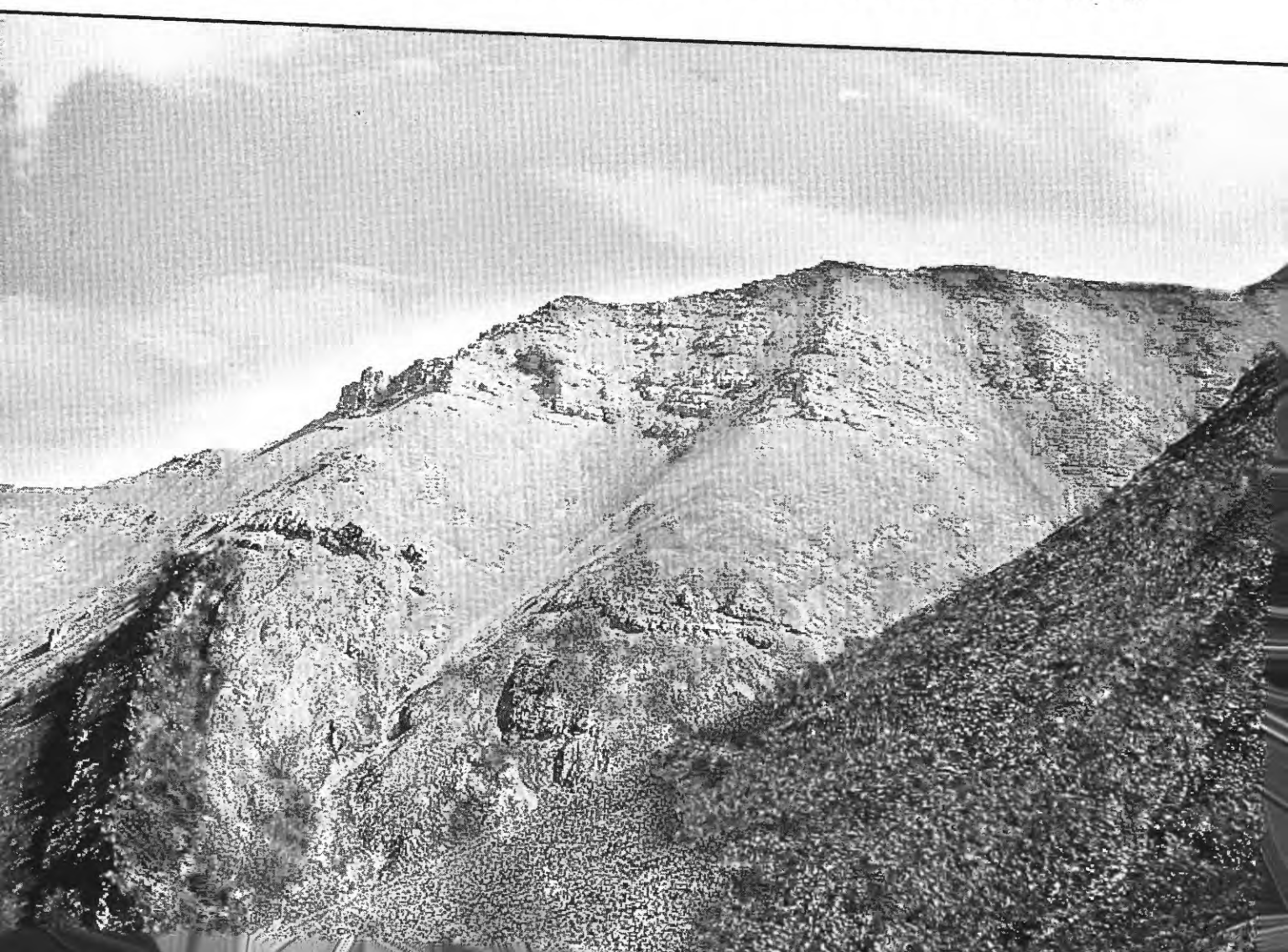


Lithostratigraphy, Microlithofacies, and Conodont
Biostratigraphy and Biofacies of the Wahoo
Limestone (Carboniferous), Eastern Sadlerochit
Mountains, Northeast Brooks Range, Alaska

U. S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1568



Cover: Angular unconformity separating steeply dipping pre-Mississippian rocks from gently dipping carbonate rocks of the Lisburne Group near Sunset Pass, eastern Sadlerochit Mountains, northeast Brooks Range, Alaska. The image is a digital enhancement of the photograph (fig. 5) on page 9.

