, 22, 23.

"Oistodus" triangularis Furnish. Repetski and Ethington, 1977, p. 95.

Acodus triangularis Furnish. Repetski, 1982, p. 13, pl. 2, figs. 9-12.

"Drepanodus" triangularis Furnish. Nowlan, 1985, p. 112, figs. 4.7, 4.8.

Description.—Specimens of *"Oistodus" triangularis* s.f. are erect to reclined coniform elements with a posterior keel that terminates at the lower margin. The cusp is compressed laterally and the cross section is triangular to ovate. One anterolateral corner of the base is keeled, but the keel does not continue to the cusp. The basal cavity is moderately deep.

Remarks.—The multielement relationship of this conodont is uncertain. It was assigned tentatively to the genus *Oistodus*; however, it lacks the diagnostic characteristics of that genus in the form and multielement sense (Nowlan, 1985). Repetski (1982) placed elements of *"Oistodus" triangularis* in an uncertain multielement apparatus that he called *Acodus triangularis* which may contain an oistodontiform element. Later, Repetski and Ethington (1983) rejected the idea of an oistodontiform element because that element was assigned to *Rossodus manitouensis*. Nowlan (1985) noted a relationship to the form genus *Drepanodus*.

Occurrence.—Narrow Passage Creek samples NPC-142, NPC-175, NPC-178, NPC-181, NPC-188, NPC-194, NPC-197; Timberville samples T-93, T-104, T-116, T-139, T-153.

Number of specimens.—32.

Figured specimen.—NPC-194.

Paltodus bassleri Furnish

Plate 2, figures 2, 3, 14

Paltodus bassleri Furnish, 1938, p. 331, pl. 42, fig. 1; Ethington and Clark, 1971, p. 72, pl. 2, figs. 2, 4, 6; Repetski and Ethington, 1977, p. 95-96, pl. 1, fig. 1; Repetski and Perry, 1980, pl. 1, fig. 9, pl. 2, figs. 3, 17; Repetski, 1982, p. 37, pl. 14, fig. 12, text-fig. 6Q; Nowlan, 1985, p. 118-120, figs. 10.1-10.4, 10.8-10.14, *non* 10.5-10.7.

Paltodus variabilis Furnish, 1938, p. 331, pl. 42, figs. 9, 10, text-fig. 1E; Ethington and Clark, 1965, p. 197-198.

Variabiloconus bassleri (Furnish). Landing and others, 1986, p. 1946, 1947, pl. 3, figs. 1?, 2-7, 9.

Remarks.—Elements from the Narrow Passage Creek and Timberville sections assigned to *Paltodus bassleri* conform to the description of Furnish (1938). Both symmetrical and asymmetrical elements were recovered. Furnish (1938) reported a relationship between the form species *Paltodus bassleri* and *P. variabilis*. This relationship was discussed by Repetski (1982), who suggested that both taxa are members of a symmetry-transition series within a single species. This symmetry-transition is recognized here and *Paltodus bassleri* is treated in the multielement sense. Landing and others (1986) referred specimens of *Paltodus bassleri* to a new genus *Variabiloconus* to emphasize the morphologic variation of elements within the apparatus; however, specimens other than those previously referred to as *Paltodus bassleri* were included in their apparatus construction.

Occurrence.—Narrow Passage Creek samples NPC-157, NPC-166, NPC-169, NPC-175, NPC-178, NPC-181, NPC-188, NPC-194, NPC-197, NPC-206; Timberville samples T-104, T-116, T-130, T-139, T-148, T-153, T-157, T-167, T-175.

Number of specimens.—77.

Figured specimens.—NPC-157, NPC-181.

Paltodus aff. P. spurius Ethington and Clark s.f.

Plate 2, figure 4

aff. *Paltodus spurius* Ethington and Clark, 1964, p. 695, pl. 114, figs. 3, 10, text-fig. 2B; Ethington and Clark, 1971, p. 72, pl. 1, fig. 12.

aff. *"Paltodus" spurius* Ethington and Clark, 1981, p. 76, pl. 8, figs. 9, 13.

Description.—This specimen is a robust coniform element with a large base that expands posteriorly and anterolaterally. A lateral groove extends from the basal margin to part way along the cusp. The basal cavity is moderately deep.

Remarks.—This specimen resembles *Paltodus spurius* s.f. of Ethington and Clark (1964). *Paltodus spurius* s.f. was reported to have a lateral groove that becomes less prominent during growth (Ethington and Clark, 1981). The specimen identified as *Paltodus* aff. *P. spurius* s.f. from Narrow Passage Creek has a lateral groove at the basal margin that extends toward the cusp. The disappearance of the groove below the cusp may be an example of the larger elements mentioned by Ethington and Clark (1981) that have a less prominent groove. The single specimen reported here occurs in the interval of Fauna C and is consistent with published reports of *Paltodus spurius* s.f.

Occurrence.—Narrow Passage Creek sample NPC-197.

Number of specimens.—1.

Figured specimen.—NPC-197.

Proconodontus muelleri Miller

Plate 2, figure 5

Proconodontus mülleri mülleri Miller, 1969, p. 437, pl. 66, figs. 30–40, text-fig. 5H.

Proconodontus muelleri muelleri Miller, 1971, pl. 2, fig. 18; Nowlan, 1985, p. 114, fig. 5.1.

Proconodontus muelleri Miller, 1980, p. 29–30, pl. 1, fig. 7, text-fig. 4C; An, 1982, p. 141–142, pl. 12, figs. 8, 9, 11–13, pl. 16, figs. 10, 12; Landing, 1983, p. 1180, figs. 11G, H; Chen and others, 1985, p. 95, pl. 26, figs. 10–13, text-figs. 13(1).

Remarks.—Specimens assigned to this species conform to the description of Miller (1980). All of the specimens contain both anterior and posterior keels that extend to the basal margin in some specimens and terminate half-way down the cusp in others.

Occurrence.—Narrow Passage Creek samples NPC-58.5, NPC-62, NPC-63.

Number of specimens.—10.

Figured specimen.—NPC-63.

Proconodontus serratus Miller

Plate 2, figures 6, 7

Proconodontus muelleri serratus Miller, 1969, p. 438, pl. 66, figs. 41–44; Lindström, 1973, p. 402, 403, 409.

Coelocerodontus burkei Druce and Jones, 1971, p. 61, pl. 11, fig. 12.

Proconodontus serratus Miller. Müller, 1973, p. 44, pl. 4, figs. 1, 2; Miller, 1980, p. 31, pl. 1, fig. 13, text-fig. 4D; Landing and others, 1980, p. 33, figs. 8I–L.

Description.—*Proconodontus serratus* consists of proclined, laterally compressed, coniform elements possessing an anterior keel that extends from the tip of the cusp to the basal margin. The posterior edge is partly serrated proximally and in some specimens may be entirely serrated. The basal cavity is very deep and extends to the tip of the cusp.

Remarks.—This species is very similar to *Proconodontus muelleri* except that *P. serratus* has a serrate posterior edge. Miller (1980) suggested that *Proconodontus serratus* evolved from *P. muelleri* because of the similarities between the two species. Specimens from Narrow Passage Creek show variation in position of the serrations on the cusp. Generally, the serrations occur close to the tip of the cusp. However, one specimen has the serrations extending to about half-way down the cusp.

Occurrence.—Narrow Passage Creek samples NPC-5, NPC-59.

Number of specimens.—3.

Figured specimens.—NPC-5, NPC-59.

Prooneotodus rotundatus (Druce and Jones)

Plate 2, figure 8

Coelocerodontus rotundatus Druce and Jones, 1971, p. 66, pl. 9, figs. 10a–13b, text-figs. 22c, d.

Prooneotodus? *rotundatus*? (Druce and Jones). Landing, 1983, p. 1180, figs. 10D, E.

Prooneotodus rotundatus (Druce and Jones). Chen and others, 1985, p. 96, pl. 26, figs. 1–3, text-fig. 14(1).

Remarks.—Druce and Jones (1971) described simple hollow cone shaped conodonts with circular cross sections and minute cusps as *Coelocerodontus rotundatus*. Müller (1973) placed these elements within the genus *Proconodontus*. However, Landing (1983) rejected this placement because *Prooneotodus rotundatus* has a protoconodont or paraconodont histology as opposed to *Proconodontus* which has a euconodont histology.

Occurrence.—Narrow Passage Creek samples NPC-5, NPC-37, NPC-43.

Number of specimens.—3.

Figured specimen.—NPC-37.

Rossodus manitouensis Repetski and Ethington

Plate 2, figures 9–11

Rossodus manitouensis Repetski and Ethington, 1983, p. 293, figs. 1A–V, 2A–T, 3A–R, 4A–D [synonymy to 1982]; Landing and others, 1986, p. 1940, pl. 2, figs. 10, 11, 14, *non* 18.

New Genus A, n. sp. A, Repetski and Perry, 1980, pl. 1, figs. 4, 6, pl. 2, figs. 11, 12, 15; Repetski, 1982, p. 56, pl. 28, figs. 1–4.

New Genus 3, Ethington and Clark, 1981, p. 118–119, pl. 13, figs. 21–23, 25, 27.

Remarks.—Repetski and Ethington (1983) described the apparatus of *Rossodus manitouensis* as including oistodontiform elements and bladelike coniform elements that show symmetry transition. The cusps of all the elements are albid. The symmetry-transition series of costate to bladelike coniform elements shows a change from nearly symmetrical through asymmetrical to bilaterally symmetrical elements. Repetski and Ethington noted a similarity of the coniform element symmetry-transition series to elements of *Juanognathus*. The major difference between these two apparatuses is the absence of oistodontiform elements in the *Juanognathus* apparatus. A similarity between the apparatuses of *Rossodus* and *Utahconus* also was recognized by Repetski and Ethington (1983) and with the presence of an oistodontiform element in *U. tenuis* (Miller), they reassigned *U. tenuis* to the genus *Rossodus*. *Rossodus tenuis* is present in rocks older than rocks with *R. manitouensis*, and is preceded by *Utahconus utahensis* (Miller). This sequence of species led these authors to suggest an evolutionary lineage from *Utahconus utahensis* through *Rossodus tenuis* to *R. manitouensis*. No specimens assignable to *Rossodus tenuis* were recovered from the Narrow Passage Creek and Timberville sections. Thus, the evolutionary lineage put forth by Repetski and Ethington (1983) was not observed in the study.

Occurrence.—Narrow Passage Creek samples NPC-166, NPC-169, NPC-172, NPC-175, NPC-178, NPC-181, NPC-188, NPC-194, NPC-197, NPC-206; Timberville samples T-104, T-134, T-153.

Number of specimens.—Coniform elements-65, oistodontiform elements-14.

Figured specimens.—NPC-169, NPC-181.

Rossodus sp.

Plate 2, figure 12

Remarks.—Several specimens resemble elements of *Rossodus* but do not conform to *R. manitouensis*. These elements are more robust than *Rossodus manitouensis* and have sharp costae situated posterolaterally and anterolaterally. Other *Rossodus* species have been reported high in Fauna C and into Fauna D (Repetski and Perry, 1980). The specimens recovered in this study are coniform elements possibly belonging to a new species of *Rossodus*.

Occurrence.—Narrow Passage Creek samples NPC-188, NPC-197.

Number of specimens.—5.

Figured specimen.—NPC-188.

Scandodus sp. s.f.

Plate 2, figure 13

Description.—One specimen of a lanceolate, reclined cone with a slightly expanded base recovered from the Narrow Passage Creek section is assigned to the genus *Scandodus* in the form sense. The base expands posteriorly and laterally, and the basal margin is slightly concave downward in lateral view.

Occurrence.—Narrow Passage Creek sample NPC-169.

Number of specimens.—1.

Figured specimen.—NPC-169.

Scolopodus sulcatus Furnish s.f.

Plate 2, figure 15

Scolopodus sulcatus Furnish, 1938, p. 334, pl. 41, figs. 14, 15, text-fig. 1I; Ethington and Clark, 1971, p. 105, pl. 12, figs. 7, 8, text-fig. 26; Repetski, 1982, p. 51, pl. 24, figs. 6, 8, text-fig. 7Y.

Remarks.—Specimens from the Narrow Passage Creek and Timberville sections identified as *Scolopodus sulcatus* Furnish s.f. conform to the diagnosis of the species by Furnish (1938). Repetski (1982) suggested that *Scolopodus sulcatus* s.f. is a member of a symmetry-transition series that includes *Acodus oneotensis* s.f., and *Scolopodus sexplicatus* s.f. This multielement relationship will remain uncertain until large collections containing these conodonts have been evaluated. The material at hand is not suitable for such an evaluation.

Occurrence.—Narrow Passage Creek samples NPC-157, NPC-181; Timberville samples T-139, T-175.

Number of specimens.—8.

Figured specimen.—NPC-139.

Scolopodus sp. s.f.

Plate 2, figure 16

Remarks.—Several coniform specimens recovered from the Narrow Passage Creek and Timberville sections have cusps or cusp fragments that contain lateral and posterior grooves or costae and a rounded anterior and posterior. These specimens conform to the diagnosis of the genus by Pander (1856) and later workers (Furnish, 1938; Ethington and Clark, 1981; Repetski, 1982).

Occurrence.—Narrow Passage Creek samples NPC-181, NPC-197; Timberville sample T-139.

Number of specimens.—12.

Figured specimen.—NPC-181.

Semiacontiodus nogamii (Miller)

Plate 2, figures 17, 18

Acontiodus (*Semiacontiodus*) *nogamii* Miller, 1969, p. 421, pl. 63, figs. 41–50, text-fig. 3G.

Semiacontiodus nogamii Miller. Lindström, 1973, p. 441–443; Miller, 1980, p. 32, pl. 2, figs. 10–12, text-figs. 4V, W; Fortey and others, 1982, text-figs. 6J, T, 8V, X; Chen and others, 1985, p. 97, 98, pl. 23, figs. 12–16, text-figs.14(13, 14).

Acodus housensis Miller, 1969, p. 418, pl. 63, figs. 11–20, text-fig. 3A.

Oneotodus datsonensis Druce and Jones, 1971, p. 80, pl. 14, fig. 4.

Oneotodus erectus Druce and Jones, 1971, p. 80, pl. 15, figs. 2–9, text-fig. 26d.

Remarks.—Specimens of this species resemble those illustrated by Miller (1969; 1980). Several asymmetrical elements possess the distinctive lateral costa and groove (= "*Acodus housensis*" morphotype). Symmetrical elements have a rounded posterior costa and are flanked by two posterolateral grooves. Miller (1980) suggested that *Teridontus nakamurai* is the ancestor of *Semiacontiodus nogamii*.

The specimens from this study that lack pronounced lateral costae are similar to those of *Teridontus nakamurai* and are distinguished from them by the posterior grooves.

Occurrence.—Narrow Passage Creek samples NPC-65, NPC-136.

Number of specimens.—14.

Figured specimens.—NPC-65.

Teridontus nakamurai (Nogami)

Plate 2, figure 19

Oneotodus nakamurai Nogami, 1967, p. 216, pl. 1, figs. 9, 12, text-figs. 3A, B; Miller, 1969, p. 435, pl. 63, figs. 1-10, text-fig. 5E; Druce and Jones, 1971, p. 82, pl. 10, figs. 3, 4, 7, 8, text-fig. 26i; Müller, 1973, p. 41, pl. 5, fig. 4; Landing and others, 1986, pl. 1, figs. 1, 2.

Oneotodus datsonensis Druce and Jones, 1971, p. 80, pl. 14, figs. 1-3, text-fig. 26c.

"Oneotodus" nakamurai Nogami. Landing and others, 1980, p. 28-31, figs. 8A-C.

Teridontus nakamurai (Nogami). Miller, 1980, p. 34, pl. 2, figs. 15, 16; Fortey and others, 1982, text-fig. 9N, Q, R; Chen and others, 1985, p. 99, pl. 21, figs. 4-6, text-fig. 14(5); Nowlan, 1985, p. 116, figs. 5.26-5.32.

Teridontus huanghuachangensis (Ni). Chen and others, 1985, p. 98, pl. 21, figs. 12, 13, text-fig. 14(10).

Remarks.—Miller (1980) reassigned the coniform elements previously assigned to *Oneotodus nakamurai* to *Teridontus*. Elements from this study having a narrow or posteriorly expanded basal margin, circular cross section, simple morphology, fine striations, and abundant white matter in the cusp are assigned to *Teridontus nakamurai*. Previously, the rounded element of *Eoconodontus notchpeakensis* was considered a paratype of *Oneotodus nakamurai*, but it was reassigned by Miller (1980). Chen and others (1985) illustrated specimens of *Teridontus huanghuachangensis* which has a cusp with the white matter ending in a sharp boundary oblique to the cusp as opposed to specimens of *T. nakamurai* with the white matter boundary transverse to the cusp. Other than the difference in the white matter boundary, there seems to be no other morphologic difference between *Teridontus huanghuachangensis* and *T. nakamurai*. The range of *Teridontus huanghuachangensis* is reported from sections in China by Chen and others (1985) and Chen and Gong (1986) as within the range of *T. nakamurai*, and I believe these two species are actually both *T. nakamurai*.

Occurrence.—Narrow Passage Creek samples NPC-5, NPC-65, NPC-108, NPC 123, NPC-136; Timberville samples T-0, T-45, T-64, T-93.

Number of specimens.—668.

Figured specimen.—NPC-65.

Teridontus aff. T. nakamurai (Nogami)

Plate 2, figures 20, 21

aff. *Teridontus nakamurai* (Nogami). Miller, 1980, p. 34, pl. 2, figs. 15, 16, [synonymy].

Remarks.—Some elements in the interval of Fauna C show affinities with *Teridontus nakamurai* but are more robust than specimens from older strata. These specimens are symmetrical or nearly symmetrical coniform elements with circular cross section, a narrow base, and abundant white matter in the cusp. They differ from *Oneotodus gracilis* (Furnish) in that they do not have a flattened posterior. *Teridontus* aff. *T. nakamurai* occurs in the range of Fauna C in this study, thus possibly extending the range of *T. nakamurai* into Fauna C. Nowlan (1985) also reported aff. *T. nakamurai* in Fauna C in the Arctic. Landing and others (1986) suggested that *Oneotodus*-like elements of this interval may belong to the *Variabiloconus bassleri* (previously *Paltodus bassleri*) apparatus. It is difficult to test the relationship between *Teridontus* aff. *T. nakamurai* and *Variabiloconus bassleri* with the collections from northwestern Virginia. Thus, *Teridontus* aff. *T. nakamurai* is recognized for its affinities to *T. nakamurai*.

Occurrence.—Narrow Passage Creek samples NPC-166, NPC-169, NPC-178, NPC-181, NPC-188, NPC-197; Timberville samples T-104, T-121, T-134, T-148, T-153, T-162.

Number of specimens.—68.

Figured specimens.—NPC-169, NPC-181.

Utahconus utahensis (Miller)

Plate 2, figures 22, 23

Paltodus utahensis Miller, 1969, p. 463, pl. 63, figs. 33-40, text-fig. 5F.

Acontiodus (*Semiacontiodus*) *unicostatus* Miller, 1969 (in part), p. 421, pl. 64, figs. 46-48, text-fig. 5F.

Acodus sevierensis Miller, 1969 (in part), p. 418, pl. 63, figs. 21-24, text-fig. 3H.

Scandodus furnishi Lindström. Druce and Jones, 1971, p. 88, pl. 13, figs. 6-8, text-fig. 29.

Semiacontiodus utahensis (Miller). Lindström, 1973, p. 442, 443, 449.

Utahconus utahensis (Miller). Miller, 1980, p. 35, 36, pl. 2, figs. 1, 2, text-figs. 3B, C, F, G; Chen and others, 1985, p. 99, 100, pl. 23, figs. 1-8, text-fig. 14(6).

Description.—The apparatus consists of two coniform elements. Bicostate elements are erect to reclined, asymmetrical to nearly symmetrical simple cones that are compressed antero-posteriorly. They possess lateral or posterolateral keels that extend from the tip of the cusp to the basal margin. The basal cavity is shallow to moderately deep. Unicostate elements are erect to reclined simple cones that possess a posterior keel that extends from the tip of the cusp to the base or basal margin.

Remarks.—This apparatus was named by Miller (1980) to include one bicostate element (*"Paltodus utahensis"*) and two unicostate elements (*Acontiodus* (*Semiacontiodus*) *unicostatus* in part; *Acodus sevierensis* in part) from a previous study (Miller, 1969). The majority of specimens recovered in this study were bicostate elements; this is the reverse of Miller's (1980) observation that the unicostate element usually is the more abundant.

Occurrence.—Narrow Passage Creek samples NPC-108, NPC-136; Timberville sample T-45.

Number of specimens.—Unicostate element-8, bicostate element-16.

Figured specimens.—NPC-108, T-45.

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PLATES 1 AND 2

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PLATE 1

FIGURES 1, 2. *Acodus oneotensis* Furnish s.f.; inner lateral views, NPC-197 (×140), USNM 417972, NPC-178 (×90), USNM 417973, respectively.

3. *Acontiodus iowensis* Furnish s.f.; posterior view, NPC-181 (×105), USNM 417974.

4. *Acontiodus propinquus* Furnish s.f.; oblique posterior view, T-116 (×160), USNM 417975.

5. *Cambrooistodus minutus* (Miller); inner lateral view, NPC-63 (×120), USNM 417976.

6. *Clavohamulus densus* Furnish; oblique upper view, NPC-197 (×160), USNM 417977.