Lithostratigraphy, Microlithofacies, and Conodont Biostratigraphy and Biofacies of the Wahoo Limestone (Carboniferous), Eastern Sadlerochit Mountains, Northeast Brooks Range, Alaska

By Andrea P. Krumhardt, Anita G. Harris, and Keith F. Watts

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1568

Description of the lithostratigraphy, microlithofacies, and conodont biostratigraphy and biofacies in a key section of a relatively widespread stratigraphic unit that straddles the Mississippian-Pennsylvanian boundary



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Lithostratigraphy, Microlithofacies, and Conodont Biostratigraphy and Biofacies of the Wahoo Limestone (Carboniferous), Eastern Sadlerochit Mountains, Northeast Brooks Range, Alaska

By Andrea P. Krumhardt,¹ Anita G. Harris,² and Keith F. Watts³

ABSTRACT

The Lisburne Group (chiefly Carboniferous) is a widespread succession of platform carbonate rocks that apparently developed along a south-facing passive continental margin in northern Alaska. Marine transgressions overlapped northward across northeast Alaska allowing the Lisburne platform to extend over terrigenous deposits of the Endicott Group and local pre-Mississippian paleotopographic highs. The Wahoo Limestone is the youngest formation of the Lisburne Group in northeasternmost Alaska, ranging from latest Mississippian (latest Chesterian) to Middle Pennsylvanian (at least early Atokan) in age. The Wahoo Limestone was systematically sampled for lithostratigraphy and conodont biostratigraphy and biofacies at a relatively continuous section (about 262 m in thickness) in the eastern Sadlerochit Mountains.

Existing Carboniferous conodont zonations could not be readily applied to the study section because most zonal indicators are absent. Species diversity is low for a section that spans at least 10 million years. Twenty-four species, distributed among 14 genera, were identified in 72 productive samples; no new species were distinguished. The following biostratigraphic zones and faunal intervals were recognized: Upper *muricatus* Subzone (latest Chesterian); *noduliferus-primus* Zone (earliest Morrowan); *minutus* Fauna (Morrowan) containing a lower subdivision (lower *minutus* Fauna of early to middle? Morrowan age); and an *Idiognathodus* Fauna (Morrowan? to early Atokan). The presence of *Idiognathodus incurvus*? and *Rhachistognathus minutus* subsp. above the first occurrence of the foraminifer *Pseudostaffella* sp. in the uppermost part of the Wahoo Limestone indicates that the youngest beds are early Atokan in age. The Mississippian-Pennsylvanian boundary is

placed at 56 m above the base of the lower member of the Wahoo Limestone on the basis of the lowest occurrence of *Declinognathodus noduliferus japonicus* above forms transitional from *Gnathodus girtyi simplex*.

Established foraminiferan biostratigraphy is somewhat inconsistent with respect to conodont-based time-rock boundaries and conodont zones in the study section and in northern Alaska in general. This indicates that the standard foraminiferan and (or) conodont zonations are not locally applicable without modification.

Conodont collections from the Wahoo Limestone across the northeast Brooks Range (from Wahoo Lake to the Clarence River) show remarkably similar faunal successions but even less species diversity than that found in the study section. Fifty-six biostratigraphically significant collections documenting the distribution of faunal units recognized in the study section are described in appendix 1.

The Wahoo Limestone formed in a range of chiefly open-platform, near-shoal, and open-marine environments on the shallow, inner part of a high-energy carbonate ramp. In the uppermost Mississippian and lowermost Pennsylvanian part of the formation, shoal facies were uncommon so that open-platform and open-marine microlithofacies and conodont biofacies were not clearly separated. Grain types and, to a lesser extent, conodonts were hydraulically spread beyond their original settings making some paleoenvironmental interpretations equivocal. The use of conodont biofacies and microlithofacies in concert clarifies some of the environmental ambiguities. In the Pennsylvanian part of the Wahoo Limestone, extensive ooid and skeletal shoal tracts separated open-marine and open-platform environments producing more distinct biofacies and diagnostic microlithofacies. *Rhachistognathids* thrived in and adjacent to the shoal facies. After death, many of their skeletal elements remained in place; however, a substantial number were washed into surrounding environments, masking natural species associations. Similarly, mixing of carbonate grains obscures microlithofacies interpretations. The vertical succession of conodont biofacies substantiates microlithofacies interpretations that indicate that the upper part of the Wahoo

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Limestone represents a transgressive-regressive sequence passing from restricted platform to shoals and, finally, back to restricted platform. Conodont species associations, abraded conodonts and bioclasts, and grain-type associations indicate a high degree of postmortem hydraulic mixing across the carbonate platform supporting the interpretation that it represents a high-energy carbonate ramp.