7. *Clavohamulus elongatus*? Miller; inner lateral view, NPC-65 (×110), USNM 413598.

8, 9. *Cordylodus angulatus* Pander; lateral views; rounded element, NPC-181 (×75), USNM 417978; and compressed element, NPC-169 (×150), USNM 417979.

10. *Cordylodus intermedius* Furnish; lateral view of rounded element, NPC-181 (×125), USNM 417980.

11. *Cordylodus lindstromi* Druce and Jones; lateral view of rounded element, NPC-178 (×100), USNM 417981.

12, 13. *Cordylodus proavus* Müller; lateral view of rounded element, NPC-65 (×90), USNM 413591; and inner lateral view of compressed element, NPC-65 (×70), USNM 417982.

14. *Cordylodus rotundatus* Pander; lateral view of rounded element, NPC-181 (×65), USNM 417983.

15. *Drepanodus* cf. *D. arcuatus* Pander; inner lateral view, NPC-197 (×130), USNM 417984.

16–18. *Drepanoistodus pervetus* Nowlan,
  16. Inner lateral view of suberectiform element, NPC-206 (×175), USNM 417985.
  17. Lateral view of homocurvatiform element, T-153 (×80), USNM 417986.
  18. Outer lateral view of suberectiform element, NPC-181 (×140), USNM 417987.

19, 20. *Eoconodontus notchpeakensis* (Miller); lateral views of rounded elements, NPC-59 (×140), USNM 417988, NPC-59 (×120), USNM 417989, respectively.

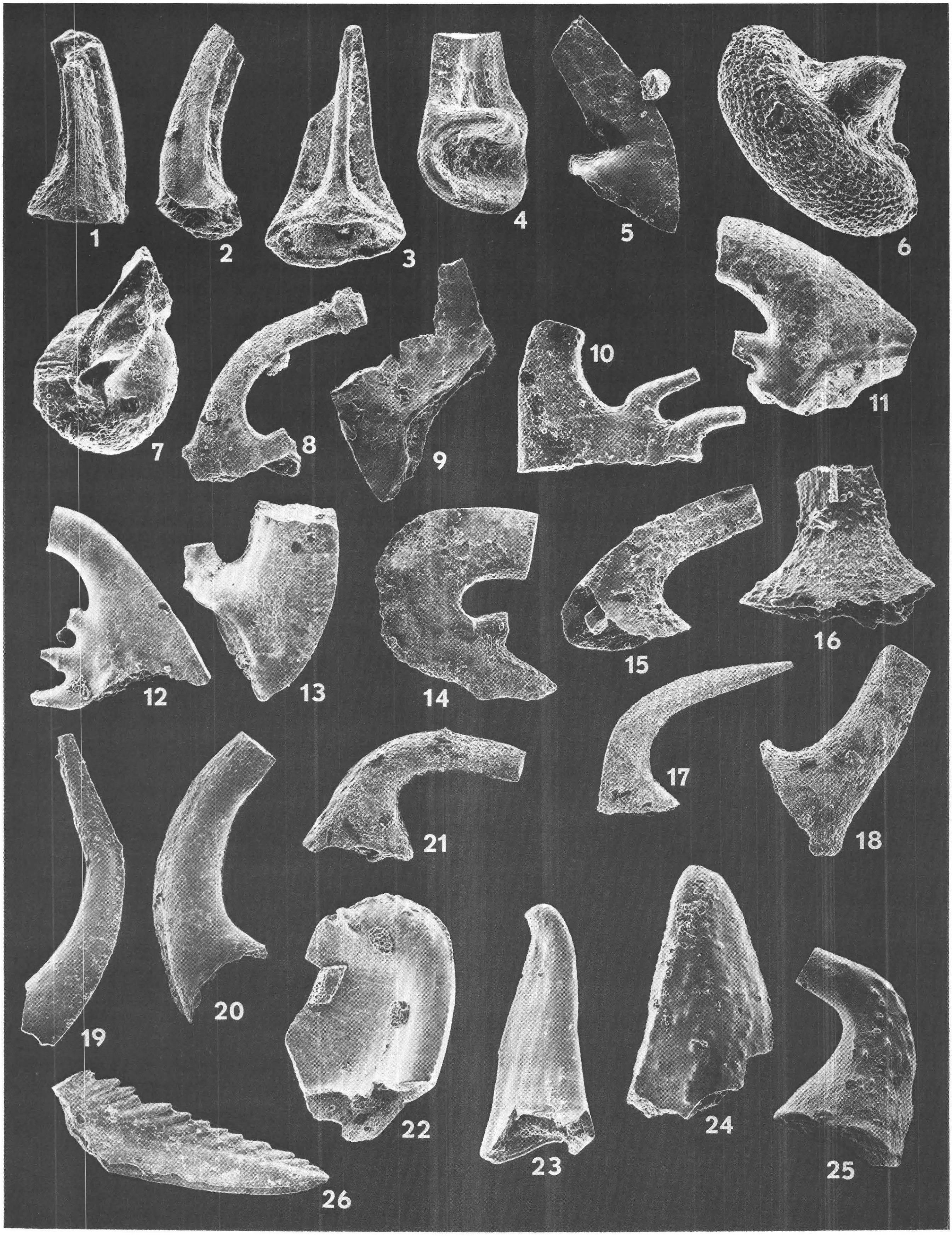
21. *Eucharodus* cf. *E. parallelus* (Branson and Mehl); lateral view, NPC-169 (×140), USNM 417990.

22, 23. *Fryxellodontus inornatus* Miller; inner lateral views, NPC-65 (×100), USNM 413595, NPC-65 (×125) USNM 417991.

24. *Fryxellodontus lineatus* Miller; outer lateral view, NPC-65 (×125), USNM 413593.

25. *Hirsutodontus hirsutus* Miller; lateral view, NPC-65 (×100), USNM 413592.

26. *Loxodus bransoni* Furnish; lateral view, T-157 (×80), USNM 413594.



ACODUS, ACONTIODUS, CAMBROOISTODUS, CLAVOHAMULUS, CORDYLODUS, DREPANODUS, DREPANOISTODUS, EOCONODONTUS, EUCHARODUS, FRYXELLODONTUS, HIRSUTODONTUS, LOXODUS

PLATE 2

FIGURE 1. *''Oistodus'' triangularis* Furnish s.f.; outer lateral view, NPC-194 (×100), USNM 417992.

2, 3. *Paltodus bassleri* Furnish; lateral view of symmetrical element, NPC-157 (×120), USNM 417993; and inner lateral view of asymmetrical element, NPC-157 (×85), USNM 417994.

4. *Paltodus* aff. *P. spurius* Ethington and Clark s.f.; oblique lateral view, NPC-197 (×90), USNM 417995.

5. *Proconodontus muelleri* Miller; lateral view, NPC-63 (×80), USNM 417996.

6, 7. *Proconodontus serratus* Miller; inner lateral views, NPC-59 (×100), USNM 413589, NPC-5 (×85), USNM 413590 respectively.

8. *Prooneotodus rotundatus* (Druce and Jones) s.f.; lateral view, NPC-37 (×190), USNM 417997.

9–11. *Rossodus manitouensis* Repetski and Ethington,

  9. Inner lateral view of coniform element, NPC-169 (×190), USNM 417998.
  10. Outer lateral view of coniform element, NPC-181 (×140), USNM 417999.
  11. Outer lateral view of oistodontiform element, NPC-181 (×200), USNM 418000.

12. *Rossodus* sp.; lateral view, NPC-188 (×70), USNM 418001.

13. *Scandodus* sp. s.f.; inner lateral view, NPC-169 (×75), USNM 418002.

14. *Paltodus bassleri* Furnish s.f.; lateral view, NPC-181 (×85), USNM 418003.

15. *Scolopodus sulcatus* Furnish s.f.; lateral view, T-139 (×100), USNM 418004.

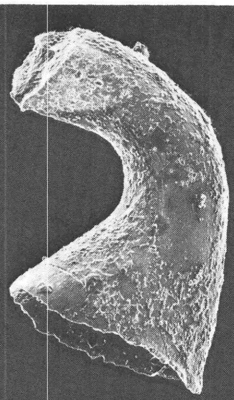
16. *Scolopodus* sp. s.f.; lateral view, NPC-181 (×100), USNM 418005.

17, 18. *Semiacontiodus nogamii* (Miller); inner lateral views, NPC-65 (×95), USNM 418006, NPC-65 (×75), USNM 418007, respectively.

19. *Teridontus nakamurai* (Nogami); lateral view, NPC-65 (×175), USNM 418008.

20, 21. *Teridontus* aff. *T. nakamurai* (Nogami); lateral views, NPC-169 (×100), USNM 418009, NPC-181 (×130), USNM 418010, respectively.

22, 23. *Utahconus utahensis* (Miller); lateral view of bicostate element, T-45 (×180), USNM 413597; and oblique posterior view of bicostate element, NPC-108 (×215), USNM 413596.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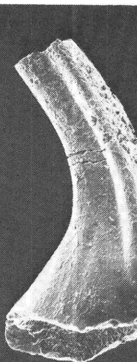
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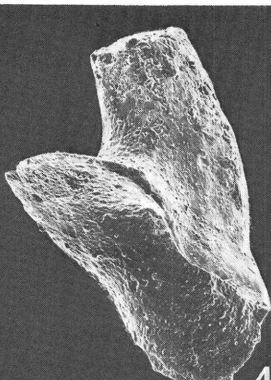
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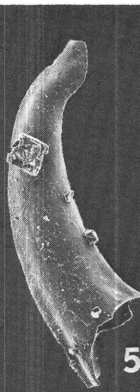
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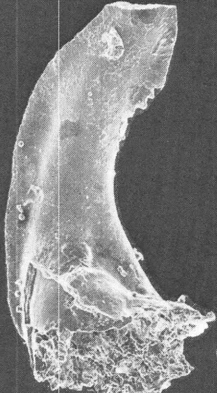
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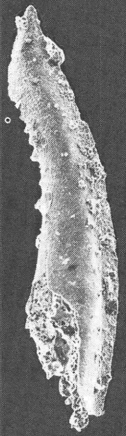
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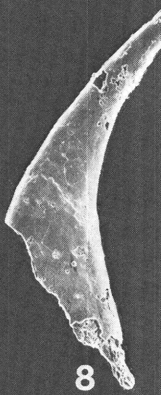
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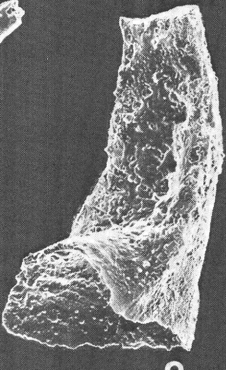
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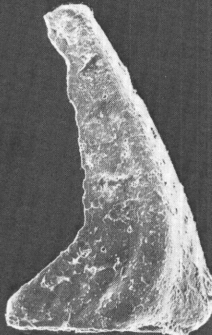
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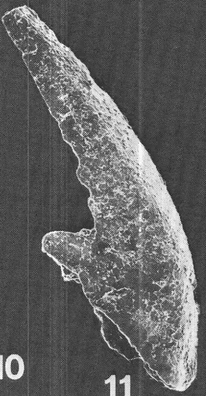
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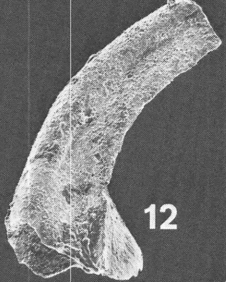
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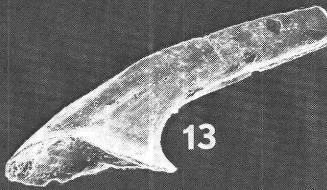
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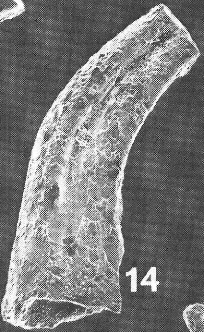
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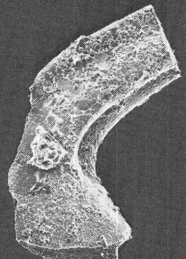
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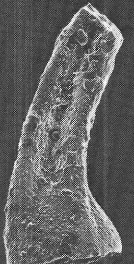
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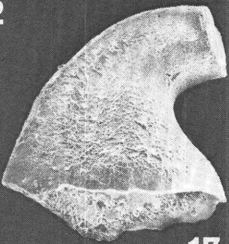
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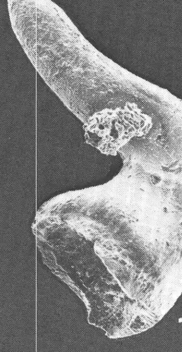
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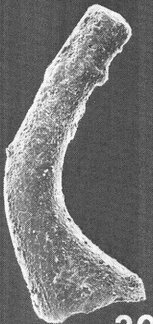
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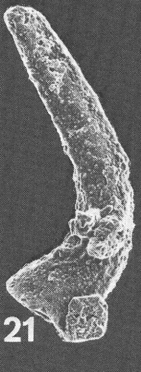
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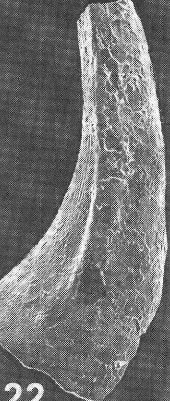
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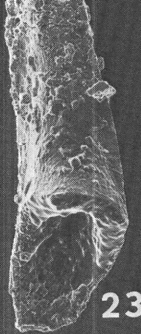
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"OISTODUS," PALTODUS, PROCONODONTUS, PROONEOTODUS, ROSSODUS, SCANDODUS, SCOLOPODUS, SEMIACONTIODUS, TERIDONTUS, UTAHCONUS

CHAPTER B

Conodont-Based Determination of the Silurian-Devonian Boundary in the Valley and Ridge Province, Northern and Central Appalachians

By KIRK E. DENKLER and ANITA G. HARRIS

U.S. GEOLOGICAL SURVEY BULLETIN 1837

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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Conodont-Based Determination of the Silurian-Devonian Boundary in the Valley and Ridge Province, Northern and Central Appalachians

By Kirk E. Denkler *and* Anita G. Harris

Abstract

The first appearance of the principal auxiliary index species to the base of the Devonian System, *Icriodus woschmidti*, is documented in 21 sections in the Valley and Ridge province of the central and northern Appalachian basin. The absence of graptolites and the endemism of the shelly fauna in this region necessitate using the first appearance of *I. woschmidti* for determination of the Silurian-Devonian boundary in the Appalachian basin, thus permitting relatively precise intrabasinal and extrabasinal correlation. In addition to *I. woschmidti*, two other species are useful accessory indices for boundary approximation: *Oulodus elegans* and *O. cristagalli*. Thus far there are four conodont-based biostratigraphic criteria that can be used to identify uppermost Silurian or lowermost Devonian strata and to approximate the base of the Devonian in the Valley and Ridge province: (1) the presence of *O. elegans* indicates a late Ludlovian–Pridolian age; (2) the co-occurrence of *O. elegans* and *O. cristagalli* indicates a very latest Pridolian age; (3) the presence of *O. cristagalli* indicates a very latest Pridolian to middle Lochkovian age; and (4) the occurrence of *I. woschmidti* indicates an earliest Devonian age. The conodont data, along with extrapolation from regional lithofacies relationships, indicate that the Silurian-Devonian boundary lies within the uppermost Keyser Limestone in the southern part of the study area and within the Whiteport Dolomite Member of the Rondout Formation in the north. The apparatuses of all three index species are briefly discussed.

INTRODUCTION

The international agreement establishing the Silurian-Devonian boundary stratotype has greatly facilitated intercontinental correlation of this chronostratigraphic horizon. The decision, however, to fix this boundary using the first occurrence of *Monograptus uniformis* at Klonk, Czechoslovakia, (Chlupáč and others, 1972; Martinsson, 1977) requires that in terranes lacking graptolite-bearing facies, the boundary can only be approximated by using other cosmopolitan taxa. Because conodonts are well documented in graptolite-bearing sequences worldwide, they are the principal auxiliary biostratigraphic indices for approximating the Silurian-Devonian boundary. The most utilized cosmopolitan conodont for diagnosing the base of the Devonian System is *Icriodus woschmidti*. Globally, *I. woschmidti* first appears 2 m below to 2 m above the first occurrence of *M. uniformis* (Jaeger, 1968; Chlupáč and others, 1972; Klapper and Murphy, 1975).

The absence of graptolites and the pronounced endemism of the shelly fauna in Upper Silurian–Lower Devonian rocks of the Appalachian basin (Boucot and others, 1969; Oliver, 1976; Copeland and Berdan, 1977) necessitates that conodonts be used to approximate the Silurian-Devonian boundary in this region. As part of a continuing investigation of the conodont biostratigraphy of the Silurian-Devonian carbonate sequence in the Appalachian basin, we have recovered representatives of *Icriodus woschmidti* from many measured sections of the Keyser and New Creek Limestones and the Manlius and Coeymans formations that span the Silurian-Devonian boundary along the eastern limit of the Appalachian basin. In addition to *I. woschmidti*, *Oulodus elegans* and *O. cristagalli* are supplemental indices of the boundary interval. Our conodont data together with data from other reports (Helfrich, 1978; Cook, 1981) now permit an approximation of the boundary in a large part of the Appalachian basin and a refined correlation with the international boundary stratotype.

Acknowledgments

We are grateful to J.M. Berdan and W.A. Oliver, Jr., U.S. Geological Survey, for sharing with us their expertise on the stratigraphy and paleontology of the Upper Silurian and Lower Devonian of the Appalachian basin.

LITHOSTRATIGRAPHY

Southern and North-Central Areas (Virginia to Central Pennsylvania)

In the Valley and Ridge province of west-central Virginia to central Pennsylvania, the Silurian-Devonian boundary is within the Keyser Limestone (figs. 1, 2). In part of this area (northeastern West Virginia through central Pennsylvania), Head (1972) formally subdivided the Keyser Limestone into three members; in ascending order, these are the Byers Island Member, Jersey Shore Member, and La Vale Member, which are herein accepted for use by the U.S. Geological Survey. The Keyser Limestone reaches a maximum thickness of approximately 85 m at its type locality near Keyser, W. Va., and thins to 30 m or less near its southern limit of exposure and to 60 m near its northern limit in Pennsylvania. The absence of the Keyser Limestone south

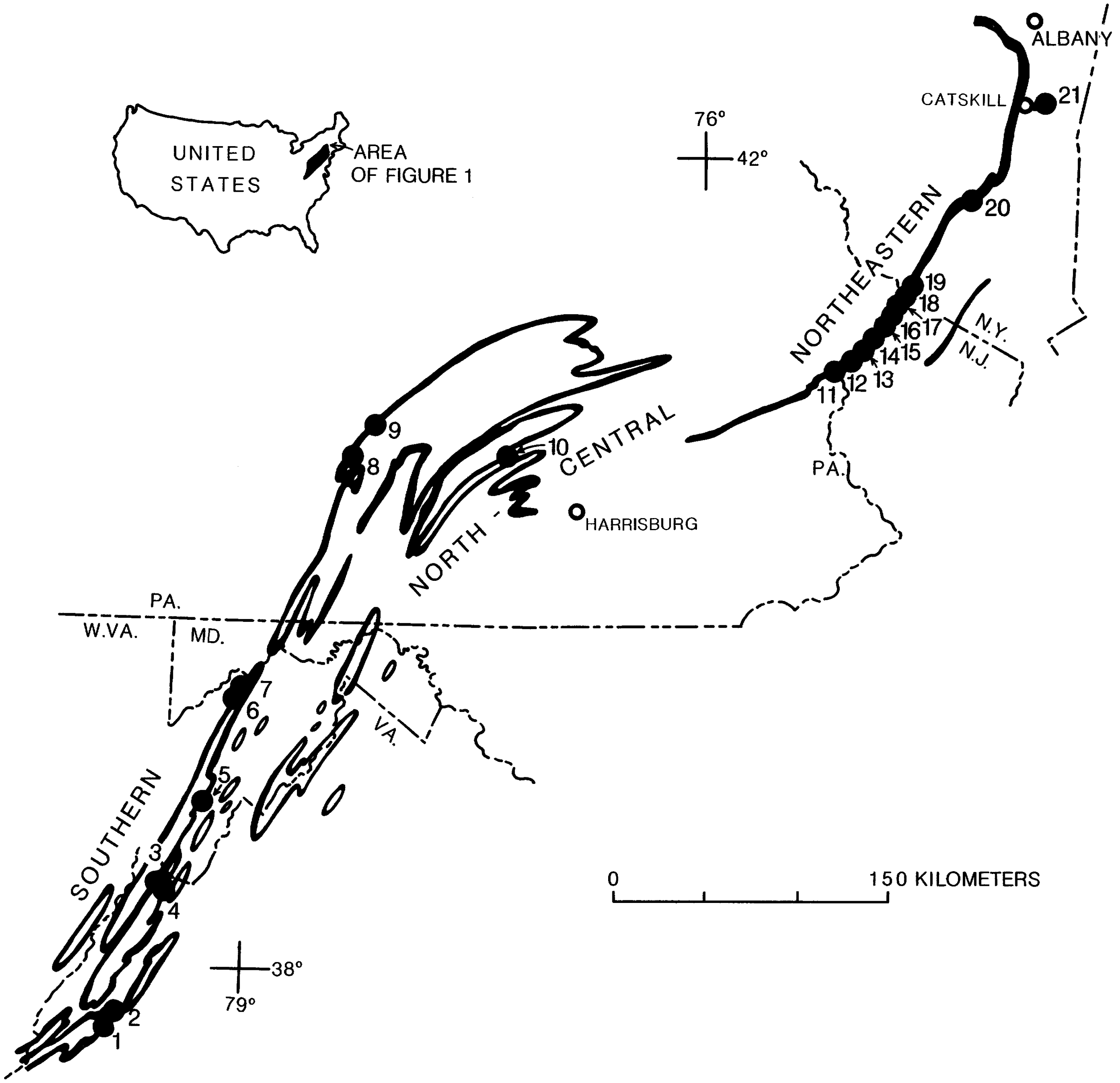

Figure 1. Index map of study area in the Appalachian basin showing outcrop belt of Upper Silurian–Lower Devonian rocks (modified from King and Beikman, 1974) and location of sampled measured sections (numbers keyed to locality register).