Conodont color alteration indices (CAI) in the study section are chiefly 4 and 6, rarely 3, and very rarely 3.5 and 4.5. Most conodont elements have a sugary and (or) corroded texture. The anomalously high CAI values of 6 have positive correlation with grainstones and dolomitized intervals and negative correlation with quartz-rich and poorly washed carbonate rocks. The range of CAI values and textures and the distribution of high CAI values suggest local, probably low-temperature hydrothermal alteration of the Wahoo Limestone.

INTRODUCTION

The Lisburne Group (chiefly Carboniferous) is a thick sequence of predominantly carbonate rocks that extends across the Brooks Range and into the subsurface of the North Slope (fig. 1). In the northeast Brooks Range, the Lisburne Group is at least 500 m thick and is subdivided into the Alapah Limestone and overlying Wahoo Limestone. The northeast Brooks Range is the area east of the Trans-Alaska Pipeline and north of the Continental Divide, which trends east-northeast between lat 68° and 69° N. and long 139° to 147° W.

The Wahoo Limestone in the eastern Sadlerochit Mountains, Arctic National Wildlife Refuge (ANWR), was measured and systematically sampled for conodonts, foraminifers, and microlithofacies (figs. 1, 2). The study section is well exposed, contains some of the youngest beds of the Wahoo Limestone in the area, and is similar to the Wahoo Limestone in the subsurface at Prudhoe Bay (Reiser, 1970; Armstrong and Mamet, 1974). It is accessible from Kakto-vik, a major embarkation point for ANWR (fig. 1).

This study was undertaken to (1) establish a conodont biostratigraphic framework for the Wahoo Limestone in ANWR, (2) determine the position of the Mississippian-Pennsylvanian boundary in the formation, (3) integrate conodont biofacies with microlithofacies studies (for example, Armstrong, 1972; Armstrong and Mamet, 1977; Watts, 1990; Gruzlovic, 1991; Krumhardt, 1992), and (4) compare conodont and foraminiferan biostratigraphic data. Previously, foraminifers provided the primary biostratigraphic control for the Lisburne Group in ANWR. Inconsistent assignment of foraminiferan zones and lithologic boundaries by previous researchers in our study area, however, indicates unresolved stratigraphic problems (see fig. 8). More recently, conodonts have been used to refine, confirm, or as an alternative to foraminiferan age determinations (>500 conodont collections from the Lisburne Group were

analyzed by A.G. Harris from 1979 to 1994 and by Harris and A.P. Krumhardt from 1989 to 1994; published and unpublished written commun.). Many of these samples indicate that conodonts have greater biostratigraphic resolution than foraminifers in the uppermost Mississippian and Lower Pennsylvanian part of the Lisburne Group. In addition, the conodont *Declinognathodus noduliferus* is the primary micropaleontologic indicator for the base of the Pennsylvanian (Lane and Manger, 1985). Thus, conodonts are the preferred microfossils for locating the mid-Carboniferous (Mississippian-Pennsylvanian) boundary.

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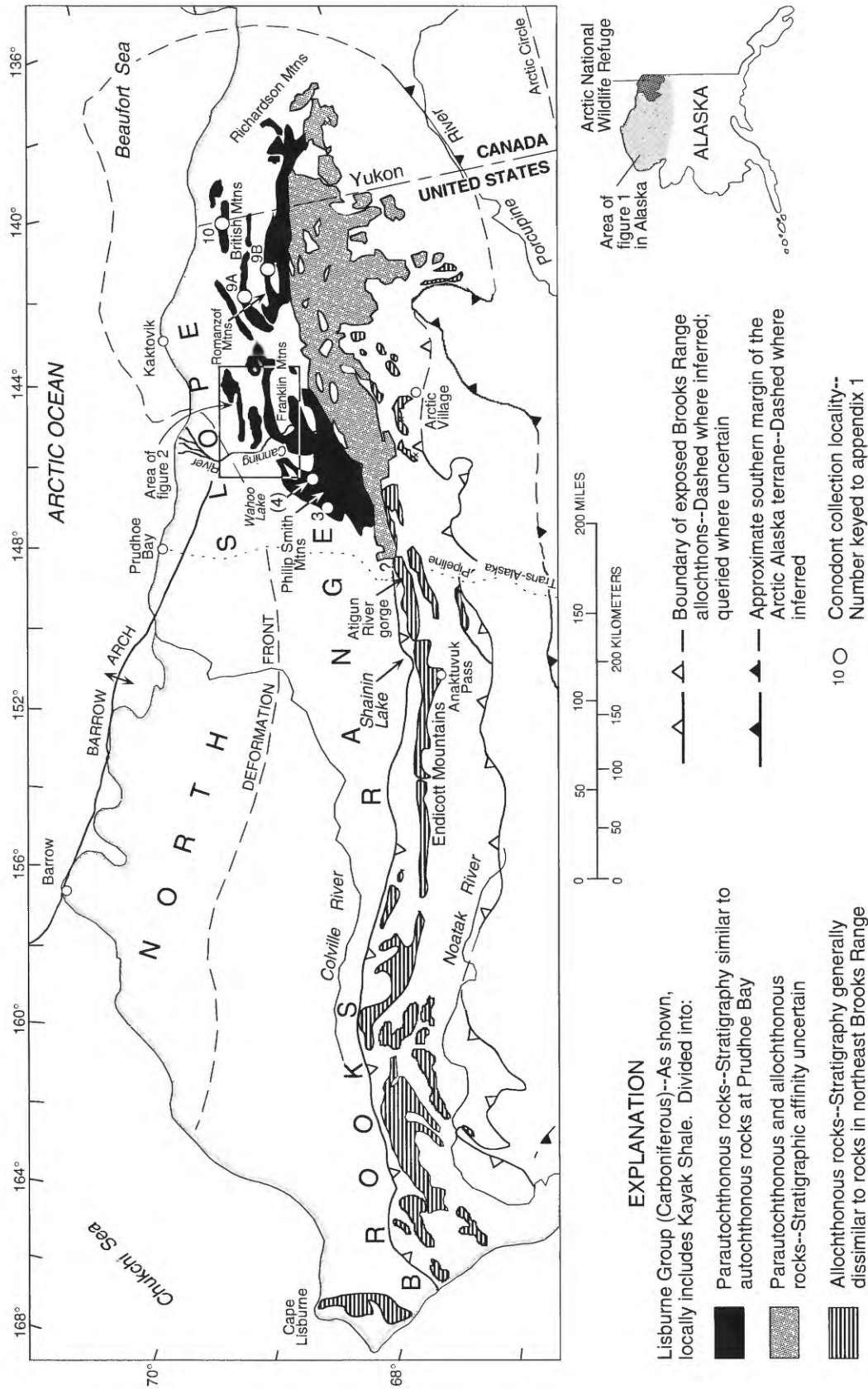


Figure 1. Distribution and tectonic affinities of the Lisburne Group in the Brooks Range; compiled from Grybeck and others (1977), Norris (1982), Craig and others (1985), Mull and others (1987), and W.K. Wallace (University of Alaska Fairbanks, oral commun., 1993).