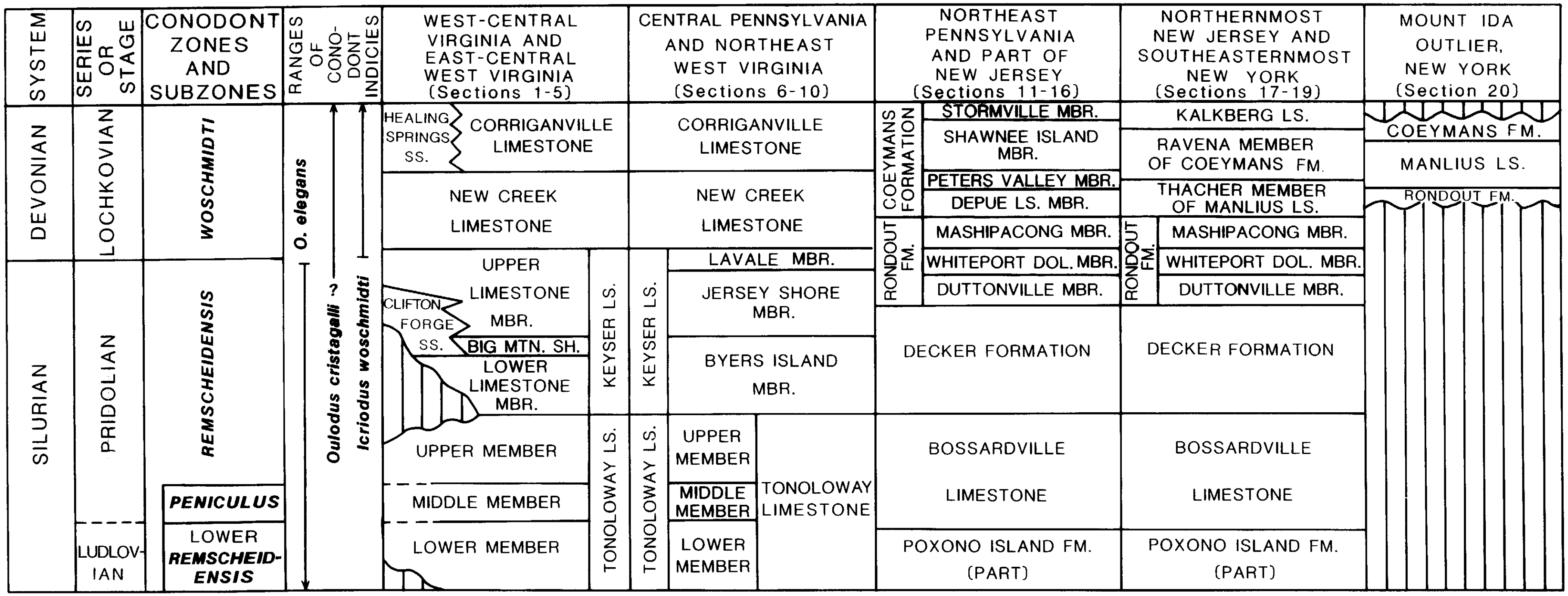

Figure 2. Correlation chart of uppermost Silurian and lowermost Devonian stratigraphic units in the Valley and Ridge province, west-central Virginia to eastern New York. Section locations shown in figure 1 and described in locality register. Latest Silurian conodont zonation from Denkler and Harris (1988).

of west-central Virginia and in the easternmost outcrop belts of the Valley and Ridge province from Virginia to southeastern Pennsylvania is due to subsequent erosion or to nondeposition (Dennison and Boucot, 1974). Fossiliferous wackestones to grainstones of the basal Keyser contrast sharply with the laminated carbonate mudstones of the underlying Tonoloway Limestone. The Keyser grades into the overlying arenaceous, crinoidal packstones and grainstones of the New Creek Limestone through a 1-m interval.

The Keyser consists of a diverse suite of carbonate and lesser siliciclastic lithofacies deposited in shallow subtidal to peritidal environments in a restricted foreland basin. Facies patterns were controlled by eustatic sea-level changes, differential basin subsidence, and rate of influx of clastic sediments (Dorobek and Read, 1986). Additional factors include proximity to a southwestern seaway through which normal marine waters entered the basin and to an eastern clastic source area, particularly to the southeast.

Two transgressive-regressive sequences characterize deposition of the Keyser Limestone. A basal transgression produced basinwide open-marine lithofacies consisting primarily of thin, nodular-bedded fossiliferous wackestone along the basin axis and massive crinoidal packstone and grainstone in the south and east of the basin axis (=Byers Island Member or lower limestone member, fig. 2). A subsequent minor regression accompanied by a northwestward progradation of clastic sediments resulted in the deposition of more restricted lagoonal and shelf deposits represented by calcareous shale (=Big Mountain Shale Member) and calcareous protoquartzite (=Clifton Forge Sandstone Member) in the southern part of the study area (fig. 2). The lower part of the upper limestone member or Jersey Shore Member marks a second, less extensive transgression and a return of more normal marine lithofacies. These units consist chiefly of massive encrinite and lesser shaly wackestone and packstone in the south to lagoonal and biohermal deposits in the north and locally along the southern basin margin. The succeeding uppermost part of the Keyser, in the north, consists chiefly of peritidal laminated dolomitic carbonate mudrock deposited during a basinwide regression (=La Vale Member or upper part of the upper limestone member). Similar lithologies predominate in the south except for a limited area in east-central West Virginia and west-central Virginia where more subtidal, normal marine conditions persisted. This area lay near the basin axis, close to the incursion of normal marine waters from the southwestern seaway and sufficiently distant from the effects of terrigenous sediments prograding northwestward. It is only in this area that conditions favorable for more normal marine faunas persisted across the Silurian-Devonian boundary. Consequently, collections from within this interval have yielded the stratigraphically lowest representatives of index species.

The overlying New Creek Limestone ranges in thickness from a maximum of approximately 20 m in west-central Virginia to a few meters in central Pennsylvania. It consists chiefly of thick- to massive-bedded and locally crossbedded, quartzose, crinoidal packstone to grainstone. Bedforms, rock type, and fossil content indicate deposition in high-energy, shallow subtidal environments. The New Creek represents the onset of a long continuous interval of normal marine deposition that persisted through the overlying Helderberg Group and into the Oriskany Group.

Northeastern Area (Northeastern Pennsylvania, New Jersey, and Easternmost New York)

From near Albany to Catskill, N.Y., a distance of about 50 km, the Rondout Formation, Manlius Limestone, and Coeymans Formation range from 20 to 30 m in thickness, combined, and rest with angular unconformity on Ordovician rocks (the Taconic unconformity). These units consist of a variety of carbonate lithofacies deposited in shallow subtidal to peritidal environments. Southwest of Catskill, increasingly older units intervene along this unconformity. Beds included in the Rondout Formation increase from a few meters in thickness to nearly 30 m, 15 km northeast of the New York–New Jersey–Pennsylvania border (Epstein and others, 1967); more significantly, about 1,000 m of dominantly clastic strata of Silurian age are interposed between the Rondout and the Taconic unconformity. From this area southwestward, the Rondout thins to 13 m at the Nearpass quarries (fig. 1, section 18) and then gradually to 9 m near the Delaware Water Gap (fig. 1, section 11). The Rondout is underlain by the Decker Formation, a fossiliferous, slightly quartzose grainstone to wackestone (in southeastern New York and northern New Jersey) that becomes increasingly quartzose southwestward. Near Delaware Water Gap (fig. 1, section 11), this unit is chiefly fossiliferous, calcareous, conglomeratic sandstone. The Decker has been interpreted as a biostromal bank (carbonate lithofacies) to barrier bar (clastic lithofacies) deposit. From southeastern New York into northeasternmost Pennsylvania, the Rondout is subdivided into three members (Epstein and others, 1967); in ascending order, the Duttonville, Whiteport Dolomite, and Mashipacong Members. The Duttonville Member consists chiefly of laminated, generally fissile and mud-cracked, argillaceous carbonate mudstone with a few layers of scattered to abundant ostracodes and corals. The Whiteport Dolomite Member is a slightly argillaceous, quartzitic and pyritic, laminated, generally mud-cracked dolomudstone. The Mashipacong Member consists of chiefly mud-cracked, laminated to thin-bedded, calcareous shale and argillaceous carbonate mudstone. The contact of the Rondout with the overlying Thacher Member of the Manlius Limestone or Depue Limestone Member of the Coeymans Formation ranges from abrupt to gradational. The Rondout has been interpreted as a chiefly carbonate mudflat deposit; the Whiteport Dolomite Member represents the most supratidal conditions during deposition of the formation as well as the culmination of the regression near the Silurian-Devonian boundary in the Appalachian basin (Epstein and Epstein, 1969). The onset of Mashipacong deposition marks the beginning of a transgression that correlates with the onset of New Creek deposition in the southern and north-central study areas.

In southeastern New York and northern New Jersey, the Rondout Formation is overlain by the Thacher Member of the Manlius Limestone. The Thacher ranges from 11 to 16 m in thickness in this area and consists of platy argillaceous and dolomitic carbonate mudrock succeeded by stromatoporoid biostromes and argillaceous limestone. It becomes increasingly quartzose and less biostromal in New Jersey where it grades laterally into the Depue Limestone Member of the Coeymans Formation. The contact of the Thacher with the overlying Ravena Member or Shawnee Island Member of the Coeymans Formation varies from abrupt to gradational. The Thacher is inferred to have been deposited in a shallow, relatively open lagoon with scattered patch reefs.

The Coeymans Formation is about 7 m thick near the northern limit of the study area, where it consists only of fossiliferous, irregularly bedded to crossbedded grainstone to wackestone of the Ravena Member. Quartzose silt, sand, and conglomerate as well as coral-stromatoporoid bioherms characterize the Coeymans in New Jersey and northeasternmost Pennsylvania. The Coeymans reaches a maximum thickness of 23 m near the Delaware Water Gap (fig. 1, sections 12 and 13) as a result of biohermal development in the Shawnee Island Member of the Coeymans and by the inclusion of suprajacent (Kalkberg equivalent) and subjacent (Manlius equivalent) beds within the Coeymans. Southwest of Delaware Water Gap the Coeymans becomes dominantly calcareous quartzose sandstone and conglomerate and thins to a feather edge (Epstein and Epstein, 1969). The contact between the Coeymans and overlying Kalkberg Limestone in New York and part of New Jersey is marked by the first appearance of relatively abundant blue-black chert nodules and an increase in clay-sized to fine sand-sized quartz. Across New Jersey, the Kalkberg becomes increasingly coarse grained and quartzose and grades into the Stormville Member of the Coeymans Formation (Epstein and others, 1967). The Stormville is abruptly overlain by argillaceous calcisiltite of the New Scotland Formation. The Coeymans was deposited in a mosaic of relatively high-energy, shallow subtidal environments that include dominantly clastic to dominantly carbonate barrier and barrier apron deposits.

SILURIAN-DEVONIAN BOUNDARY

Previous Work

The position of the Silurian-Devonian boundary in relation to the Keyser Limestone has long been controversial. The Keyser contains a predominantly endemic shelly fauna with affinities to underlying Silurian and overlying Devonian strata. Endemism coupled with relatively long species ranges has inhibited high-resolution interregional and intercontinental correlation.

Affinities between the Keyser shelly fauna and that of the overlying Helderberg led some early workers to assign the entire Keyser Limestone to the Devonian (Ulrich, 1911; Swartz, 1913; Reeside, 1917). Other investigators have also placed the Keyser in the Devonian because of its lithostratigraphic affinities with the rest of the overlying Helderberg Group of established Devonian age (Swartz, 1929; Woodward, 1943). The entire Keyser was placed in the Silurian by Swartz and others (1942) and excluded from the Devonian by Cooper and others (1942).

Early investigators recognized two successive faunas in the Keyser, a lower *Eccentricosta jerseyensis* Zone and an upper *Favosites helderbergiae praecedens* Zone (Swartz, 1913; Reeside, 1917; Swartz, 1929). Bowen (1967), in a study of the brachiopods of the Keyser Limestone, proposed the *Meristella praenuntia* Zone as an approximate replacement of the *praecedens* Zone. He considered this zone to be Early Devonian based on the presence of representatives of the brachiopods *Cyrtina* and the terebratulid *Nanothyris*. The strong Silurian affinities of the brachiopods in the lower Keyser as well as the presence of *Cystihalysites* supported a Late Silurian age for the *jerseyensis* Zone. The Silurian-Devonian boundary was thus placed within the middle of the Keyser Limestone. Some subsequent studies (Head, 1969; Berry and Boucot, 1970; Dennison and Head, 1975; Stock and Holmes, 1986) followed Bowen and placed the base of the Devonian at the base of the *praenuntia* Zone. In Pennsylvania and western Maryland, this corresponds to the base of the Jersey Shore Member and, further south, to the base of the upper limestone member. The most recent correlation charts for Silurian and Devonian rocks in Pennsylvania and Maryland (Berg and others, 1983; American Association of Petroleum Geologists, 1985) have placed the base of the Devonian within the uppermost beds of the Keyser Limestone based on extrapolations, we assume, from published (Helfrich, 1978) and unpublished conodont data (Cook, 1981).

In the northeastern area, the Silurian-Devonian boundary has been placed historically at the contact between the Manlius Limestone and Coeymans Formation because at most localities a stromatoporoid-coral biostrome at the top of the Manlius is abruptly succeeded by crinoidal packstone to grainstone of the Coeymans. This contact is sharp and undulose and has been interpreted as a disconformity at the Silurian-Devonian boundary. In addition, similar to the Keyser–New Creek relationship in the southern and north-central parts of the study area, the fauna of the Coeymans Formation is definitively Devonian whereas the Manlius contains a fauna of mixed Silurian-Devonian aspect. More recent studies (Rickard, 1962; Laporte, 1969) have shown that the contact between the Manlius and Coeymans is not an unconformity but at most a diastem and possibly merely a sharp, conformable lithofacies change. Rickard (1962) included the Thacher Member of the Manlius Limestone in the Helderberg Group and placed the Silurian-Devonian boundary at the base of the Thacher in eastern New York. The Silurian-Devonian boundary has also been placed at the base of the Rondout Formation in the Becraft Mountain and Mount Ida outliers, New York (fig. 1, section 21) and Green Pond–Schunemunk Mountain outlier, New York–New Jersey (Rickard, 1975) and in the main outcrop belt of southeastern New York (American Association of Petroleum Geologists, 1985). In addition, the boundary has been placed within the Rondout Formation in the easternmost outcrop belt of the Valley and Ridge province in Pennsylvania and New Jersey (Epstein and Epstein, 1969; Oliver and others, 1967) and southeastern New York (Rickard, 1975). Although until now, beds of the Rondout Formation have not produced index fossils, definitive Silurian megafossils and conodonts have been recovered from the underlying Decker Formation and definitive Devonian conodonts have been recovered from the upper part of the overlying Manlius Limestone. Thus, by default and somewhat arbitrarily, the boundary has been placed within the Rondout Formation.

Studies based on shelly faunas from the Keyser Limestone (Head, 1969; Makurath, 1975) and Manlius Limestone and Coeymans Formation (Laporte, 1969; Anderson, 1967) have contributed significantly to the interpretation of the depositional environments of these units. Brachiopods, ostracodes, and corals form the basis for the regional biostratigraphic framework of these rocks (Swartz and Whitmore, 1956; Bowen, 1967; Berdan, 1972; Oliver and Pedder, 1979; Sorauf and Oliver, 1983, among others). These faunal elements, however, have proven limitations for intercontinental and even intracontinental correlation because of endemism and facies dependence. Although conodonts, in general, exhibit some facies restrictions and various degrees of provinciality, they are more cosmopolitan and thus more biostratigraphically useful than the shelly benthos. In this study, we document the distribution of the most biostratigraphically diagnostic conodont species in uppermost Silurian and lowermost Devonian rocks in the Valley and Ridge province of the Appalachian basin and use these data for intercontinental correlation and determination of the base of the Devonian System.

Conodont Biostratigraphy

Since established by Walliser (1964), the *Icriodus woschmidti* Zone has been used to delineate lowermost Devonian strata worldwide. Prior to formal acceptance of the Silurian-Devonian boundary stratotype in 1972, the base of the *woschmidti* Zone was considered by some to mark the base of the Devonian (Walliser, 1971). Detailed analysis of the distribution of graptolites and conodonts as well as other fossil groups in the Barrandian of Czechoslovakia (Chlupáč and others, 1972) indicated that in the Certovy schody section, *I. woschmidti* occurs with *Monograptus transgrediens* and first appears 1.5 m below the base of the *M. uniformis* Zone. In the Carnic Alps (Jaeger, 1968) and in the Roberts Mountains, Nevada (Klapper and Murphy, 1975), the base of the *woschmidti* Zone is approximately 2 m below the base of the *uniformis* Zone. At the international boundary stratotype at Klonk, Czechoslovakia, however, *I. woschmidti* first appears approximately 2 m above the base of the *uniformis* Zone (Chlupáč and others, 1980). The same biostratigraphic relationship occurs at three other sections in the Barrandian area, including the auxiliary stratotype section. Even though the relative first appearance of these two index species is apparently not coincident, their stratigraphic separation is known to be within 2 m, thus making *I. woschmidti* an acceptable alternative index for recognition of the base of the Devonian.

The shallow-water carbonate rocks of the Keyser Limestone consistently yield low-diversity conodont faunas of generally low abundance. Like those of the underlying Tonoloway Limestone, the conodont faunas are dominated by morphotypes of *Ozarkodina remscheidensis* (Ziegler). Aside from locally abundant representatives of *Oulodus elegans* (Walliser), all other conodont species known to occur in this interval elsewhere in the world are either absent or present in less than 5 percent of the approximately 170 samples collected.

Denkler and Harris (1988) used the first appearance and stratigraphic range of a new endemic species from the middle member of the Tonoloway Limestone to define the Ludlovian-Pridolian boundary and delineate lower Pridolian strata in the central Appalachian basin. Attempts to further subdivide Pridolian strata in this area based on morphometric studies or subspecies distribution of *Ozarkodina remscheidensis* proposed by Barnett (1971, 1972) or Walliser (1964, 1971) and Klapper and Murphy (1975), among others, have been unsuccessful. Denkler and Harris (1985) noted that *O. remscheidensis* morphotypes are long-ranging (late Ludlovian–early Lochkovian), coeval, intergradational ecophenotypes that cannot be used for biostratigraphic subdivision in the central Appalachian basin. In addition, some cosmopolitan long-ranging Silurian species that do not extend into the latest Pridolian, such as *O. confluens* (Branson and Mehl), have not been found above the middle member of the Tonoloway Limestone (lower Pridolian). Thus far, *Oulodus elegans* (Walliser) appears to be the only species possibly restricted to the Silurian that extends into the Keyser Limestone. Its highest occurrences in nine sections (table 1) that include the upper half of the Keyser Limestone and its contact with the overlying New Creek Limestone range from as high as 1.8 m below the top of the Keyser Limestone in the southern study area to at least 20.1 m below the top in the north-central study area. Thus, the presence of this

Table 1. Stratigraphic position of important conodont biohorizons for the placement of the Silurian-Devonian boundary in the Valley and Ridge province of the central and northern Appalachian basin

[Location of sections shown in fig. 1 and described in locality register; sections 1 and 4 from Cook (1981); sections 5 and 7 from Helfrich (1978)]

Measured sections	First appearance or last occurrence of species in meters above (+) or below (−) contact of Keyser–New Creek Limestones (sections 1–10) or Manlius Limestone and correlatives[8]Coeymans Formation (sections 11–21)		
	Oulodus elegans[1]	*Oulodus cristagalli*[2]	*Icriodus woschmidti*[2]
Virginia			
1	−4.5	−4.5	+2.7
2	−1.8	—	+0.8
3	−17.0	−2.7	−1.7
4	−9.0	−13.5	−3.3
West Virginia			
5	−9.5 to −12.5	—	−2.5 to −5.5
6	−34.8	−3.6	+1.2
7	−7.0 to −11.0	—	+1.0
Central Pennsylvania			
8	−26.0	+0.3	+0.3
9	—	—	+1.2
10	−20.1	+0.1	+0.1
Northeast Pennsylvania			
11	—	—	+1.0
12	—	−2.3	+2.3
13	—	−2.7	+1.3
New Jersey			
14	—	−0.3	+1.5
15	—	−1.5	+0.3
16	—	−0.3	+0.3
17	—	−1.6	+0.3
18	—	−2.6	−2.6
New York			
19	—	−3.0	+0.3
20	−22.0	—	−13.4
[3]21	—	−7.5	−5.0

[1] Last occurrence.

[2] First appearance.

[3] A collection (USGS colln. 10649-SD) from at least 2 m below the top of the Manlius Limestone at Becraft Mountain outlier, about 5 km southwest of section 21, also produced representatives of *Oulodus cristagalli* and *Icriodus woschmidti*.

species can be used to identify Silurian strata in sections that straddle the Silurian-Devonian boundary in the Appalachian basin.

O. cristagalli is a common associate of the basal Devonian index species *I. woschmidti*. This species is known only from shallow-water facies in eastern North America, part of Europe, Turkey, and eastern Australia, but unfortunately has not been reported from the boundary stratotype. The Pb1 element of the species has been reported, however, from one section, near the base of the Lochkovian in the Barrandian area (Walmsley and others, 1974, table 2). In the central Appalachian basin there is a small overlap in the ranges of *O. elegans* and *O. cristagalli* within the uppermost Keyser Limestone (table 1) that is below the first appearance of *I. woschmidti*. Thus *O. cristagalli* apparently ranges into the very latest Pridolian. In the northern part of the basin, inappropriate lithofacies (La Vale Member of the Keyser Limestone or Rondout Formation–lower Manlius Limestone) within this interval of overlap separate the occurrences of *O. elegans* and *O. cristagalli*. In central Pennsylvania, *O. cristagalli* first appears within the basal meter of the New Creek Limestone coincident with the first occurrence of *I. woschmidti*. In the northeastern study area, however, *O. cristagalli* typically first occurs within the upper 3 m of the Thacher Member of the Manlius Limestone (table 1) and generally below the first occurrence of *I. woschmidti* in the base of the overlying Ravena or Shawnee Island Member of the Coeymans Formation.

Icriodus woschmidti is a significant component of the conodont fauna of the New Creek Limestone and Ravena and Shawnee Island Members of the Coeymans Formation. In most measured sections it first appears within the basal few meters (table 1) of these stratigraphic units. Exceptions include the Mohonk Lake section in New York (fig. 1, section 20) where *I. woschmidti* occurs as low as 1 m above the base of the Manlius Limestone, 3 m below the top of the Manlius Limestone in the Nearpass quarries section in New Jersey, and in three sections in east-central Virginia and west-central West Virginia where it occurs within the Keyser Limestone, 3 m below the base of the New Creek Limestone. Other species commonly associated with *I. woschmidti* are *Oulodus cristagalli*, morphotypes of *Ozarkodina remscheidensis*, and simple-cone species. This species association is generally indicative of high-energy, relatively shallow-water, normal marine depositional environments.

Stratigraphic Position of the Base of the Devonian System

As indicated above, there are four biostratigraphic criteria based on conodonts that can be used to identify uppermost Silurian or lowermost Devonian strata and to approximate the base of the Devonian in the central and northern Valley and Ridge province: (1) the presence of *Oulodus elegans* indicates a late Ludlovian–Pridolian age; (2) the co-occurrence of *O. elegans* and *O. cristagalli* indicates a very latest Pridolian age; (3) the presence of *O. cristagalli* indicates a very latest Pridolian to middle Lochkovian age; and (4) the occurrence of *Icriodus woschmidti* indicates the *woschmidti* Zone and an earliest Lochkovian age. We are well aware that *I. woschmidti* has been reported from the uppermost *Monograptus transgrediens* Zone (Chlupáč and others, 1972) at a single locality in the Barrandian. We also recognize that the first occurrence of *I. woschmidti* in any section does not necessarily correspond to the base of the *woschmidti* Zone. Nevertheless, we choose to follow the recommendation of Chlupáč and others (1972) by using the first occurrence of *I. woschmidti* as an auxiliary index to the base of the Devonian System.

Southern and North-Central Areas

Icriodus woschmidti occurs as low as 3 m below the top of the Keyser Limestone in three sections in Virginia and West Virginia (table 1). Of these, the Silurian-Devonian boundary can be most precisely placed at Strait Creek, near Monterey, Va. Cook (1981) reported the highest occurrence of *O. elegans* together with *O. cristagalli* 6 m below the first appearance of *I. woschmidti*. Thus the Silurian-Devonian boundary is between 9 and 3.3 m below the top of the Keyser Limestone. Even though in all other sections sampled thus far *I. woschmidti* is restricted to beds above the Keyser Limestone, its presence in uppermost Keyser strata near the southern basin axis strongly suggests that elsewhere in this area uppermost Keyser beds are also of Devonian age. Because the Silurian-Devonian boundary occurs within strata that were deposited during a basinwide regression (uppermost Keyser Limestone), appropriate environments for the occurrence of index conodonts persisted only in a limited part of the southern study area (fig. 1, sections 3–5). We suspect that a greater thickness of the upper Keyser is of Devonian age in the north-central part of the study area than in the south, because the New Creek transgression proceeded northward and therefore Keyser lithofacies persisted longer in the north. At Tyrone, Pa. (fig. 1, section 10), the Silurian-Devonian boundary lies within the upper 20 m of the Keyser in an interval that contains no biostratigraphically diagnostic conodonts (table 1). In general, basinwide regression during uppermost Keyser deposition and the subsequent transgression that initiated New Creek deposition resulted in a northward lowering of the lithostratigraphic position of the Silurian-Devonian boundary and a younging of the first occurrence of *I. woschmidti*.

Northeastern Area

Icriodus woschmidti first appears within the basal 2 m of the Ravena and Shawnee Island Members of the Coeymans Formation in all sections sampled except at the Nearpass quarries, New Jersey, in the Mohonk Lake quadrangle, New York, and at Mount Ida, New York (fig. 1, sections 18, 20, 21). At the Nearpass quarries, *I. woschmidti* occurs in the Thacher Member of the Manlius Limestone, 2.6 m below the base of the Coeymans. The lowest occurrence of *Oulodus cristagalli* in this area is 2.6 m below the top of the Manlius in this section. Out of nearly 100 samples processed for conodonts from the Bossardville, Decker, Rondout, and lower Manlius formations in the area that includes sections 11 to 19 (fig. 1), *O. elegans* has been recovered from only one sample (USGS colln. 10657-SD) collected 5 m above the base of the Decker Formation at Bossardsville, Pa., approximately 10 km southwest of section 11 (fig. 1). All other samples only produced variable abundances of morphotypes of *Ozarkodina remscheidensis*. Brachiopods and corals from the Decker Formation indicate a definitive Late Silurian age. The overlying Rondout and lower Manlius formations have only yielded fossils of limited biostratigraphic utility. Thus the Silurian-Devonian boundary is within a 30-m interval. For reasons cited above, we suspect the first appearance of *I. woschmidti* is higher within the *woschmidti* Zone in this area than to the south and possibly the west. The position of the Silurian-Devonian boundary is less precisely located here than elsewhere in the study areas. Collections from the Mohonk Lake quadrangle, New York (fig. 1, section 20), however, once again permit a more precise placement of the boundary. *Oulodus elegans* was recovered from within the Glasco Member of the Rondout Formation (USGS colln. 11815-SD) at Accord, N.Y. (fig. 1, section 20), indicating a definitive Late Silurian age for a relatively high level within the Rondout Formation. About 5.5 km northeast of Accord, M, S, and fragments of Pa elements of *Icriodus* have been recovered from two samples, 1 and 2.5 m above the base of the Manlius Formation (USGS collns. 11818-SD, 11819-SD), indicating a Devonian age for the entire Manlius. Thus, in this area, the Silurian-Devonian boundary lies within a 5- to 7-m interval that includes the upper beds of the Glasco Member and the entire Whiteport Dolomite Member of the Rondout. We depart somewhat from the interpretation used by Rickard (1975) and Berg and others (1983) in placing the base of the Devonian System not at the base of the Rondout Formation, but rather within the Whiteport Dolomite Member of the Rondout, as did Oliver and others (1967) or at the base of the overlying Mashipacong Member (=base of Manlius Limestone in eastern New York). The Whiteport Dolomite Member consists of mud-cracked, laminated dolomudstone that probably represents maximum regression near the Silurian-Devonian boundary. This unit corresponds to some level in the upper limestone member of the Keyser Limestone associated with lowest conodont diversity in the more consistently normal marine sections in the southern study area near the basin axis.

SYSTEMATIC PALEONTOLOGY

All figured specimens are reposited in the U.S. National Museum, Washington, D.C. (USNM).

Genus ICRIODUS Branson and Mehl, 1938

Icriodus woschmidti woschmidti Ziegler, 1960

Plate 1, figures A-H

Remarks.—The elements of representatives of *Icriodus woschmidti woschmidti* in our collections from the central and northern Appalachian basin conform in virtually all respects to elements of the subspecies figured by Serpagli (1983) from Sardinia and to the elements we assign to the subspecies figured by Ziegler (1960, pl. 13, figs. 6, 17; pl. 14, figs. 11, 19, 21; pl. 15, figs. 12, 16–22) from the Gedinnian of the Rheinisches Schiefergebirge in the Federal Republic of Germany. Our collections contain Pa elements and four symmetry transition series in what we consider the Pb, M, and two Sa–Sd series positions. The latter consist of an adenticulate and denticulate series (pl. 1, figs. E–H). Although Serpagli (1983) figured many morphotypes of the denticulate S series, he may have included some members of the adenticulate S series in his e-position series (fig. 4A?). Unfortunately, representatives of both S series are rare in our collections; it appears, however, there are at least three elements in the denticulate series and four in the adenticulate series.

Genus OULODUS Branson and Mehl, 1933

Remarks.—We follow the multielement diagnosis given by Sweet and Schönlaub (1975) for the genus *Oulodus* which permits a wide range in apparatus composition and morphotype and thus accommodates many types of digyrate apparatuses of Middle Ordovician through Devonian age. We emend their multielement diagnosis to allow two types of Pb elements in the same species and a vacancy in the M as well as the Pa position. Sweet and Schönlaub acknowledged, however, the possibility that the inclusion of post-Silurian species in *Oulodus* may be a polyphyletic grouping. Klapper and Philip (1971) established the genus *Delotaxis* for Type 3 apparatuses of Silurian and Devonian age (=digyrate apparatuses) and designated *Ligonodina elegans* Walliser the type species of the genus. The apparatus to which *L. elegans* belongs is equally dissimilar to Ordovician and Late Devonian digyrate apparatuses. We believe, however, that the Late Silurian and earliest Devonian digyrate apparatuses, particularly in the aspect of their Pb element(s), form a continuum with Ordovician and older Silurian representatives of *Oulodus*.

Oulodus cristagalli (Ziegler)

Plate 1, figures I–T

Pa element

1960. *Lonchodina walliseri* Ziegler, p. 188–189 (part), only pl. 14, fig. 2.

?1968. *Lonchodina serbica* Schulze, p. 198, pl. 17, figs. 25, 27.

Pb1 element

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

1964. *Lonchodina cristagalli* Ziegler. Walliser, p. 43, pl. 9, fig. 23.

1968. *Lonchodina cristagalli* Ziegler. Schulze, p. 196, pl. 17, fig. 23.

1970. *Lonchodina cristagalli* Ziegler. Epstein, p. 174–176, pl. 5, figs. 1, 2.

1975. *Falcodus* sp. Hamdi, pl. 1, fig. 2.

1980. *Delotaxis walliseri* (Ziegler). Pickett, p. 79–81, fig. 10M.

1981. *Delotaxis excavata cristagalli* (Ziegler), Pb element. Cook, p. 68–71, pl. 2, figs. 1, 4.

1986. *Oulodus greilingi hirpex* Mawson, p. 46, pl. 1, fig. 4.

1988. *Oulodus cristagalli* (Ziegler), Pb1 element. Elbert and others, pl. 1, figs. H–J.

Pb2 element

1960. *Lonchodina walliseri* Ziegler, p. 188–189, pl. 14, figs. 6, 7.

1970. *Lonchodina walliseri* Ziegler. Epstein, p. 179–181 (part), pl. 5, fig. 3, pl. 4, fig. 16.

1980. *Delotaxis walliseri* (Ziegler). Pickett, p. 79–81, figs. 10J, 10K.

1981. *Delotaxis excavata cristagalli* (Ziegler), Pa element. Cook, p. 68–70, pl. 2, fig. 7.

1981. *Delotaxis excavata cristagalli* (Ziegler), M element. Cook, p. 68–72, pl. 2, fig. 5.

1986. *Oulodus greilingi hirpex* Mawson, p. 46, pl. 1, figs. 2?, 3.

?M element

1960. *Prioniodina excavata* Branson and Mehl. Ziegler, p. 192, pl. 15, fig. 5.

?1986. *Oulodus walliseri* (Ziegler), M element. Mawson, p. 48, pl. 9, fig. 5.

Sa element

1960. *Trichonodella inconstans* Walliser. Ziegler, p. 197, pl. 14, figs. 14, 17.

1970. Trichonodella inconstans Walliser. Epstein, p. 232–235, pl. 6, figs. 7–10.

1981. *Delotaxis excavata cristagalli* (Ziegler), Sa element. Cook, p. 72, pl. 2, fig. 3.

Sb element

1960. *Lonchodina greilingi* Walliser. Ziegler, p. 188, pl. 14, figs. 15, 16, 18, 20.

1970. *Lonchodina greilingi* Walliser. Epstein, p. 176–179, pl. 5, fig. 10.

1981. *Delotaxis excavata cristagalli* (Ziegler), Sb element. Cook, p. 69–72, pl. 2, fig. 2.

1988. *Oulodus cristagalli* (Ziegler), Sb element. Elbert and others, pl. 1, fig. K.

Sc element

?1960. *Ligonodina diversa* Walliser. Ziegler, p. 186–187, pl. 14, figs. 8, 12.

1960. *Ligonodina* n. sp. Walliser. Ziegler, p. 187, pl. 14, figs. 9, 10.

1960. *Ligonodina* n. sp. a, Ziegler, p. 187, pl. 14, fig. 13.

1970. *Ligonodina salopia* Rhodes. Epstein, p. 170–174 (part), pl. 7, figs. 1, 2, 6, 7.

1981. *Delotaxis excavata cristagalli* (Ziegler), Sc element. Cook, p. 69–73, pl. 2, fig. 6.

Description.—Robust multielement species with Pa (rare), Pb1, Pb2, Sa, Sb, and Sc elements; M position appears to be vacant or rarely occupied. Pa element angulate (priniodiniform); Pb elements digyrate (oulodontiform), Pb1 (cristagalliform) element processes have greater inversion of attachment surface, are more twisted and form a smaller angle than processes of Pb2 (walliseriform); Sa element alate (trichonodelliform); Sb element digyrate (lonchodiniform); Sc element bipennate (ligonodiniform).

All elements have discrete denticles that are subround to oval in cross section. All elements, except the Pa element, have been adequately described previously. The Pa element is angulate with processes of nearly equal length; lower margin of cusp is slightly flared; basal cavity extends as a slit to the end of the anterior process and is wider and weakly inverted on the posterior process; cusp only slightly wider and higher than largest process denticles; process denticles extremely variable in size (pl. 1, fig. I); posterior process denticles may be bowed inward.

Remarks.—Representatives of Oulodus are characteristic of high-energy, shallow-water biofacies and are generally hydraulically sorted and broken. Consequently apparatus reconstruction and adequate description of even discrete elements is difficult. Thus far, only three geographically widespread multielement species of *Oulodus* have been documented in Upper Silurian and lowermost Devonian rocks: *Oulodus elegans* (Walliser) (Jeppsson, 1969, 1974; Sweet and Schönlaub, 1975; Cook, 1981; Bultynck, 1986), which ranges from the late Ludlovian to the latest Pridolian; *Oulodus siluricus* (Branson and Mehl) (Chlupáč and others, 1980, pl. 17, fig. 20) which ranges from the middle Ludlovian to at least the early Pridolian; and *Oulodus cristagalli* (Ziegler) (Pickett, 1980; Cook, 1981; Mawson, 1986; Elbert and others, 1988) which ranges from the latest Pridolian to at least middle Lochkovian. The apparatus composition and element morphotype of *Oulodus cristagalli* is closer to *O. siluricus* than *O. elegans*. Even though *O. elegans* is common in our sections and overlaps the lowest part of the range of *O. cristagalli*, and though *O. siluricus* has not been recognized in the central Appalachian basin, it seems more likely that *O. cristagalli* evolved from *O. siluricus* or related forms. Plate 1 shows the apparatus composition of *O. elegans* and *O. cristagalli* in samples from the central Appalachian basin.

Our reconstruction of the apparatuses of *O. cristagalli* and *O. elegans* is based on large collections with low species diversity. In these collections, all other elements not assigned to *Oulodus* belong to other well known multielement species. The sample which forms the basis of our reconstruction of *O. elegans* is from the upper limestone member of the Keyser Limestone at Lambert Gap, W. Va., of late Pridolian age (USGS colln. 10669-SD). This collection contains abundant representatives of *O. elegans* and only a few ramiform element fragments of *Ozarkodina remscheidensis* (Ziegler) and decoriconids. Our reconstruction agrees in element composition with that of Cook (1981), except that we place both oulodontiform elements in the Pb position whereas she assigned our Pb1 to an Sd position. The sample that produced abundant representatives of *O. cristagalli* is from the New Creek Limestone near McDowell, Va., of earliest Devonian age (USGS colln. 11549-SD). In addition to abundant *O. cristagalli*, the sample contains abundant *Icriodus woschmidti woschmidti* Ziegler, lesser numbers of *Ozarkodina remscheidensis* (Ziegler), and a few representatives each of *Belodella* sp. and *Pseudooneotodus beckmanni* (Bischoff and Sannemann). In this collection, there are 3 Pa, 11 Pb1, 46 Pb2, 17 Sa, 45 Sb, and 62 Sc elements of *O. cristagalli*. We could not identify any specimens assignable to the M position. In addition to the apparent absence of an M element in our collections, Pa elements appear to be underrepresented in this species. Because other species of *Oulodus* may contain two Pb elements (for example, *O. elegans*, pl. 1, figs. V, W) as well as an M element (pl. 1, fig. X), we did not place either of the oulodontiform elements in the M position. Cook (1981, pl. 2, fig. 5) figured an incomplete digyrate specimen as an M element of *O. cristagalli*. Moreover, she stated that all specimens assigned to the M position in her collections are broken and resemble what we consider the Pb2 element. We interpret her material to be incomplete Pb2 elements.

Pickett (1980) placed the cristagalliform and walliseriform elements described by Ziegler (1960) in the Pb and Sb positions of an apparatus that he designated *Delotaxis walliseri* (Ziegler). His material, from three limestone units in the Cobar Supergroup of central New South Wales, Australia, consisted of 22 specimens distributed in 13 samples through at least 100 m of section that ranges from the *woschmidti* Zone into the *pesavis* Zone. Apparatus reconstruction based on a few specimens from samples that are widely separated stratigraphically and chronologically is risky, particularly for apparatuses that apparently possess as many vicarious elements as digyrate apparatuses. Consequently, the only specimens figured by Pickett (1980) that are included in our synonymy for *O. cristagalli* are those we consider Pb1 and Pb2 elements. Although Pickett's collections contained no forms that he could assign to an M position, he placed elements assigned to *Prioniodina excavata* by Ziegler (1960, pl. 15, fig. 5) in the M position of *Delotaxis walliseri*. Because specimens referred to *Prioniodina excavata* by Ziegler (1960) occur in topotype material with all the other elements we include in the apparatus of *O. cristagalli* and because these specimens resemble elements of *O. cristagalli*, it seems possible that M elements may have occurred, though rarely, in some individuals of this species.

Mawson (1986) reported five species of *Oulodus* from beds representative of the *eurekaensis* and *delta* Zones in the Windellama Limestone of central eastern New South Wales, Australia. Mawson included cristagalliform and walliseriform elements in an apparatus she designated *Oulodus greilingi* (Walliser) and which, we believe, she erroneously considered synonymous with the apparatus of *Oulodus elegans*. We consider that these elements, and probably several other S elements figured by her, belong in *O. cristagalli*. None of the specimens figured in Mawson's plates are characteristic of forms we and other workers (for example, Sweet and Schönlaub, 1975), with the exception of Pickett (1980, fig. 9), include in *O. elegans*. Examination of Mawson's plates indicates her collections contain at least three species of *Oulodus*, one of which is *Oulodus cristagalli* as we interpret it. Moreover, specimens that may belong to *O. cristagalli* appear to have been included in other species of *Oulodus* (particularly specimens assigned to the Pa and Pb positions of *O. spicula* Mawson). As in the case of Pickett's material, we have only synonymized the cristagalliform and walliseriform elements of Mawson's material and we have refrained from including even all of these elements in our synonymy. This is because samples that contained the most abundant representatives of *Oulodus* were assigned, by Mawson, to three or four species per sample. Mawson (1986) synonymized *Delotaxis walliseri* of Pickett (1980) with her *Oulodus walliseri* and assigned M elements in her collections to this species. These specimens resemble elements included in *Prioniodina excavata* Branson and Mehl by Ziegler (1960) which possibly confirms Pickett's (1980) interpretation discussed above.

LOCALITY REGISTER

Section numbers keyed to index map (fig. 1).

Section 1. Price's Bluff, Botetourt Co., Va., lat 37°42.5′ N., long 79°49.6′ W., Eagle Rock, Va., 7.5-minute quadrangle. Chesapeake & Ohio Railroad cut, above the James River near Va. Rte. 622, 1.3 km from U.S. Rte. 220 and 2.4 km north of Gala, Va. Measured and columnar section in Cook (1981).