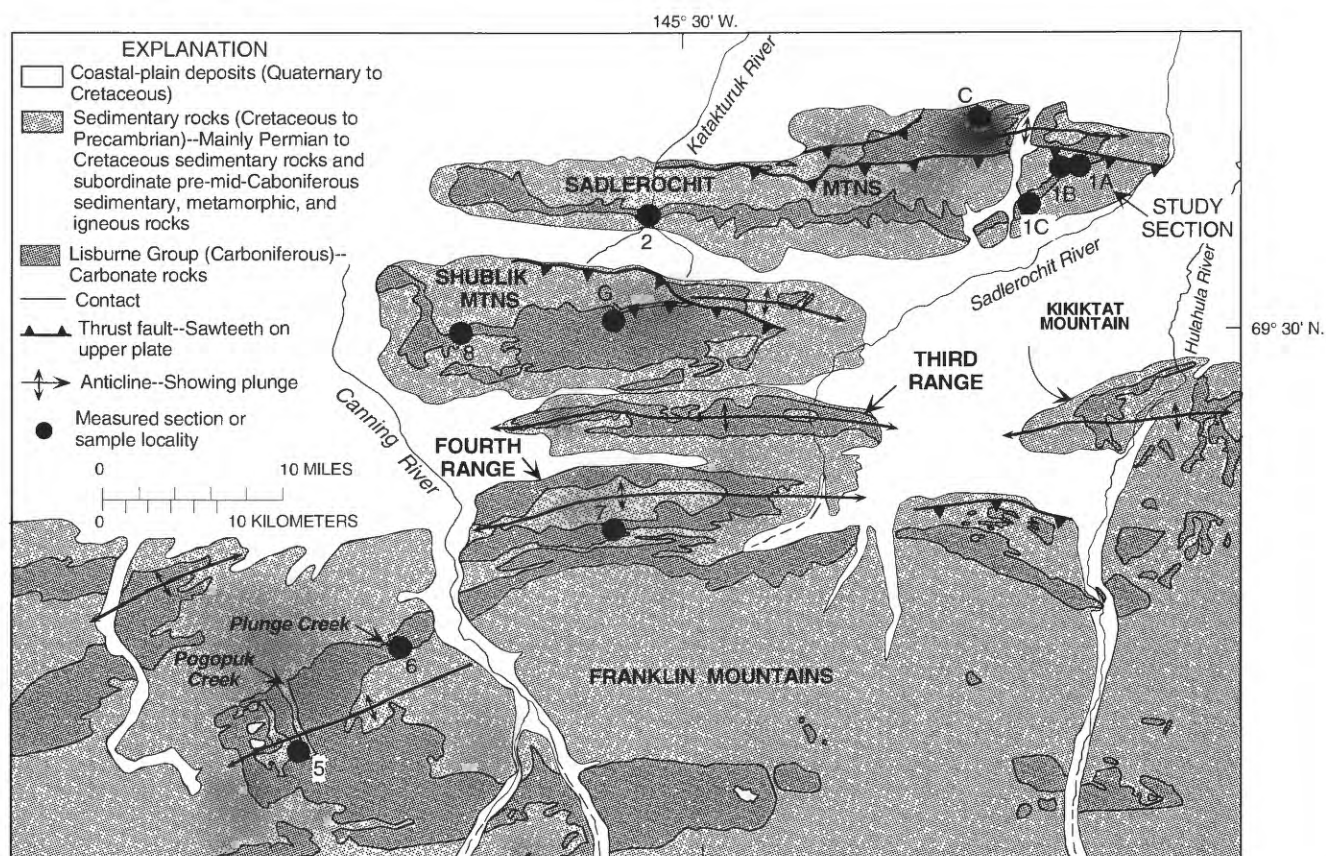


Figure 2. Distribution of the Lisburne Group, major structural features, and locations of study section (1A) and selected measured sections discussed in this report, northeast Brooks Range (geology modified from Bader and Bird, 1986; see fig. 1 for regional setting). Numbered localities refer to measured sections and (or) conodont collection sites described in appendix 1. Lettered and some numbered localities are sections described by other

workers referred to in text: 1B, Armstrong and co-workers (Armstrong and others, 1970; Armstrong, 1972; Armstrong and Mamet, 1975, 1977; Mamet and Armstrong, 1984; Wood and Armstrong, 1975); C, 1B, and 1C, Carlson (1987); 2, Clough and Bakke (1986) and Imm (1986); G, 6, and 7, Gruzlovic (1991); and 5, Morgan (1992).

measured sections and providing us with microlithofacies analyses of their samples. We are most grateful to J.A. Dumoulin, U.S. Geological Survey; P.H. von Bitter, Royal Ontario Museum and University of Toronto; L.M. Brown, Lake Superior State University; and G.D. Webster, Washington State University for their heroic, timely, and thorough reviews of the manuscript. This paper was considerably improved by their technical reviews.

PREVIOUS STUDIES

Schrader (1902, p. 241) first used the name "Lisburne formation" for limestone and shale exposed in the vicinity of Anaktuvuk Pass in the central Brooks Range (fig. 1). The regional extent and character of the formation were more fully described by him in a later paper in which he states that the Lisburne extends from Cape Lisburne to Anaktuvuk Pass and eastward "nearly to the international boundary and

probably beyond it" (Schrader, 1904, p. 67). Subsequently, in the central Brooks Range, Bowsher and Dutro (1957) raised the Lisburne to group rank and subdivided it into two new formations, the Wachsmuth Limestone and overlying Alapah Limestone. Brosgé and others (1962) distinguished a third and the youngest formation of the group, the Wahoo Limestone, in the eastern Brooks Range.

Detailed regional biostratigraphic and microlithofacies analyses of the Lisburne Group accompanied the expansion of hydrocarbon exploration of the North Slope during the 1970's. Armstrong and others (1970) first applied Mamet's Carboniferous foraminiferan zonation to the Lisburne Group in the northeast Brooks Range, and, later, Armstrong (1972) described the carbonate lithology, coral biostratigraphy, and paleoecology. Mamet and Armstrong (1972) examined sections in the Franklin and Romanzof Mountains (fig. 1) and later Armstrong and Mamet (1974) tied the Lisburne Group in the subsurface at Prudhoe Bay to exposures in ANWR. Wood and Armstrong (1975) described the

diagenesis and stratigraphy of the Lisburne Group in the Sadlerochit Mountains and adjacent areas while Armstrong and Mamet (1975) extended their biostratigraphic studies to other sections in the northeast Brooks Range. Ultimately, Armstrong and Mamet (1977) produced a regional synthesis of their investigations for the entire northern Brooks Range. Armstrong and Mamet (1978) extended their work to the Lisburne Group in the allochthonous thrust sheets in the central and western Brooks Range. Mamet and Armstrong (1984) discussed the Mississippian-Pennsylvanian boundary in the Sadlerochit, Franklin, and Romanzof Mountains and placed the boundary at the contact between the Alapah and Wahoo Limestones. A revised megafossil zonation for the Carboniferous of the northern Brooks Range and its relation to Mamet's foraminiferan zonation is given in Dutro (1987). As in Mamet and Armstrong (1984), Dutro (1987) placed the Mississippian-Pennsylvanian boundary at the contact between the Alapah and Wahoo Limestones.