Section 2. Iron Gate, Alleghany Co., Va., lat 37°48.3′ N., long 79°47.8′ W., Clifton Forge, Va., 7.5-minute quadrangle. Chesapeake & Ohio Railroad cut along west side of Jackson River below U.S. Rte. 220, immediately north of Iron Gate, Va.

Section 3. McDowell, Highland Co., Va., lat 38°19.4′ N., long 79°27.4′ W., McDowell, Va., 7.5-minute quadrangle. Roadcut on north side of U.S. Rte. 250, 4.6 km (road distance) east of McDowell, Va.

Section 4. Strait Creek, Highland Co., Va., lat 38°25.9′ N., long 79°32.1′ W., Monterey, Va.-W.Va., 7.5-minute quadrangle. Roadcut on Va. Rte. 629, approximately 1.6 km southeast of intersection with U.S. Rte. 220, 5.6 km north of Monterey, Va. Measured and columnar section in Cook (1981).

Section 5. Smoke Hole, Pendleton Co., W. Va., lat 38°50.5′ N., long 79°15.9′ W., Upper Tract, W. Va., 7.5-minute quadrangle. Roadcut on W. Va. Rte. 2, 3 km west of intersection with U.S. Rte. 220. Columnar section in Helfrich (1978).

Section 6. New Creek, Mineral Co., W. Va., lat 39°22.1′ N., long 79°01.9′ W., Antioch, W. Va., 7.5-minute quadrangle. Abandoned quarry on north side of U.S. Rte. 50, 100 m east of New Creek stream and immediately south of New Creek, W. Va.

Section 7. Keyser, Mineral Co., W. Va., lat 39°26.3′ N., long 78°57.5′ W., Keyser, W. Va.-Md., 7.5-minute quadrangle. Westernmost of two abandoned quarries (city dump), approximately 1.5 km east of Keyser, on the south side of the Baltimore & Ohio Railroad tracks. Columnar section in Helfrich (1978).

Section 8. Altoona, Blair Co., Pa., lat 40°29.6′ N., long 78°24.3′ W., Hollidaysburg, Pa., 7.5-minute quadrangle. Abandoned quarry and streamcut on west side of parking lot behind Altoona Bible Church within city limits of Altoona. Church on Pa. Rte. 36 (Union Ave.) and 1.4 km north of intersection with U.S. Rte. 220.

Section 9. Mexico, Juniata Co., Pa., lat 40°31.8′ N., long 77°21.5′ W., Mexico, Pa., 7.5-minute quadrangle. Small abandoned quarry on south side of Penn Central Railroad tracks and south side of Juniata River, about 1 km southwest of Mexico, Pa.

Section 10. Tyrone, Blair Co., Pa., lat 40°41.3′ N., long 78°14.7′ W., Tyrone, Pa., 7.5-minute quadrangle. Abandoned quarry (town baseball field) and streamcut of Sink Creek behind American Legion building, 0.2 km west of intersection of Lincoln and 15th Streets (Pa. Rte. 453).

Section 11. Godfrey Ridge, Monroe Co., Pa., lat 40°59.6′ N., long 75°09.1′ W., Stroudsburg, Pa.-N.J., 7.5-minute quadrangle. Streamcut on southeast bank of Brodhead Creek, approximately 0.2 km above dam. Measured and columnar section in Epstein and others (1967, section 15-c).

Section 12. Shawnee on Delaware, Monroe Co., Pa., lat 41°00.5′ N., long 75°06.9′ W., Bushkill, Pa.-N.J., 7.5-minute quadrangle. Roadcut on northwest side of road, 1 km southwest of Shawnee on Delaware, Pa. Measured and columnar section in Epstein and others (1967, section 14-b).

Section 13. Wallpack Bend, Monroe Co., Pa., lat 41°05.4′ N., long 74°58.7′ W., Flatbrookville, N.J.-Pa., 7.5-minute quadrangle. Outcrop in woods on northeast side of secondary road along ascent of Wallpack Ridge in Pennsylvania, immediately southwest of where Delaware River cuts through the ridge. Measured and columnar section in Epstein and others (1967, section 11).

Section 14. Flatbrookville, Sussex Co., N.J., lat 41°06.7′ N., long 76°56.8′ W., Flatbrookville, N.J.-Pa., 7.5-minute quadrangle. Roadcut on northwest side of county road which extends along southwest side of Wallpack Ridge, 2.4 km northwest of Flatbrookville, N.J., and 0.2 km southwest of V-shaped bend in road. Measured and columnar section in Epstein and others (1967, section 10).

Section 15. Cliff section, Sussex Co., N.J., lat 41°10.5′ N., long 74°52.2′ W., Culvers Gap, N.J.-Pa., 7.5-minute quadrangle. Series of ledges on steep southeast slope of Wallpack Ridge at an elevation of about 620 ft, 2.7 km (road distance) southwest of Peters Valley, N.J. Columnar section in Epstein and others (1967, section 6).

Section 16. Peters Valley, Sussex Co., N.J., lat 41°12.2′ N., long 74°50.8′ W., Culvers Gap, N.J.-Pa., 7.5-minute quadrangle. Series of ledges along hillside above small abandoned quarry at an elevation of about 600 ft, 1 km northeast of Peters Valley, N.J. Columnar section in Epstein and others (1967, section 5).

Section 17. Montague, Sussex Co., N.J., lat 41°17.7′ N., long 74°46.7′ W., Milford, Pa.-N.J., 7.5-minute quadrangle. Section on southwest side of county road and in woods on northeast side of road, about 1.6 km southeast of Montague, N.J. Columnar section in Epstein and others (1967, section 4).

Section 18. Nearpass quarries, Sussex Co., N.J., lat 41°20.1′ N., long 74°42.3′ W., Port Jervis South, N.J.-N.Y.-Pa., 7.5-minute quadrangle. Abandoned quarry on southwest slope of Wallpack Ridge, approximately 3 km southwest of Duttonville, N.J. Measured and columnar section in Epstein and others (1967, section 3).

Section 19. Tristates, Orange Co., N.Y., lat 41°21.8′ N., long 74°42.3′ W., Port Jervis South, N.J.-N.Y.-Pa., 7.5-minute quadrangle. Abandoned quarries on northwest side of Lime Kiln Road, on southeast slope of Trilobite Mountain, Port Jervis, N.Y. Measured and columnar section in Epstein and others (1967, section 2).

Section 20. Mohonk Lake, Ulster Co., N.Y., Mohonk Lake, N.Y., 7.5-minute quadrangle, composite section. Glasco Member of the Rondout Formation exposed in abandoned quarry, 0.7 km west-southwest of town center of Accord, lat 41°47.0′ N., long 74°13.5′ W.; Whiteport Dolomite Member of the Rondout Formation and Manlius Limestone exposed in bed of small tributary of Rondout Creek, 0.3 km northwest of Epworth Church, lat 41°48.7′ N., long 74°10.2′ W.

Section 21. Mount Ida quarry, Columbia Co., N.Y., lat 42°15.6′ N., long 73°43.8′ W., Stottville, N.Y., 7.5-minute quadrangle. Southeast side of abandoned quarry, Mount Ida, 2.9 km south-southeast of Stottville, N.Y.

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PLATE 1

Contact photographs of this plate are available, at cost, from U.S. Geological Library, Federal Center, Denver, Colorado 80225

PLATE 1

Conodont indices to the Silurian-Devonian boundary interval, Valley and Ridge province, Appalachians

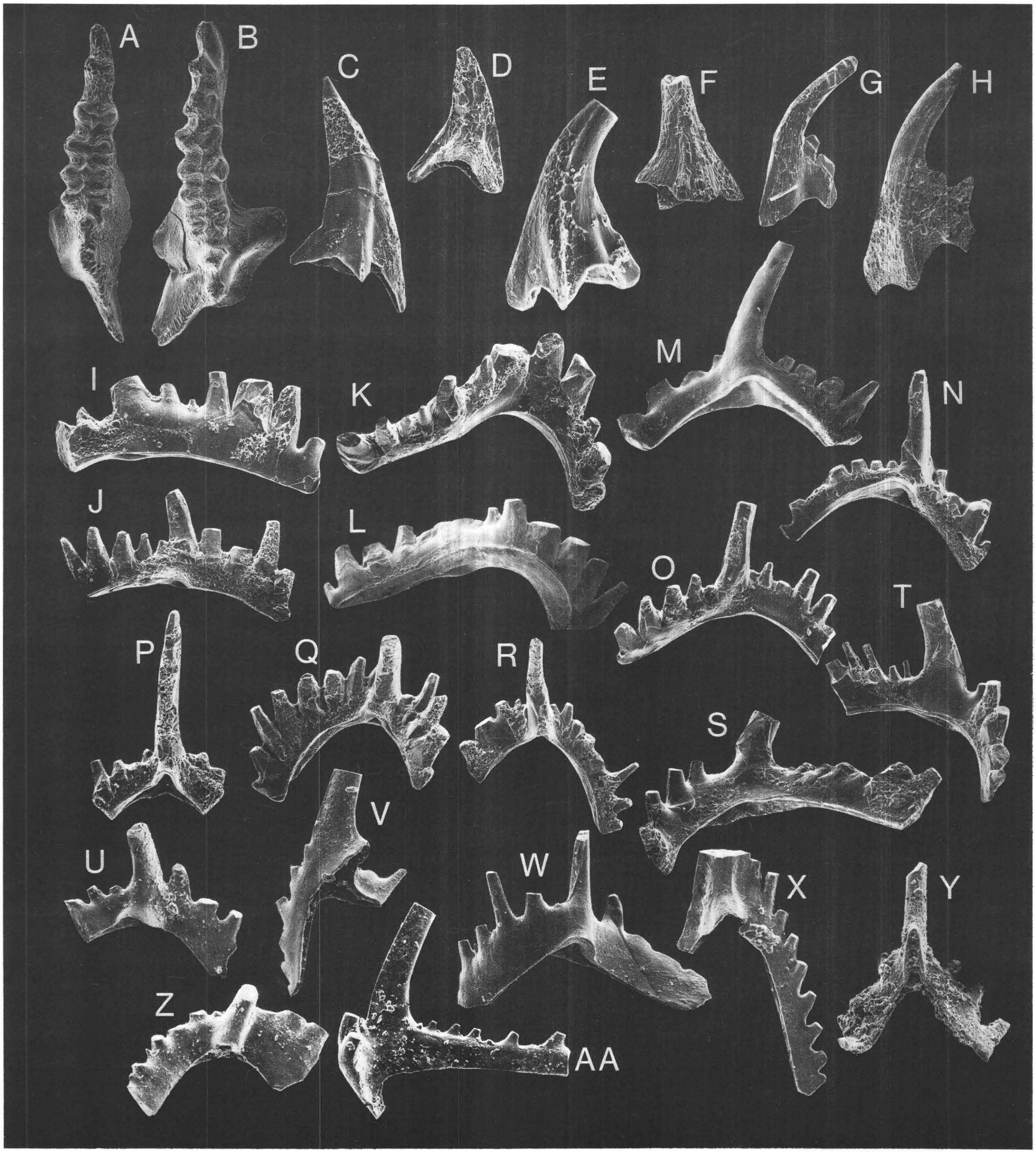
[SEM photomicrographs of specimens coated with carbon and gold]

FIGURES A–T. Earliest Devonian conodonts from 1.7 m above the base of the New Creek Limestone, near McDowell, Va. (USGS colln. 11549-SD).

- A–H. *Icriodus woschmidti woschmidti* Ziegler.
  - A. Upper view of Pa element (lower margin incomplete), ×50, USNM 418409.
  - B. Upper view of Pa element with seven transverse rows of nodes and a prominent inner lateral spur, ×40, USNM 418410.
  - C. Outer lateral view of Pb element, ×50, USNM 418411.
  - D. Inner lateral view of M element, ×50, USNM 418412.
  - E. Outer lateral view of Sb1 element (adenticulate series), ×100, USNM 418413.
  - F. Lateral view of slightly asymmetric Sd1 element, ×50, USNM 418414.
  - G, H. Inner and outer lateral views of Sb2 elements (denticulate series), ×50 and ×75, USNM 418415–16.
- I–T. *Oulodus cristagalli* (Ziegler).
  - I, J. Inner lateral views of rare Pa elements (J is complete), ×40 and ×50, USNM 418417–18.
  - K, L. Inner and outer lateral views of Pb1 (cristagalliform) elements, ×40, USNM 418419–20.
  - M–O. Two inner and one outer lateral views of Pb2 (walliseriform) elements; M, ×50, USNM 418421; N, O, ×40, USNM 418422–23.
  - P. Posterior view of Sa element, ×40, USNM 418424.
  - Q, R. Inner lateral views of Sb elements, ×40, USNM 418425–26.
  - S, T. Inner lateral view of Sc elements, ×40 and ×50, USNM 418427–28.

U–AA. *Oulodus elegans* (Walliser), from 1.4 m above the base of the upper limestone member of the Keyser Limestone (upper Pridolian), Lambert Gap, West Virginia (USGS colln. 10699-SD); all specimens incomplete and ×75.

- U. Inner lateral view of Pa element, USNM 418600.
- V. Oblique inner lateral view of Pb1 element, USNM 418601.
- W. Inner lateral view of Pb2 element, USNM 418602.
- X. Inner lateral view of M element, USNM 418603. M elements of Appalachian basin *O. elegans* have an adenticulate anticusp, whereas some European representatives of this species have M elements with a denticulate anticusp (Jeppsson, 1969, fig. 4B; 1974, pl. 3, fig. 4).
- Y. Posterior view of Sa element, USNM 418604.
- Z. Inner lateral view of Sb element, USNM 418605.
- AA. Inner lateral view of Sc element, USNM 418606.



ICRIODUS, OULODUS

CHAPTER C

Homeognathodus peniculus (Conodonta), a New Earliest Pridolian Index Species, and the Ludlovian-Pridolian Boundary in the Central Appalachian Basin

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SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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Homeognathodus peniculus (Conodonta), a New Earliest Pridolian Index Species, and the Ludlovian-Pridolian Boundary in the Central Appalachian Basin

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Abstract

A new index species, *Homeognathodus peniculus*, is described and its stratigraphic distribution documented from eight localities, all from within the middle member of the Tonoloway Limestone and its equivalents, in the central Appalachian basin. The latest Silurian conodont zonation is revised; the *eosteinhornensis* Zone is renamed the *remscheidensis* Zone and its base is placed at the lowest occurrence of *Ozarkodina remscheidensis* in the latest Ludlovian. Two new subzones are established for the latest Ludlovian and earliest Pridolian part of the *remscheidensis* Zone: the Lower *remscheidensis* Subzone represents the interval of overlap of the name bearer with subspecies of *O. snajdri*; the succeeding *peniculus* Subzone is defined by the range of the name bearer and its lower boundary approximates the base of the Pridolian. *H. peniculus* is probably an Appalachian endemic; thus, recognition of the *peniculus* Subzone is most likely limited to the Appalachian basin.

INTRODUCTION

Precise correlation of Ludlovian and Pridolian rocks of the central Appalachian basin with other regions has defied paleontologists for over a century. Although these Silurian rocks are widespread (fig. 1), relatively well exposed from Maryland to northernmost Tennessee, and as much as 1,000 m thick, they are only locally fossiliferous and contain chiefly endemic species. Because other fossil groups have been unable to provide detailed correlation, conodonts have been utilized (Helfrich, 1975) to effect a biostratigraphic correlation of the carbonate rocks in these series in part of the central Appalachians. In this area, however, carbonate rocks are only abundant in the late Ludlovian and Pridolian, in the Wills Creek, Tonoloway, and Keyser formations and their equivalents.

Berry and Boucot (1970) placed the Ludlovian-Pridolian boundary within the Wills Creek Formation primarily on the basis of the similarity of its eurypterid fauna with that of the Syracuse Formation in New York. They assumed that the presence of *Ozarkodina remscheidensis* (Ziegler) group conodonts in the Syracuse Formation indicated an age no older than Pridolian for that unit. The most recent correlation charts for the Appalachian basin also show the Ludlovian-Pridolian boundary within the Wills Creek Formation (American Association of Petroleum Geologists, 1985a, b). In contrast, Helfrich (1975) placed the base of the Pridolian in the middle of the overlying Tonoloway Limestone on the basis of the occurrence of latest Ludlovian conodonts (*Ozarkodina snajdri crispa* (Walliser), in particular) in the lower half of the formation. In the same paper, Helfrich reported a new species, herein designated *Homeognathodus peniculus*, from a single collection in the lower part of the upper Tonoloway; he suggested the new species descended from *O. s. crispa* and was Pridolian in age.

In 1982, W. B. Brent, Tennessee Division of Geology, submitted a sample of coralline-stromatoporoid limestone from the lower half of the Sneedville Limestone of Stafford (1856) in Tennessee for biostratigraphic analysis. The corals, identified by W. A. Oliver, Jr., indicated a Late Silurian age. The conodont faunule included representatives of *Ozarkodina confluens* (Branson and Mehl) and *H. peniculus*, suggesting an early Pridolian age based on Helfrich's (1975) conodont biostratigraphy. Because this distinctive species was recovered from two widely separated localities and because the *O. s. crispa–H. peniculus* lineage proposed by Helfrich appeared to have biostratigraphic potential for defining the Ludlovian-Pridolian boundary, we undertook to find this species succession in other sections in the central Appalachians.

LITHOSTRATIGRAPHY

Uppermost Ludlovian and Pridolian rocks in the study area are represented, at their thickest, by 280 m of the Tonoloway and most of the overlying Keyser Limestones. The Tonoloway Limestone and its equivalents decrease in thickness southwestward, from 200 m in western Maryland to less than 30 m in northeastern Tennessee (fig. 2). Where thickest, the Tonoloway is subdivided into three informal members. The lower and upper members consist chiefly of thin-bedded carbonate mudstone and calcareous shale that are generally laminated, stromatolitic, mud-cracked, and poorly fossiliferous. The middle member is composed of a wider variety of carbonate rock types containing, in part, a diverse marine fauna representing a transgression that produced normal marine subtidal facies between the peritidal mudflat facies of the lower and upper members. Distinctions between members gradually disappear as the Tonoloway thins southwestward. In the northern part of the study area, the Tonoloway is sharply to gradationally overlain by fossiliferous wackestone to grainstone of the Keyser Limestone. Southwest of central Virginia, an unconformity of increasing magnitude separates the Tonoloway and its equivalents from younger rocks (fig. 2). Details of the areal distribution, thickness, and vertical and lateral relationships and measured sections of these rocks can be found in Maryland Geological Survey (1923), Woodward (1941), Colton (1970), and Smosna and others (1977).

The Tonoloway Limestone and its equivalents were deposited in a generally shallow-water, restricted foreland

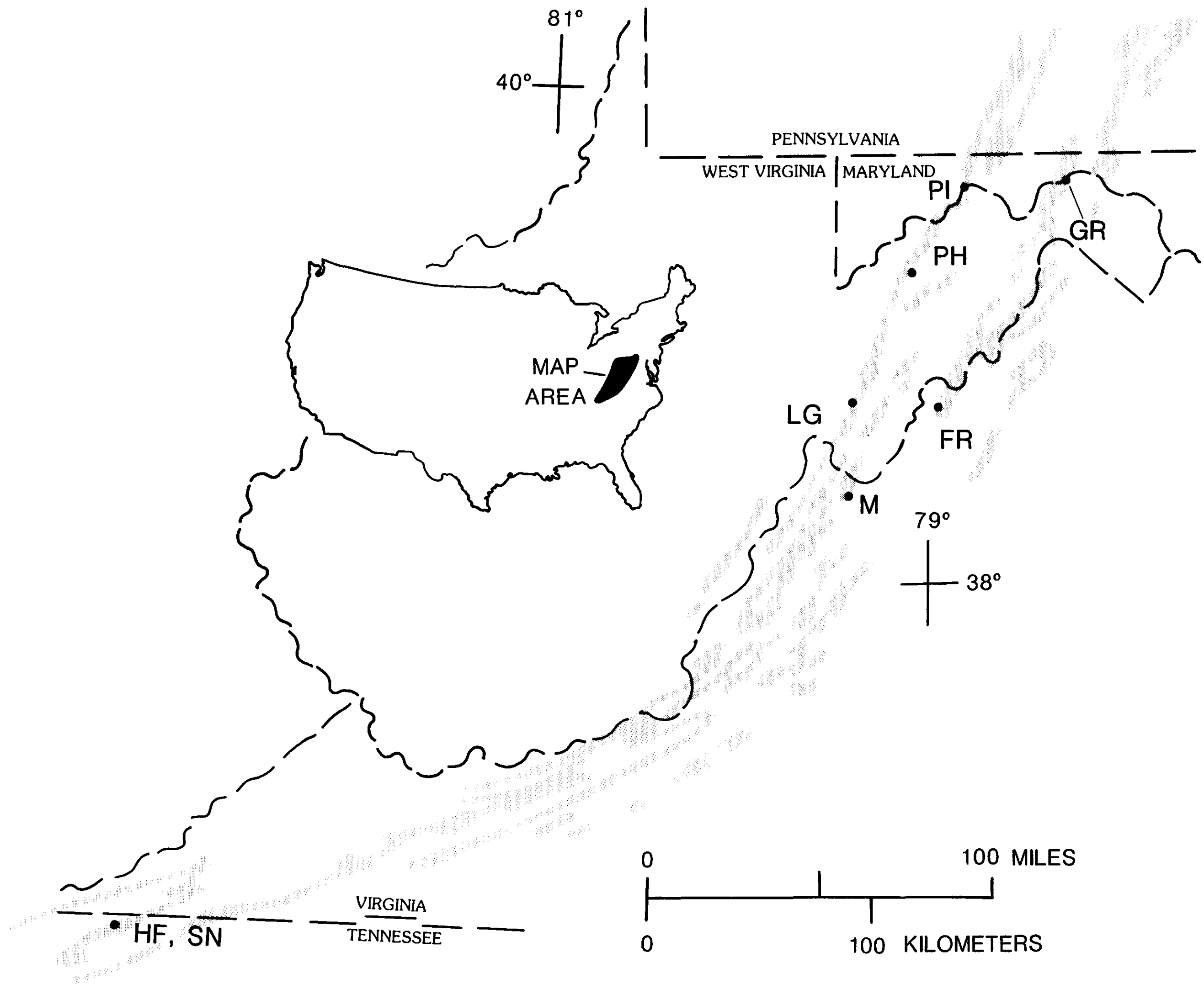

Figure 1. Silurian outcrop belt (shaded) and location of sections that yielded representatives of *Homeognathodus peniculus* n. sp. in the central Appalachians. See locality register for geographic description. Sections are: GR, Grasshopper Run, W. Va.; PI, Pinto, Md.; PH, Powers Hollow, W. Va.; LG, Lambert Gap, W. Va.; FR, Fulks Run, Va.; M, McDowell, Va.; HF, Hatfield farm, Tenn.; SN, Sneedville, Tenn.

basin, bounded on the east by low-relief uplands and on the north and west by the craton; marine waters entered the basin from the southwest. In the study area, the clastic-to-carbonate ratio increases toward the eastern limit of the Silurian outcrop belt; grain size of the clastic rocks generally increases southward. An evaporite basin lay north and west of the study area, where equivalent facies consist of dolostones and evaporites (Salina Formation).