Since 1985, many reports have been produced on the geology of ANWR by investigators at the University of Alaska Fairbanks (for example, Crowder, 1990; Wallace and Hanks, 1990; Watts, 1990). Of particular importance to our study are reports on the depositional environments, cyclicity, and diagenetic history of the Wahoo Limestone in the eastern Sadlerochit Mountains and the stratigraphic evolution and lateral facies changes of carbonate cycles (parasequences) across the Lisburne Group carbonate platform (fig. 2; Carlson, 1987; Gruzlovic, 1991). Additional studies describing the geology of ANWR are included in Bird and Magoon (1987), Tailleux and Weimer (1987), and Grantz and others (1990).

REGIONAL GEOLOGIC SETTING

The parautochthonous rocks of northeastern Alaska are part of the tectonically complex Arctic Alaska terrane that also includes allochthonous thrust sheets of the southern Brooks Range and the relatively little deformed autochthonous rocks beneath the North Slope (fig. 1; Reiser, 1970; Mull, 1982; Crowder, 1990). The rocks in the Arctic Alaska terrane have been subdivided into the Franklinian, Ellesmerian, and Brookian tectono-depositional sequences (fig. 3; Grantz and May, 1983; Bird and Molenaar, 1987; Hubbard and others, 1987) using terminology established by Lerand (1973) in the Canadian Arctic.

The Franklinian sequence in the northeast Brooks Range includes Precambrian to Devonian sedimentary, metamorphic, and igneous rocks. Erosion of these rocks following orogenic uplift during the middle Paleozoic produced a paleotopography that considerably influenced subsequent depositional patterns and structural deformation (Watts and others, 1988; Wallace and Hanks, 1990).

Mississippian to Lower Cretaceous sedimentary rocks of the Ellesmerian sequence unconformably overlie the Franklinian sequence (fig. 3). The Ellesmerian sequence documents a long interval of sedimentation from a northerly source onto a broadly subsiding, passive continental margin. In the Carboniferous part of the sequence, terrigenous clastic sedimentary deposits of the Endicott Group (Mississippian in age in the Sadlerochit Mountains) are succeeded by carbonate-platform deposits of the Lisburne Group. A major unconformity with a hiatus of about 40 m.y. separates the Lisburne Group from the overlying terrigenous clastic deposits of the Sadlerochit Group (Permian and Triassic) (Crowder, 1990). The upper part of the Ellesmerian sequence (Triassic to Lower Cretaceous) is dominated by terrigenous shale of the Kingak Shale (primarily Jurassic) with lesser amounts of sandstone and rare phosphatic limestone and calcareous sandstone to siltstone of the Shublik Formation (Triassic). This report concerns the Carboniferous part of the Ellesmerian sequence.

LISBURNE GROUP, NORTHEAST BROOKS RANGE

The Lisburne Group (chiefly Carboniferous) is a thick succession (>500 m) of platform-carbonate rocks that apparently developed along a south-facing passive continental margin in northern Alaska (relative to present coordinates). Marine transgressions overlapped northward across northeast Alaska so that eventually the Lisburne platform extended over much of Arctic Alaska. In most of the northeast Brooks Range, the Lisburne Group gradationally overlies the fluvial to marginal-marine deposits of the Endicott Group (fig. 4). In the Sadlerochit Mountains, however, the pre-Mississippian rocks formed a paleotopographic high so that the Endicott Group is thin or absent (Armstrong and Mamet, 1975; Watts and others, 1988). Where the Endicott Group is absent, the Lisburne Group rests with angular discordance on southward-dipping, pre-Mississippian rocks (fig. 5); this relationship influenced the structural development of northeastern Alaska (Wallace and Hanks, 1990). South of the Sadlerochit Mountains, the Kayak Shale of the Endicott Group provides a major detachment surface. Because the Kayak Shale is absent or thin in the Sadlerochit Mountains, Ellesmerian rocks (fig. 3) remained attached to the underlying Franklinian rocks, and both deformed as a unit (Wallace and Hanks, 1990). Thus, the Lisburne Group here is parautochthonous and has undergone little northward tectonic transport.