CONODONT BIOSTRATIGRAPHY AND THE LUDLOVIAN-PRIDOLIAN BOUNDARY

Walliser (1964) was the first to propose a conodont zonation for the entire Silurian, based on one rather complete section at Cellon, Austria, and additional collections from key areas in central Europe. The upper Ludlovian, as used by Walliser (1964), included what is now upper Ludlovian and Pridolian. He included the upper part of the *siluricus* Zone and the succeeding *latialata*, *crispa*, and *eosteinhornensis* Zones in this interval. At that time, Walliser presumed the base of eβ2 in Bohemia (=base of Pridoli Formation) coincided with the base of the *latialata* Zone. In 1971, based on new data, Walliser revised the base of eβ2 to approximate the base of his *eosteinhornensis* Zone. Moreover, he was also aware of the co-occurrence of *O. r. eosteinhornensis* and *O. s. crispa* in collections from Gotland (Walliser, 1971, p. 200). As a result, he expressed doubt about the validity of the *crispa* Zone as well as its relationship to the *eosteinhornensis* Zone; that is, does the range of *O. r. eosteinhornensis* partly or completely overlap the range of *O. s. crispa*. In the same year, Rexroad and Craig (1971) reported *O. r. eosteinhornensis* together with *O. s. snajdri* in collections from the upper Bainbridge Formation in Missouri and speculated that *O. r. eosteinhornensis* could range as low as the upper *siluricus* Zone. *O. s. snajdri* and *O. r. eosteinhornensis* were found together once again in the Kokomo Limestone Member of the Wabash Formation in Indiana, as used by Pollock and Rexroad (1973).

Klapper and Murphy (1975) noted that in the type area of the Pridolian, *O. r. eosteinhornensis* extends downward into the top of the Kopanina Formation where it occurs with *O. s. crispa*. Nonetheless, they showed the Ludlovian-Pridolian boundary, at Cellon, at the boundary between the *crispa* and *eosteinhornensis* Zones. Since then, many authors have reported a considerable overlap of the ranges of *O. s. crispa* and *O. r. eosteinhornensis* (fig. 3). For example, at the Muslovka quarry in the type Pridolian of Czechoslovakia, the lower range of *O. r. eosteinhornensis* completely overlaps the range of *O. s. crispa* and extends 3 m below the base of the Pridoli Formation; moreover, *O. s. crispa* extends upward into the basal 0.5 m of the Pridoli Formation (Chlupáč and others, 1980). Consequently, neither the first or last occurrence of these zonal indices, nor of other conodont species reported from the type Pridoli Formation, could be used to mark the base of the Pridolian. In 1980, Chlupáč

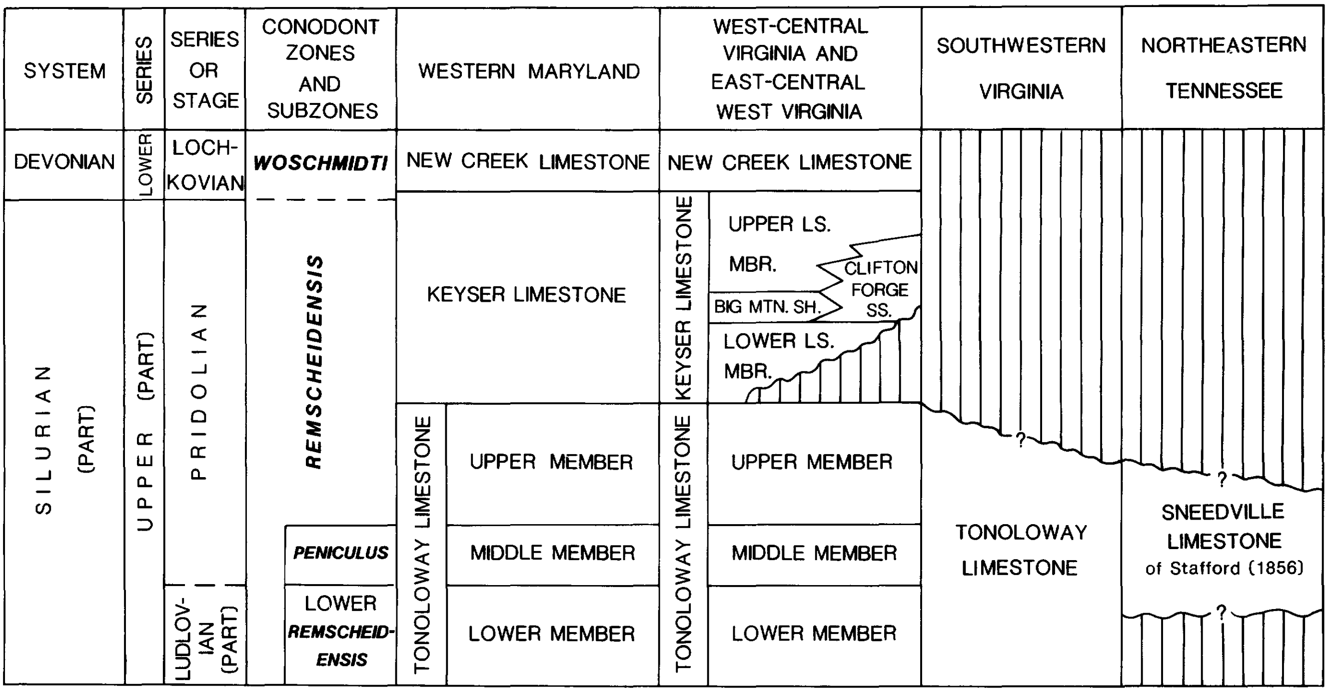

Figure 2. Conodont-based correlation of uppermost Ludlovian to lowermost Lochkovian stratigraphic units in the east-central Appalachians.

and others proposed reducing the *crispa* Zone to a subzone of the *eosteinhornensis* Zone and that the base of the *eosteinhornensis* Zone, following Walliser (1964), be taken at the first occurrence of that species within the latest Ludlovian, a proposal followed by Harris and others (1983). In 1984, the Subcommission on Silurian Stratigraphy formally established the Pridolian Series and placed its base at the first appearance of *Monograptus parultimus* in the Pozary section in the Barrandian area, Czechoslovakia (Holland, 1985). Kříž and others (1986) published a detailed biostratigraphic analysis of fossils in the Ludlovian-Pridolian boundary beds in many sections in the Barrandian area. These authors also changed the name of the Pridoli Formation to the Pozary Formation in order to avoid duplication of formation and series names. Their data showed that representatives of subspecies of *Ozarkodina snajdri* do not extend into the *parultimus* Zone, but range to within 50 cm of the base of the zone at the Pozary section.

In our sections in the central Appalachians, *O. r. remscheidensis* and *O. r. eosteinhornensis* are coeval and intergradational ecophenotypes that repeatedly replace one another in shallowing-upward or transgressive-regressive cycles from the latest Ludlovian through early Lochkovian (Denkler and others, 1983; Denkler and Harris, 1985), from within the lower member of the Tonoloway Limestone through the Keyser Limestone. As a result, we have changed the name of the latest Silurian conodont zone to the *remscheidensis* Zone to better reflect the concurrent range of both subspecies. Moreover, in these same sections, *O. s. snajdri* precedes, occurs together with and considerably above *O. s. crispa*, extending as high as the upper meter of the lower member of the Tonoloway. In central European sections (Kříž and others, 1986), in contrast, *O. s. snajdri* precedes and only overlaps the lowest part of the range of *O. s. crispa* and *O. s. crispa* extends to very near the top of the Ludlovian (fig. 3). In both the central Appalachians and central Europe subspecies of *O. remscheidensis* overlap the upper part of the range of subspecies of *O. snajdri*. In the central Appalachians, *O. s. snajdri* appears to extend to the top of the Ludlovian, overlapping and extending well beyond the range of *O. s. crispa*. Consequently, we prefer to designate the interval of overlap of subspecies of *O. remscheidensis* with subspecies of *O. snajdri*, the Lower *remscheidensis* Subzone thereby avoiding confusion with the central European concept of a *crispa* Zone or Subzone that only contains *O. s. snajdri* in its lower part. *Homeognathodus peniculus* appears to be restricted to the middle member of the Tonoloway Limestone and its equivalents and can occur throughout an

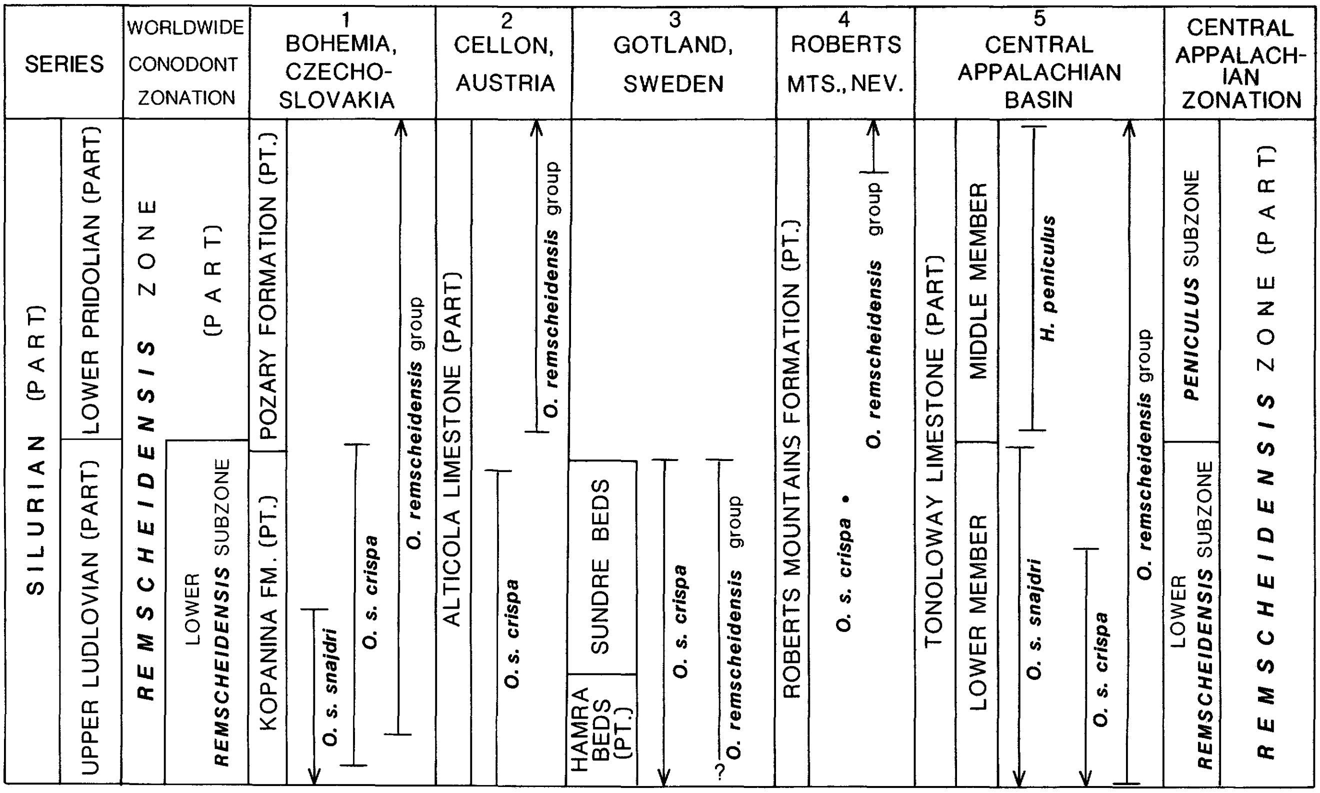

Figure 3. Stratigraphic range of important conodont indices across the Ludlovian-Pridolian boundary in key European and North American sections. References for columns are: 1, Kříž and others (1986) and Mehrtens and Barnett (1976); 2, Walliser (1964); 3, Jeppsson (1983); 4, Klapper and Murphy (1975); 5, Helfrich (1975) and this report.

interval about 30 m thick. In all sections, *H. peniculus* first appears above the upper limit of representatives of its probable ancestor, *O. snajdri*. At McDowell, Va., these species are separated by an interval only 1 m thick. Consequently, we propose to use *H. peniculus* as a subzonal indicator for the early Pridolian and to use its lowest stratigraphic occurrence as the base of the Pridolian in the central Appalachians. The base of the Pridolian Series in at least three sections in the Barrandian area of Czechoslovakia is 30 to 50 cm above the last occurrence of *O. s. crispa*. Significantly, the biostratigraphic horizon we have chosen to approximate the base of the Pridolian in the central Appalachians is 1 m above the last occurrence of *O. s. snajdri*.

CONODONT ZONATION

Lower *remscheidensis* Subzone

This zone equals the former *crispa* Subzone of Harris and others (1983, fig. 2).

Lower boundary.—The first appearance of *Ozarkodina remscheidensis remscheidensis* (Ziegler) or *O. r. eosteinhornensis* (Walliser) and transitional forms in the presence of subspecies of *O. snajdri* (Walliser).

Upper boundary.—The first appearance of *Homeognathodus peniculus* n. sp. in the central Appalachians; elsewhere, the last occurrence of subspecies of *Ozarkodina snajdri* (Walliser).

Associated conodonts.—*Oulodus elegans* (Walliser), *Ozarkodina confluens* (Branson and Mehl), and *Panderodus* spp. are present throughout the subzone and *Distomodus dubius* (Rhodes) and *Ozarkodina highlandensis* (Helfrich) appear to be limited to the lower part of the subzone in the central Appalachians. Elsewhere, *Belodella* spp. (Pollock and Rexroad, 1973), *Ozarkodina excavata* (Branson and Mehl) (Chlupáč and others, 1980; Jeppsson, 1974; Walliser, 1964) and *Ozarkodina wimani* (Jeppsson, 1983) occur in the subzone.

Remarks.—Because *Homeognathodus peniculus* is probably an Appalachian endemic and is known only from beds above the last occurrence of the cosmopolitan subspecies of *O. snajdri*, the upper boundary of this subzone elsewhere can be taken as the last occurrence of *O. snajdri* subspp. From the data of Rexroad and Craig (1971, table 1), it is possible that *O. r. eosteinhornensis* extends into the upper limit of the range of *Polygnathoides siluricus* Branson and Mehl; they report *P. emarginatus* (Branson and Mehl) s.f. (which we interpret as the Pb element of *P. siluricus*) above and together with representatives of *O. r. eosteinhornensis* and *O. s. snajdri*.

The subzone is present at various levels throughout the lower member of the Tonoloway Limestone and its equivalents in the central Appalachians and in the Kokomo Limestone Member of the Wabash Formation, north-central Indiana (Pollock and Rexroad, 1973), upper part of the Bainbridge Formation, Missouri (Rexroad and Craig, 1971), the Hamra b through Sundre Beds, Gotland (Jeppsson, 1983), and the upper Kopanina and very lowermost Pozary Formations, Bohemia (Walliser, 1964; Mehrtens and Barnett, 1976; and Chlupáč and others, 1980; Kříž and others, 1986).

peniculus Subzone of the *remscheidensis* Zone

Lower boundary.—The first appearance of *Homeognathodus peniculus* n. sp.

Upper boundary.—The last occurrence of *H. peniculus*.

Associated conodonts.—*Oulodus elegans* (Walliser), *Ozarkodina confluens* (Branson and Mehl), *Ozarkodina remscheidensis remscheidensis* (Ziegler) and *O. r. eosteinhornensis* (Walliser) and transitional forms, and *Panderodus* spp. occur in many samples with *H. peniculus*.

Remarks.—We are using the lowest occurrence of *H. peniculus* to approximate the base of the Pridolian in the central Appalachians. Thus far, the subzone is restricted to the middle member of the Tonoloway Limestone and is represented by a maximum thickness of about 30 m. The subzone occurs within 1 m of the base and 7 m of the top of the member at McDowell, Va., and Lambert Gap, W. Va., respectively. The zone occurs in eight sections, from Grasshopper Run, W. Va., at the northern limit of the study area, to Sneedville, Tenn., 400 km southwest (fig. 1). Five other sections of the Tonoloway and its equivalents within the study area were sampled for conodonts, but did not yield *H. peniculus*. Equivalent strata at many localities in Pennsylvania, from the Allegheny front to the eastern limit of Silurian outcrop, were examined for possible conodont sampling, but were of inappropriate lithofacies. The recognition of the subzone is probably limited to the Appalachian basin.

SYSTEMATIC PALEONTOLOGY

Homeognathodus peniculus n. sp. is represented only by Pa elements in our collections; its suprageneric classification, therefore, cannot be determined at this time.

All figured specimens are reposited in the U.S. National Museum, Washington, D.C. (USNM).

Genus **HOMEOGNATHODUS** n. gen.

Type species.—*Homeognathodus peniculus* n. sp.

Derivation of name.—For its similarity to the gnathodid cup of many Carboniferous and Permian conodont genera.

Diagnosis.—A genus of conodont with a carminiscaphate Pa element having a somewhat irregularly ornamented upper platform and a carina that is subterminal. Apparatus unknown, possibly unimembrate.

Remarks.—This genus is known only from a single species. Forms linking this genus to representatives of other genera have not yet been found, but we suspect that the genus is descended from *Ozarkodina snajdri* by the posterior expansion of the platform and development of ornamentation on its upper surface. *Homeognathodus* resembles the Permian genus *Sweetognathus* (whose apparatus is also probably unimembrate), but the former differs in having a longer free blade and more irregular platform ornament.

Discussion.—Along with Helfrich (1975), we believe *Homeognathodus* (=N. Gen. et n. sp. of Helfrich) descended from *Ozarkodina snajdri crispa* (Walliser). Contrary to Clark and others (1981, p. W165), we do not believe that forms with carminiscaphate Pa elements, such as *O. s. crispa* and *O. s. snajdri*, belong in *Ozarkodina*. It is, however, inappropriate to undertake a major revision of this multispecific genus at this time. Nonetheless, we want to emphasize that *Homeognathodus* did not evolve directly from a generalized, carminate ozarkodinid, but rather from an intermediate form with an expanded posterior platform such as *"O." snajdri*, which we would either place in a separate genus or include in *Homeognathodus*.

Homeognathodus peniculus n. sp.

Plate 1, figures A–I

1975. N. Gen. et n. sp. Helfrich, p. 86 of appendix 1, text-fig. 17F, pl. 16, figs. 1–3, 6.

Types.—Holotype, USNM 403810 (pl. 1, figs. A–C); paratypes, USNM 403811–403814.

Derivation of name.—Latin *peniculus*, meaning brush. In oblique lateral view, Pa element resembles a hair brush.

Type locality.—Roadcut on north side of U.S. Highway 250, about 4.6 km east of McDowell, Highland Co., Va., USGS colln. 11272-SD. From a stromatoporoid-coralline biolithic wackestone, approximately 0.7 m above the base of the middle member of the Tonoloway Limestone. Only a single specimen of *H. peniculus* has been recovered from the type locality. This specimen was selected as the holotype because it is the best preserved in our collections and is from the lowest known stratigraphic level of the *peniculus* Subzone.

Reference locality.—*H. peniculus* is most abundant, although not as well preserved as the holotype, in two collections from intraclastic packstone to wackestone at 23 m (98 specimens) (pl. 1, figs. D–H) and 25 m (21 specimens) above the base of the middle member of the Tonoloway Limestone on the north side of the Baltimore & Ohio Railroad cut, about 0.3 km east-southeast of the Pinto Post Office, Allegany Co., Md.

Diagnosis.—Diminutive (average length 0.5 mm), carminiscaphate Pa element with ratio of free blade to platform length varying from 2:1 in juveniles to 1:1 in adults. Height of free blade decreases posteriorly except for a single denticle at the blade-platform junction (pl. 1, fig. G) which is nearly twice as high as adjacent denticles or nodes. In lateral view, upper platform margin straight. Platform elliptical to subcircular with steep, slightly concave sides (pl. 1, fig. G). Upper surface ornamented with a nodose (pl. 1, fig. D) to adenticulate (pl. 1, figs. A, I) carina and a variable number of subcircular to transversely elongate marginal nodes or ridges. Lower platform margin extends out as an apronlike shelf. Gnathodid basal cavity with pit at anterior edge of platform (pl. 1, figs. B, H). In lateral view, lower platform margin descends in gentle convex arc to lowest point at junction with free blade; lower margin of free blade is straight or rises slightly anteriorly.

Remarks.—The largest specimens in our collections are slightly more than 1 mm in length. Some variation in platform ornament appears to be ontogenetic; small specimens tend to have nodes whereas larger specimens may develop transverse ridges. The carina may be adenticulate or nodose in all growth stages. No evolutionary trends in ornamentation were observed through 30 m of section.

Most of our specimens are poorly preserved; they are commonly abraded and corroded and generally have an incomplete free blade and lower margin. Their color alteration index is 1.5 at the Tennessee localities and 3.5 to 4 at all other localities. *H. peniculus* is a very rare component of the middle Tonoloway conodont fauna (table 1). Our most abundant collections were recovered from lag concentrates, and we believe most specimens are present as a result of postmortem transport. Although it is likely that *H. peniculus* evolved during the transgressive event represented by the middle member of the Tonoloway Limestone, it was apparently not a significant component of the conodont biofacies represented in these rocks. Thus, when present it is represented by no more than 1 or 2 specimens per kilogram (table 1).

Occurrence.—Throughout the middle member of the Tonoloway Limestone in the central Appalachians. Table 1 lists all collections from which *H. peniculus* has been recovered (see locality register for sample locations).

Material.—152 specimens from 12 samples distributed among eight localities.

LOCALITY REGISTER

Grasshopper Run, Morgan Co., W. Va., lat 39°40.5′ N., long 78°12.3′ W., Hancock, W. Va.-Md.-Pa., 7.5-minute quadrangle. South side of Baltimore & Ohio Railroad cut, 2.3 km south-southwest of south end of U.S. Highway 522 bridge across Potomac River. Entire Tonoloway Limestone exposed and is 181 m thick: lower member 48 m; middle member, 39 m; upper member, 94 m. USGS colln. 11271-SD from 29 m above base of middle member.

Pinto, Allegany Co., Md., lat 39°34.0′ N., long 78°50.2′ W., Cresaptown, W. Va.-Md., 7.5-minute quadrangle. North side of Baltimore & Ohio Railroad cut, 0.3 km east-southeast of Pinto Post Office. Entire Tonoloway Limestone exposed and is 181 m thick: lower member, 79 m; middle member, 29 m; upper member, 73 m. USGS colln. 10685-SD from 23 m and USGS colln. 10686-SD from 25 m above base of middle member.

Table 1. Locality and sample data for *Homeognathodus peniculus* n. sp.

Locality[1]	USGS collection number	Sample weight (kg)	Number of specimens	Associated conodonts (in order of decreasing abundance)
Pinto, Md.	10685-SD	39.0	98	*Ozarkodina remscheidensis* group, *O. confluens*, *Oulodus elegans*, and *Panderodus* sp.
	10686-SD	45.5	21	*O. remscheidensis* group, *O. confluens*, and *Panderodus* sp.
Grasshopper Run, W. Va.	11271-SD	12.4	2	*O. remscheidensis* group
Powers Hollow, W. Va.	10692-SD	8.4	10	*O. remscheidensis* group and *O. confluens*
Lambert Gap, W. Va.	11273-SD	10.6	4	*O. remscheidensis* group
	11274-SD	8.0	1	*O. remscheidensis* group
	11687-SD	11.3	2	*O. remscheidensis* group and *Oulodus elegans*
Fulks Run, Va.	11270-SD	7.4	6	*O. remscheidensis* group and *Oulodus elegans*
McDowell, Va.	11271-SD	8.7	1	*O. remscheidensis* group, *Oulodus elegans*, and *Panderodus* sp.
	11589-SD	7.9	1	*O. remscheidensis* group, *Panderodus* sp., and *Oulodus elegans*
Hatfield farm, Tenn.	11269-SD	11.9	1	*O. confluens*
Sneedville, Tenn.	10417-SD	15.8	5	*O. confluens* and *O. remscheidensis* group

[1] See figure 1 and locality register for location and geographic description.

Powers Hollow, Grant Co., W. Va., lat 38°59.9′ N., long. 79°13.0′ W., Petersburg West, W. Va., 7.5-minute quadrangle. Active quarry on northwest side of West Virginia Route 28, opposite Cabins, W. Va. Base of vertical quarry wall exposes beds of middle member of Tonoloway Limestone; section not measured because of inaccessibility. USGS colln. 10692-SD, from within middle member.

Lambert Gap, Pendelton Co., W. Va., lat 38°41.1′ N., long 79°28.6′ W., Circleville, W. Va., 7.5-minute quadrangle. On north side of private dirt road that parallels north side of Morgan Run, 2.4 km south (road distance) along West Virginia Route 28 from intersection of West Virginia Route 28 and U.S. Highway 33, and then about 0.3 km east of West Virginia Route 28. Entire Tonoloway Limestone exposed and is about 174 m thick: lower member, 80 m; middle member, 37 m; upper member, about 57 m. USGS colln. 11278-SD from 58 m above base of lower member; USGS colln. 11273-SD from 4 m, USGS colln. 11687-SD from 27.7 m, and USGS colln. 11274-SD from 30.2 m above base of middle member.

Fulks Run, Rockingham Co., Va., lat 38°40.3′ N., long 78°55.6′ W., Fulks Run, Va., 7.5-minute quadrangle. Roadcut on east side of Virginia Route 259, 2.6 km (road distance) west of intersection of Virginia Route 259 and Virginia Route 612. Most of Tonoloway Limestone is exposed, but lower part of lower member may be concealed; 125.5 m exposed: lower member (part?), 46 m; middle member, 40.5 m; upper member, 39 m. USGS colln. 11270-SD from 20 m above base of middle member.

McDowell, Highland Co., Va., lat 38°19.4′ N., long 79°27.4′ W., McDowell, Va., 7.5-minute quadrangle. Roadcut on north side of U.S. Highway 250, 4.6 km (road distance) east of McDowell, Va. Incomplete exposure of Tonoloway Limestone 111 m thick: lower member (part), 13 m; middle member, 25 m; upper member, 73 m. USGS colln. 11272-SD from within 1 m of base of middle member and USGS colln. 11589-SD from 3.8 m above base of middle member. Type locality of *Homeognathodus peniculus* n. sp.

Hatfield farm, Hancock Co., Tenn., lat 36°33.6′ N., long 83°14.3′ W., Sneedville, Tenn.-Va., 7.5-minute quadrangle. Streamcut in Blackwater Creek, 0.7 km east of Gollihon Cemetery at the intersection of Newman Ridge Rd. and Blackwater Creek Rd. Incomplete exposure of Sneedville Limestone 22 m thick; lower contact with Rockwood Formation exposed, upper contact missing. USGS colln. 11279-SD from 5 m and USGS colln. 11269-SD from 12.3 m above base of Sneedville Limestone.

Sneedville, Hancock Co., Tenn., lat 36°31.8′ N., long 83°13.0′ W., Sneedville, Tenn.-Va., 7.5-minute quadrangle. Roadcut on north side of county road to Campbell Cemetery, 0.3 km north-northwest of its intersection with Tennessee Route 33. Only 2 m of the Sneedville Limestone is exposed. USGS colln. 10417-SD from within 1 m of base of exposure.

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PLATE 1

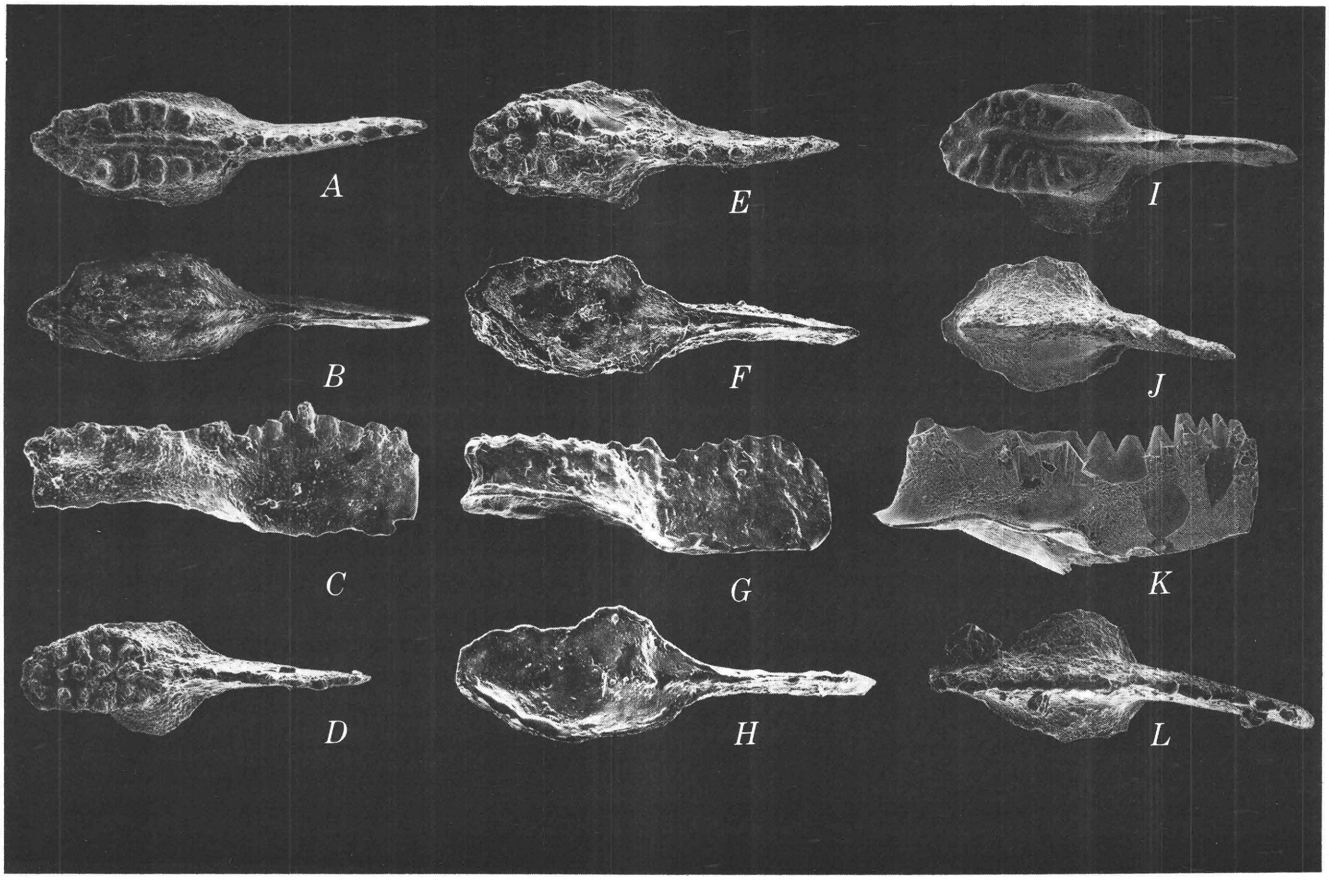
Contact photographs of this plate are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225

PLATE 1

Some biostratigraphically significant conodonts from the Tonoloway Limestone and equivalents, central Appalachian basin

[Scanning electron micrographs of specimens coated only with carbon]

FIGURES A–I. *Homeognathodus peniculus* n. sp., from middle member of Tonoloway Limestone.
  A–C. Upper, lower, and lateral views of holotype, ×85, USNM 403810, USGS colln. 11272-SD.
  D–H. Paratypes, USGS colln. 10685-SD.
    D. Upper view, ×70, USNM 403812.
    E, F. Upper and lower views, ×70, USNM 403813.
    G, H. Lateral and lower views, ×95, USNM 403814.
  I. Upper view of paratype, ×50, USNM 403811, USGS colln. 11273-SD.
J, K. *Ozarkodina snajdri crispa* (Walliser), from 58 m above base of lower member of Tonoloway Limestone at Lambert Gap, W. Va. Upper and lateral views, ×75, USNM 403815 and 403816, USGS colln. 11278-SD. Note similarity with lateral views of *Homeognathodus peniculus* shown in figures C and G.
L. *Ozarkodina snajdri snajdri* (Walliser), from lower part of Sneedville Limestone at Hatfield farm, Tenn. Upper view, ×100, USNM 403814, USGS colln. 11279-SD.



HOMEOGNATHODUS, OZARKODINA

CHAPTER D

Occurrence of the Early Cretaceous Ammonite *Venezoliceras* in Puerto Rico

By WILLIAM A. COBBAN and GLENN R. SCOTT

Descriptions and illustrations
of two species of Albian age

U.S. GEOLOGICAL SURVEY BULLETIN 1837

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

Occurrence of the Early Cretaceous Ammonite *Venezoliceras* in Puerto Rico

By William A. Cobban *and* Glenn R. Scott

Abstract

Several crushed specimens of *Venezoliceras* were collected from the Fajardo Formation near Fajardo in eastern Puerto Rico. This genus, of late middle Albian to early late Albian age, has not been previously recorded from Puerto Rico. The specimens are compared to *Venezoliceras commune* (Renz) and *V. texanum* Young.

INTRODUCTION

Ammonites are scarce in the Lower Cretaceous rocks of Puerto Rico. Young (1972) recorded two collections from near Aibonita in south-central Puerto Rico. One of the collections, from southeast of Aibonita, contained *Eogaudryceras*? sp., *Puzosia* cf. *P. planulata* (Bayle), and *Engonoceras* spp. Young assigned an early Albian age to this lot. The other collection, from north of Aibonita, contained two fragments of *Manuaniceras* closely related to *M. supani* (Lasswitz), a species that occurs in the youngest part of the middle Albian of Texas.

While vacationing in Puerto Rico in May 1968, Glenn and Juanita Scott collected several specimens of the Albian ammonite *Venezoliceras* near Fajardo in eastern Puerto Rico. The nearest localities where the genus is known are Venezuela, Colombia, Peru, Ecuador, and Texas. Owing to the scarcity of ammonites in the Lower Cretaceous rocks of Puerto Rico, the discovery of *Venezoliceras* is worth recording.

The two specimens illustrated in this report are kept in the National Museum of Natural History, Washington, D.C., where they have the catalog numbers 409327 and 409328. R.E. Burkholder of the U.S. Geological Survey photographed the specimens.

LOCALITY

The fossils were collected about 0.8 km south of Fajardo on the north face of a hill south of highway 3. The fossils were found in weathered brown shale in the Fajardo Formation in a road cut about 3 m below the base of a newly constructed steel tower at the top of the hill. At this locality the part of the Fajardo Formation that includes the fossiliferous bed consists of yellowish-gray, siliceous, silty shale and fine-grained sandstone that dip about 45° to the north. The fossils, which are crushed flat, occurred in a thin bed of pale-yellowish-brown shale. None of the fossils has the sutures preserved.

SYSTEMATIC PALEONTOLOGY

Family BRANCOCERATIDAE Spath, 1934
Subfamily MOJSISOVICZIINAE Hyatt, 1903
Genus VENEZOLICERAS Spath, 1925

Type species.—Oxytropidoceras venezolense Stieler, 1920.

Spath (1925, p. 182) named this genus for *Oxytropidoceras venezolense* Stieler (1920, p. 394), a compressed, high-keeled ammonite. Young (1966, p. 65) gave the following concise generic diagnosis: "Large, widely umbilicated, high-keeled ammonites with rounded umbilical periphery. The ribs of the adults are large, relatively high, and with steeper forward slopes than aborad slopes. There are both flank and shoulder tubercles at some stage of growth, but these seldom extend onto the adults. There is usually slight flexing of ribs at the flank tubercle; and the flexing appears earlier, ontogenetically, than do the tubercles and persists beyond the tubercles."

In Texas, where the genus is well represented, Young (1966, p. 26) noted a range of late middle Albian to early late Albian. Renz (1982, p. 56) recorded *Venezoliceras* from Peru, Ecuador, Colombia, Venezuela, Texas, Madagascar, South Africa, Morocco, and France.

Venezoliceras cf. V. commune (Renz)

Plate 1, figure 2

Type.—Figured specimen USNM 409328.

Description.—The largest specimen in the collection has a diameter of 180 mm and an umbilicus of 39.5 mm (ratio to diameter of 0.22). Only the outer whorl is preserved, which has a high, smooth keel. Ribs on the older half of the whorl are wirelike and much narrower than the interspaces; they are rursiradiate at first and prorsiradiate later and number 26. Most ribs on that part of the whorl begin on the umbilical shoulder, but about every fourth rib arises low on the flank. The ribs are inclined forward to a position about a third of the way to the ventrolateral shoulder, where they are flexed a little and may or may not support a small bullate tubercle. The ribs then continue to the ventrolateral shoulder where they rise into forwardly inclined, arcuate, bullate tubercles. Ribs on the younger half of the whorl are prorsiradiate and number 20. Each arises on the umbilical shoulder or on the umbilical wall. All are flexed a little on the lower third of the flank, where each supports a small bullate tubercle. The ribs become broader as they cross the outer two-thirds of the flank, and their adoral slopes become steeper then the adapical slopes. Each rib terminates in an arcuate ventrolateral tubercle.

In its general appearance and rib density, this specimen resembles *Venezoliceras commune* Renz (1968, p. 639, pl. 4, fig. 2a, b; pls. 5-7; pl. 8, fig. 3a, b; text figs. 5f-k, 6b). The ventrolateral tubercles, however, are more arcuate on the Puerto Rican specimen.

Venezoliceras cf. V. texanum Young

Plate 1, figure 1

Type.—Figured specimen USNM 409327.

Description.—This sparsely ribbed specimen consists of an outer whorl that encloses half of the penultimate whorl. The outer whorl has a diameter of 155 mm and an umbilicus of 39.8 mm (ratio to the diameter of 0.26). The keel is high and smooth and ends in a conspicuous rostrum. Ornament on the penultimate whorl consists of weak, narrow, prorsiradiate ribs of irregular height. The stronger ribs support small bullate tubercles at midflank, and all ribs terminate in ventrolateral clavi. The 12 ribs on the older half of the outer whorl are prorsiradiate; most have weak midflank bullate tubercles and all end in ventrolateral clavi. Nineteen prorsiradiate ribs are present on the younger half of the outer whorl. The ribs are sparse and rather straight at first but then become more closely spaced, flexed near midflank, and asymmetric with steep adoral faces. A midflank tubercle is present on every other rib on most of this half whorl. Ribs on the older part end in ventrolateral clavi, whereas those on the younger part terminate in arcuate bullae. These changes in ornament and the presence of a rostrum suggest that this specimen is an adult microconch.

In its sparse ribbing on the inner and outer whorls and in its midflank position of tubercles, this specimen resembles *Venezoliceras texanum* Young (1966, p. 75, pl. 7, figs. 1-3, 7; pl. 8, figs. 1-4; pl. 11, figs. 3, 4; pl. 34, fig. 3; text figs. 5a-c, 7d, f, 8b, h). Whether the whorl sections are the same cannot be determined owing to the crushed condition of the Puerto Rican specimen.

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PLATE 1

Contact photographs of this plate are available, at cost, from U.S. Geological Survey Library,
Federal Center, Denver, Colorado 80225

PLATE 1

[Both figures × 0.78 of natural size]

FIGURE 1. *Venezoliceras* cf. *V. texanum* Young. Figured specimen USNM 409327, from the Fajardo Formation about 0.8 km south of Fajardo, Puerto Rico.

2. *Venezoliceras* cf. *V. commune* (Renz). Figured specimen USNM 409328, from the same locality.

1

2

VENEZOLICERAS

CHAPTER E

Ammonites in Clasts of the Juana Lopez Member of the Carlile Shale (Upper Cretaceous) near Pueblo, Colorado

By WILLIAM A. COBBAN

Unusually good external molds of mollusks
date the clasts as middle late Turonian

U.S. GEOLOGICAL SURVEY BULLETIN 1837

SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

Ammonites in Clasts of the Juana Lopez Member of the Carlile Shale (Upper Cretaceous) near Pueblo, Colorado

By William A. Cobban

Abstract

Clasts of hard calcarenite derived from the upper Turonian Juana Lopez Member of the Carlile Shale occur sparingly in the basal bed of the Fort Hays Limestone Member of the Niobrara Formation. The Fort Hays Member, of late Turonian to early Coniacian age, rests disconformably on the middle Turonian Codell Sandstone Member of the Carlile Shale in the Pueblo area. Over most of southeastern Colorado, the Juana Lopez Member lies between the Codell Member and the Niobrara Formation. The clasts reveal the former presence of the Juana Lopez Member in the Pueblo area.

Impressions of the ammonites *Prionocyclus wyomingensis* Meek and *Scaphites warreni* Meek and Hayden on the clasts have unusually good detail, which reveal features that have not been noted previously. Among these are the presence of double umbilical tubercles on *P. wyomingensis* and details of the notching on the keel of this species.