In the northeast Brooks Range, the Lisburne Group consists of the Alapah Limestone and Wahoo Limestone. Three large-scale transgressive-regressive (TR) sequences are recognized in these strata (fig. 4; Gruzlovic, 1991). Superimposed on these large-scale sequences are many parasequences of variable thickness that record the response

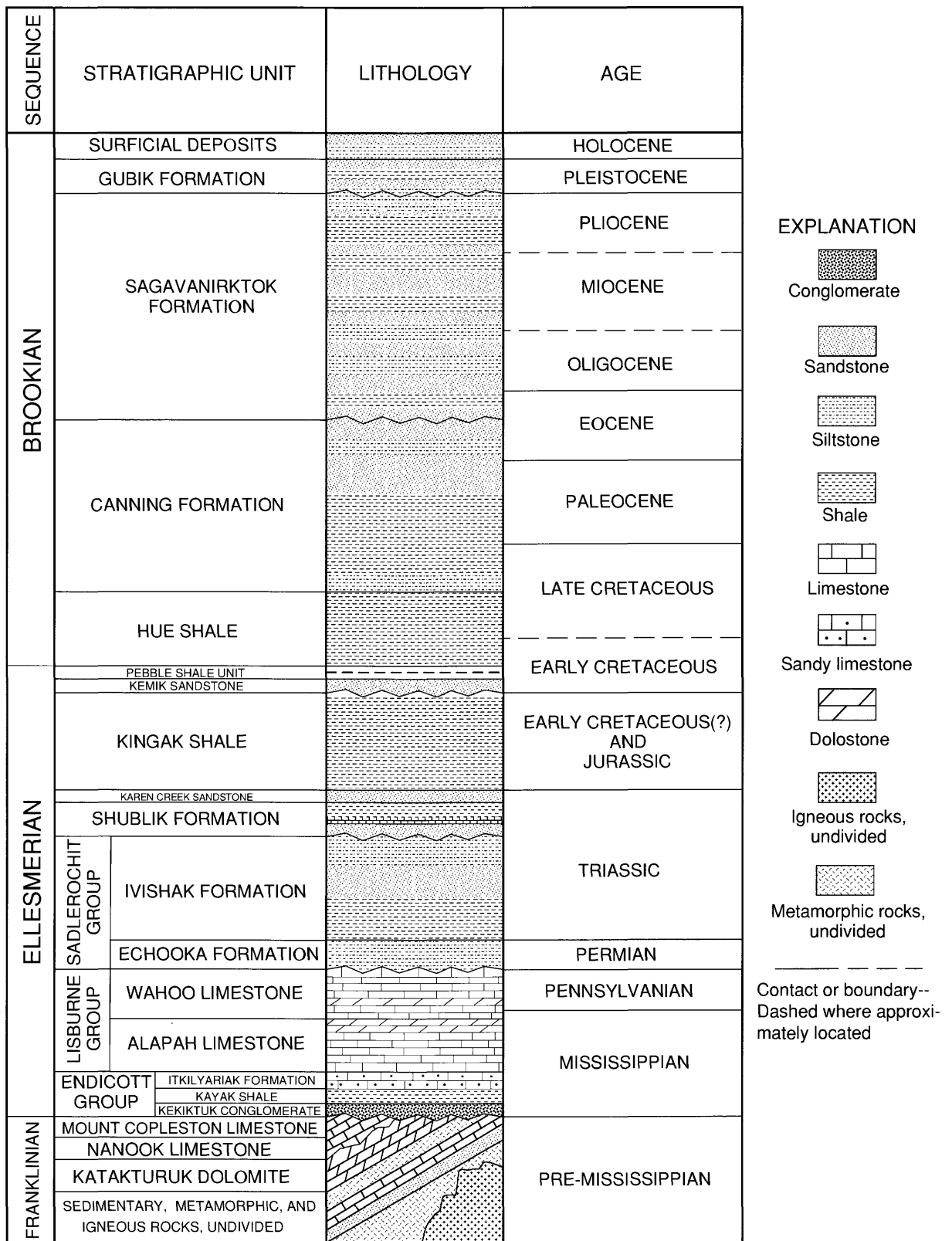


Figure 3. Generalized stratigraphic succession, northeast Brooks Range and northeast coastal plain, Alaska (not to scale; modified from Bird and Molenaar, 1987).

of the platform to eustacy and (or) changes in carbonate production and platform subsidence (fig. 4: Watts, 1990; Gruzlovic, 1991). The Endicott Group (where present) and the Alapah Limestone represent the first large-scale TR sequence. The remaining TR sequences generally correspond to the lower and upper members of the Wahoo Limestone.