INTRODUCTION

Excellent external molds of a bivalve and three species of ammonites were collected by G.R. Scott, of the U.S. Geological Survey, in 1961 from clasts of hard limestone at the base of the Niobrara Formation in the area now included in the Pueblo Reservoir State Recreation Area. The clasts were derived from a bed or beds of hard limestone in the Juana Lopez Member of the Carlile Shale. In the Pueblo area, the Fort Hays Limestone Member of the Niobrara Formation rests disconformably on the Codell Sandstone Member of the Carlile Shale, and the clasts at the base of the Fort Hays Member reveal the former presence of the Juana Lopez Member in the area. The clasts are also of much interest in that external molds of the ammonite *Prionocyclus* reveal the presence of double umbilical tubercles as well as details of the ventral keel.

The specimens described and illustrated in this report came from U.S Geological Survey Mesozoic locality D3999 in the E½ sec. 26, T. 20 S., R. 66 W., Pueblo County, Colo. The illustrated specimens are kept in the National Museum of Natural History in Washington, D.C., where they have been given USNM catalog numbers. R.E. Burkholder, of the U.S. Geological Survey, made the photographs.

JUANA LOPEZ CLASTS

Clasts of limestone derived from the Juana Lopez Member of the Carlile Shale lie in the basal 15–30 cm of the Fort Hays Limestone Member of the Niobrara Formation. The clasts are brownish-gray and very hard. Most are lenticular and usually 7–8 cm thick and as much as 60–70 cm in length. The rock is a calcarenite containing abundant prisms of calcite that were derived from the disaggregation of the shells of *Inoceramus*. Larger fragments of *Inoceramus* are usually present. The clasts are sparse and lie in a softer 20- to 40-cm-thick bed of light-gray to brownish-gray, burrow-mottled, calcareous mudstone that forms the base of the Niobrara Formation and rests disconformably on the Codell Sandstone Member of the Carlile Shale (fig. 1). The burrows in the basal Niobrara bed are usually lighter or darker than the matrix, variable in diameter (5–10 mm), and horizontal to inclined. Most could be classified as *Thalassinoides*. An occasional specimen of *Inoceramus costellatus* Woods, of late Turonian age, is present in this bed.

The clasts of Juana Lopez calcarenite are corroded and burrowed. Their upper surface is irregular and pitted with the depressions filled by the lighter gray lime mudstone of the basal bed of the Fort Hays Member. Molds of ammonites have been eroded leaving excellent impressions from which good casts can be obtained. The clasts were formed during a period of nondeposition before the advent of Niobrara deposition. Similar clasts in the base of the Fort Hays Member in southwestern Kansas were described by Hattin (1975, p. 199, pl. 1, fig. 1). At Pueblo the clasts reveal the former presence of the Juana Lopez Member. McLane (1983, fig. 6) has shown the feather-edge of the member a few kilometers west of Pueblo.

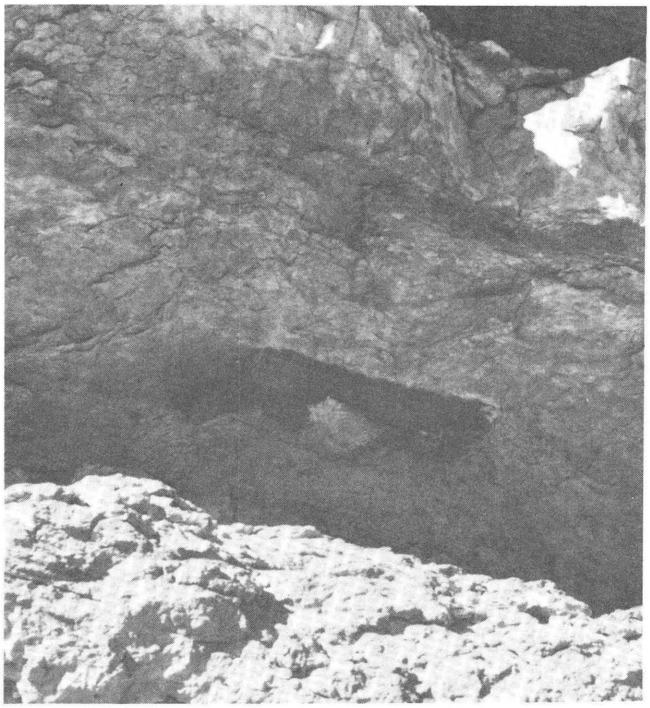

Figure 1. Fifteen-centimeter-long clast of dark-brownish-gray calcarenite derived from the Juana Lopez Member of the Carlile Shale lying in the basal 25 cm (shadowed) of the Fort Hays Limestone Member of the Niobrara Formation in the NW¼ SE¼ SE¼ sec. 26, T. 20 S., R. 66 W., Pueblo County, Colo.

Fossils in the clasts are abundant but of low diversity. Only *Inoceramus dimidius* White, *Lopha* sp., *Prionocyclus wyomingensis* Meek, and *Scaphites warreni* Meek and Hayden have been observed. This assemblage is characteristic of the late Turonian zone of *Scaphites warreni* (Cobban and Reeside, 1952, p. 1018).

SYSTEMATIC PALEONTOLOGY

Family COLLIGNONICERATIDAE Wright and Wright, 1951
Genus PRIONOCYCLUS Meek, 1871

Type species.—Ammonites (*Pleuroceras*?) *serrato-carinatus* Meek, 1870, p. 429 (*non* Stoliczka, 1865, p. 57) = *Prionocyclus wyomingensis* Meek, 1876a, p. 452.

Prionocyclus wyomingensis Meek

Plate 1, figures 2–4, 7–9

Ammonites serrato-carinatus Meek, 1870, p. 429.
Ammonites (*Pleuroceras*?) *serrato-carinatus* Meek. Meek, 1871, p. 298.
Prionocyclus wyomingensis Meek. Meek, 1876a, p. 452, footnote.
Prionocyclus wyomingensis Meek. White, 1880, p. 35, pl. 15, fig. 1a–e.
Prionocyclus wyomingensis Meek. White, 1883, p. 35, pl. 15, fig. 1a–e.
Prionocyclus wyomingensis Meek. Stanton, 1893 [1894], p. 171, pl. 40, figs. 1–4.
Prionocyclus wyomingensis Meek. Gilbert, 1896, p. 565, pl. 58, figs. 1–3.
Prionocyclus wyomingensis Meek. Logan, 1898, p. 463, pl. 106, figs. 1–4.
Prionocyclus wyomingensis Meek. Johnson, 1903, p. 139.
Prionocyclus wyomingensis Meek. Barbour, 1903, pl. 5, figs. 4, 5.
Prionocyclus wyomingensis Meek. Grabau and Shimer, 1910, p. 228, fig. 1510a–d.
Prionocyclus wyomingensis Meek. Grabau, 1921, fig. 1697e–h.
Prionocyclus wyomingensis Meek. Diener, 1925, p. 155.
Prionocyclus wyomingensis Meek. Roman, 1938, p. 457, pl. 46, figs. 435, 435a.
Prionocyclus wyomingensis Meek. Shimer and Shrock, 1944, p. 593, pl. 247, figs. 3–5.
Prionocyclus wyomingensis Meek, *forma typica*. Haas, 1946, p. 200, pl. 18, figs. 3–6; pl. 19, figs. 8–10; pl. 20, figs. 1, 2, 5; text figs. 93–97.
Prionocyclus wyomingensis Meek. Wright, 1957, p. 427, fig. 547 (6a, b).
Prionocyclus wyomingensis Meek. Termier and Termier, 1960, fig. 2418.
Prionocyclus wyomingensis Meek. Hattin, 1962, p. 90, pl. 25, fig. A.
Prionocyclus wyomingensis Meek. Matsumoto, 1965, p. 18, pl. 16, fig. 1a–c; pl. 17, fig. 2a–c (not pl. 18, fig. 1a–c).
Prionocyclus wyomingensis Meek. Hattin, 1975, pl. 2, fig. 11.
Prionocyclus wyomingensis Meek. Kauffman, 1977, pl. 26, figs. 2, 3.
Prionocyclus wyomingensis Meek. Hook and Cobban, 1979, p. 39.
Not *Prionocyclus wyomingensis* Meek. Whitfield, 1880, p. 440, pl. 14, figs. 1–3 [=*P. novimexicanus* (Marcou, 1858)].
Not *Prionocyclus wyomingensis* Meek. Luppov and Drushchits, 1958, p. 123, text fig. 97b; pl. 60, fig. 3a, b =*P. novimexicanus* (Marcou, 1858).
Not *Prionocyclus wyomingensis* Meek. Matsumoto, 1971, p. 132, pl. 21, fig. 2a, b; pl. 22, fig. 1a–c; text fig. 2 =*P. novimexicanus* (Marcou, 1858).
Not *Prionocyclus wyomingensis* Meek. Case, 1982, text fig. 12 (63) =*P. novimexicanus* (Marcou, 1858).

Diagnosis.—Prionocyclus wyomingensis is a large, moderately evolute, rather densely ribbed species that has inner and outer ventrolateral tubercles and a finely serrated keel.

Description.—This species was originally described by Meek (1870, p. 429) as follows: "Shell attaining a rather large size; discoid, with periphery provided with a very narrow, prominent, serrated mesial keel, including the siphuncle. Volutions increasing rather gradually in size, somewhat compressed laterally, and a little excavated without being distinctly channeled on each side of the ventral keel; inner ones but slightly embraced by each succeeding turn, and consequently well exposed in the wide umbilicus. Surface ornamented with numerous unequal costae, some of the larger of which bear a small, somewhat elongated node near the umbilicus, and two closely approximated small nodes around the ventro-lateral margins, where they all curve very strongly forward as they pass upon the periphery; spaces between each two of the large nodose costae occupied by from one to about three smaller ones. Septa unknown."

No illustrations were given by Meek. Before his death, Meek placed the type lot in C.A. White's hands. White (1880, p. 35, pl. 15, fig. 1a–e) redescribed the species and illustrated three specimens including the suture of one. All or part of White's illustrations have been reprinted by many later authors (Stanton, 1893; Gilbert, 1896; Logan, 1898; Barbour, 1903; Grabau and Shimer, 1910; Grabau, 1921; Roman, 1938; Shimer and Shrock, 1944; Wright, 1957; Termier and Termier, 1960; Kauffman, 1977).

Matsumoto (1965, p. 18) designated as lectotype one of the specimens figured by White (1880, pl. 15, fig. 1a). This specimen consists of parts of two adjoining whorls, each of which is less than half a whorl. The larger whorl is about 114 mm in length. Whorls are higher than wide with flattened flanks and venter and narrowly rounded umbilical shoulder. Ornament consists of conspicuous, narrow, prorsiradiate ribs, elongate umbilical tubercles, inner and outer ventrolateral tubercles, and prominent serrated keel. Ribs begin on the vertical umbilical wall, where they are inclined backward. On the umbilical shoulder, the ribs curve forward and then cross the flank with forward inclination; they bend forward again on the ventrolateral shoulder and disappear at or near the base of the keel. Conspicuous elongated umbilical tubercles are present on ribs at irregular intervals; they are separated by one to three nontuberculated ribs. Umbilical tubercles begin on the umbilical shoulder and extend on to the lower part of the flank, where they rise highest. The ribs that support umbilical tubercles also support strong, nodate inner ventrolateral tubercles; other ribs have weak nodate to bullate inner ventrolateral tubercles. All ribs either have weak bullate outer ventrolateral tubercles or incipient ones. Ribs probably numbered about 35 per half whorl on the lectotype. The keel is high, bounded by low grooves, and notched into clavi that are a little more numerous than the ribs.

The impressions of *Prionocyclus wyomingensis* on the Juana Lopez clasts closely resemble the lectotype in size and general appearance. However, latex casts of the impressions reveal more detail than that visible on Meek's types. Ribs are mostly narrow and sharp to threadlike (pl. 1, figs. 2, 4). Most ribs are narrower than the interspaces, and some ribs may be flexuous (pl. 1, fig. 4). Ribs that support umbilical tubercles are broader and higher than the others (pl. 1, fig. 8). Umbilical tubercles on some specimens are doubled and consist of a bullate inner tubercle on the shoulder and a larger nodate one on the lower part of the flank (pl. 1, fig. 4). Inner ventrolateral tubercles are nodate and high. Some outer ones are also nodate, high, and sharp. Both rows may have supported spines. The high, rounded keel is notched only on its upper surface. This notching results in siphonal tubercles of irregular height and strength. Most of these tubercles are low and transverse (pl. 1, figs. 1, 7), but some may be high and nodate (pl. 1, fig. 3). The siphonal tubercles are usually more numerous than the ribs (pl. 1, figs. 1, 7), but there are rare exceptions (pl. 1, fig. 3). Only three of the impressions consist of a half whorl or more. Ribs per half whorl are 38 at a diameter of 74.5 mm (pl. 1, fig. 4), 34 at 93 mm (pl. 1, fig. 2), and 23 at 120 mm.

Remarks.—*Prionocyclus wyomingensis* is the immediate ancestor of *P. novimexicanus* (Marcou, 1858, p. 35, pl. 1, fig. 2, 2a) from which it differs in its slightly more robust form and in its double ventrolateral tubercles (Hook and Cobban, 1979, p. 39). *Prionocyclus macombi* Meek (1876b, p. 132, pl. 2, fig. 3a-d), which is probably the ancestor of *P. wyomingensis*, differs from it chiefly in having weaker ornament and a more rounded venter.

Occurrence.—*Prionocyclus wyomingensis* is known from the Juana Lopez Member of the Carlile Shale at many localities in eastern Colorado, northeastern New Mexico, and southwestern Kansas, and from the Juana Lopez Member of the Mancos Shale in northwestern New Mexico, western Colorado, and eastern Utah. Farther north, the species is abundant in the Wall Creek Sandstone Member of the Frontier Formation of southeastern Wyoming and in the equivalent part of the Turner Sandy Member of the Carlile Shale of the Black Hills area in northeastern Wyoming, western South Dakota, and southeastern Montana. The species becomes scarce northwestward away from the Black Hills, and only a single specimen has been found in northwestern Montana (Mudge, 1972, table 9). A part of a whorl from Alberta illustrated by Jeletzky (1970, pl. 26, fig. 3) as *P. wyomingensis* var. *robusta* Haas lacks double ventrolateral tubercles and may be *P. novimexicanus* (Marcou).

Types.—Hypotypes USNM 401077-401082.

Family SCAPHITIDAE Meek, 1876a

Genus SCAPHITES Parkinson, 1811

Type species.—*Scaphites equalis* J. Sowerby, 1813, p. 53, pl. 18, figs. 1-3.

Scaphites warreni Meek and Hayden

Plate 1, figures 1, 5, 6

Scaphites warreni Meek and Hayden, 1860, p. 177.

Scaphites warreni Meek and Hayden. Meek, 1876a, p. 420, pl. 6, fig. 5.

Scaphites warreni Meek and Hayden var. *wyomingensis* Meek, 1876a, p. 423, text figs. 61-63.

Scaphites warreni Meek and Hayden. White, 1877, p. 200 (not pl. 19, fig. 3a).

Scaphites warreni Meek and Hayden. Stanton, 1893 [1894], p. 185, pl. 44, fig. 4 (not figs. 5-7).

Scaphites warreni Meek and Hayden. Logan, 1898, p. 475, pl. 104, fig. 4 (not figs. 5-7).

Scaphites warreni Meek and Hayden. Logan, 1899, p. 210 (not pl. 22, fig. 1; pl. 23, fig. 5).

Scaphites warreni Meek and Hayden. Herrick and Johnson, 1900, pl. 45, fig. 4 (not figs. 5-7).

Holcoscaphites warreni (Meek and Hayden). Nowak, 1916, p. 66.

Scaphites warreni Meek and Hayden. Diener, 1925, p. 204.

Scaphites warreni Meek and Hayden. Reeside, 1927, p. 36.

Scaphites warreni Meek and Hayden. Cobban, 1951b [1952], p. 21, pl. 3, figs. 8-21.

Scaphites warreni var. *ubiquitosus* Cobban, 1951b [1952], p. 23, pl. 3, figs. 26, 27; pl. 4, figs. 1-15.

Scaphites warreni var. *haydeni* Cobban, 1951b [1952], p. 23, pl. 3, figs. 22-25.

Scaphites warreni Meek and Hayden. Easton, 1960, text fig. 11.28 (2a, b).

Scaphites warreni var. *ubiquitosus* Cobban. Hattin, 1975, pl. 2, figs. 8-10.

Scaphites warreni Meek and Hayden. Cobban, 1976, p. 122, pl. 1, fig. 3.

Scaphites warreni Meek and Hayden. Kauffman and others, 1976 [1978], pl. 5, figs. 11, 12.

Scaphites warreni Meek and Hayden. Kauffman, 1977, pl. 22, figs. 11, 12; pl. 23, figs. 5, 6.

Scaphites warreni Meek and Hayden. Merewether and others, 1979, pl. 2, figs. 6-9.

Diagnosis.—This fairly stout, nontuberculated, small species has conspicuous ribbing in which ribs that cross the venter on the older part of the adult body chamber are more widely spaced than those on the younger part.

Description.—*Scaphites warreni* has been described in detail (Cobban, 1951b, p. 21–23). The species is dimorphic and includes stout forms (macroconchs) and smaller, more slender forms (microconchs). The holotype (Meek, 1876a, pl. 6, fig. 5) is a macroconch. Microconchs were assigned the name *S. warreni* var. *ubiquitosus* (Cobban, 1951b, p. 23).

Ornament consists of narrow, threadlike primary and secondary ribs. Body chambers of macroconchs from the Carlile Shale of western South Dakota have 6 to 13 primary ribs, averaging 8.4, and 27 to 41 secondaries, averaging 34.2 (Cobban, 1951b, p. 22). Body chambers of microconchs from the same area have 5 to 9 primaries and an average of 32.2 secondaries.

Juana Lopez clasts from the Pueblo area have several excellent impressions of macroconchs of *S. warreni* and a few poorer impressions of microconchs. The macroconchs range in diameter from 32 to 40 mm (pl. 1, figs. 1, 5, 6). Body chambers have about 7–9 primary ribs and 38–44 secondaries.

Remarks.—The high rib counts on the specimens from the clasts suggest that this assemblage of *S. warreni* is transitional to *S. ferronensis* Cobban (1951b, p. 23, pl. 4, figs. 16–29), a densely ribbed species that marks a zone between the zone of *S. warreni* and the younger zone of *S. whitfieldi* Cobban (Cobban, 1951a, fig. 2). Inasmuch as *Prionocyclus wyomingensis* Meek occurs with both *S. warreni* and *S. ferronensis*, a zone of *P. wyomingensis* with subzones of *S. warreni* and *S. ferronensis* has been proposed (Cobban, 1984, p. 86).

Occurrence.—*Scaphites warreni* is widely distributed in the western interior region at most of the localities of *Prionocyclus wyomingensis*. However, *S. warreni* has not been found north of the extreme southeast corner of Montana.

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PLATE 1

Contact photographs of this plate are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225

PLATE 1

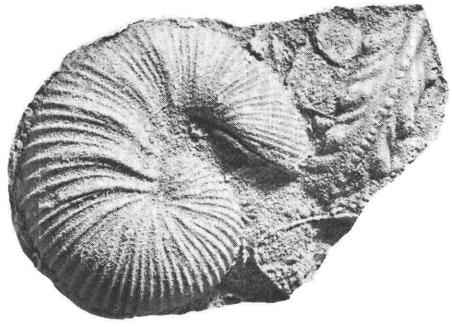
[All figures natural size]

FIGURES 1, 5, 6. *Scaphites warreni* Meek and Hayden. From USGS Mesozoic locality D3999 in the E½ sec. 26, T. 20 S., R. 66 W., Pueblo County, Colo.

1. Latex cast of hypotype USNM 401083.
5. Latex cast of hypotype USNM 401084.
6. Latex cast of hypotype USNM 401085.

2–4, 7–9. *Prionocyclus wyomingensis* Meek. From the same locality.

2. Latex cast of hypotype USNM 401077.
3. Latex cast of hypotype USNM 401078.
4. Latex cast of hypotype USNM 401079.
7. Latex cast of hypotype USNM 401080.
8. Latex cast of hypotype USNM 401081.
9. Latex cast of hypotype USNM 401082.



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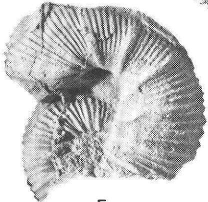

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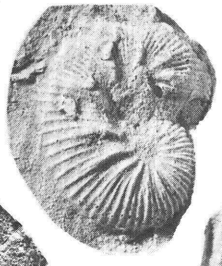

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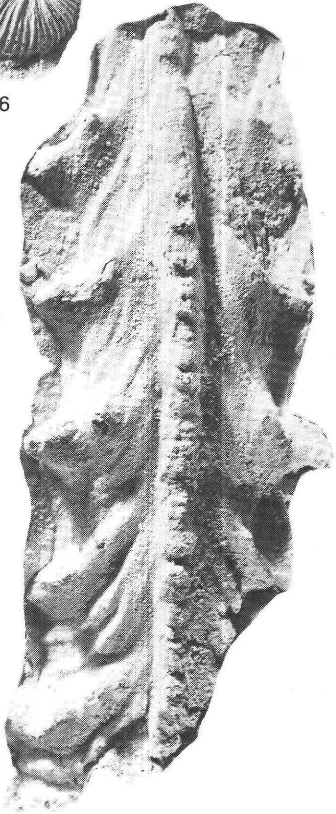

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SCAPHITES, PRIONOCYCLUS

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