ALAPAH LIMESTONE

The age of the Alapah Limestone (~200 to >500 m in thickness) is Meramecian and (or) Chesterian on the basis of foraminiferan (Armstrong and others, 1970; Armstrong and Mamet, 1977) and conodont biostratigraphy (this report). In the Sadlerochit Mountains, Alapah deposition began in the Chesterian (Mamet and Armstrong, 1984). The age of the base of the Lisburne Group is progressively older southward and westward. In the northern part of the northeast Brooks Range, continued transgression during much of the deposition of the Alapah Limestone is indicated by a transition from algal limestone into cross-stratified skeletal grainstone culminating in bryozoan-pelmatozoan limestone. The upper member of the Alapah Limestone is dominantly spiculitic dolostone and dolomitic lime mudstone-wackestone containing lesser amounts of cryptalgal laminite (fig. 4: Watts, 1990; Gruzlovic, 1991) indicating restricted and (or) peritidal conditions associated with a major regression. The uppermost part of the Alapah Limestone is late Chesterian in age (Armstrong and Mamet, 1977; this report). The contact with the overlying Wahoo Limestone is relatively sharp in the study area but is more gradational and difficult to define farther to the south.

ALAPAH LIMESTONE-WAHOO LIMESTONE BOUNDARY, NORTHEAST BROOKS RANGE

The base of the Wahoo Limestone is placed at the first light-weathering, cliff-forming, fossiliferous limestone above the slope-forming, darker limestone and dolostone characteristic of the underlying Alapah Limestone (fig. 5). A similar contact was chosen by Brosgé and others (1962), Armstrong (1972, 1974), Wood and Armstrong (1975), and Carlson (1987). Other authors were inconsistent in their placement of the contact (see fig. 8) and used biostratigraphic rather than lithostratigraphic criteria so that their contact approximated the Mississippian-Pennsylvanian boundary (Armstrong and others, 1970; Armstrong and Mamet, 1974, 1975, and 1977; and Mamet and Armstrong, 1984).

WAHOO LIMESTONE

The age of the Wahoo Limestone (0 to >350 m in thickness) is late Chesterian to Atokan on the basis of foraminifers (Armstrong, 1972, 1974; Wood and Armstrong, 1975; Carlson, 1987) and conodont biostratigraphy (this report). Brosgé and others (1962) named the Wahoo Limestone and subdivided it into lower and upper members at its type section near Wahoo Lake (fig. 1). They assigned the formation a Pennsylvanian(?) and Permian age on the basis of brachiopod-bryozoan assemblages in the basal part of the lower member and brachiopods in the uppermost part of the upper member. Our conodont collections from the formation, 1.5 km west of the type section, show that the lower member is within the late Chesterian *muricatus* Zone at its base, and the appearance of *Adetognathus lautus* 15 m higher indicates the Upper *muricatus* Subzone (app. 1, locs. 4A1a, b). The first definitive Pennsylvanian strata are marked by the appearance of *Declinognathodus noduliferus*, the guide to the Pennsylvanian, at 155 m above the base of the lower member (app. 1, loc. 4A1d). The youngest bona fide Wahoo Limestone at the type locality is Morrowan to early Atokan in age (Watts and others, 1992; app. 1, loc. 4E). At its type locality, Watts and others (1989) referred the calcareous beds of Permian age to the Echooka Formation in their examination of the upper member of the Wahoo Limestone. A collection from 4.5 m below the top of the formation, about 5 km west of the type section, helps constrain the age of the uppermost beds to the late Morrowan or early Atokan (app. 1, loc. 4D).

Grainstone makes up two-thirds of the Wahoo Limestone at the study section indicating deposition under dominantly high-energy conditions. We recognize two mappable members of the Wahoo Limestone: light-gray, massive, cliff-forming grainstone and packstone of the lower member overlain by the heterolithic upper member that forms ledge-and-slope topography. The lower member represents a large-scale TR sequence (fig. 4) consisting primarily of bryozoan-pelmatozoan grainstone and packstone that probably formed in an open-marine environment. Four to five parasequences (each 10–20 m in thickness) are recognized within the lower member (fig. 4; Carlson, 1987; Watts, 1990; Gruzlovic, 1991); these probably formed in slightly deeper water than those of the upper member. Parasequences in the lower member are more difficult to distinguish in the field because they lack the marked lithologic contrasts characteristic of the upper member; parasequences of the lower member are best recognized by microlithofacies analysis.

In the eastern Sadlerochit Mountains, the contact between the lower and upper members of the Wahoo Limestone appears to be planar but locally has erosional relief (Carlson, 1987; Krumhardt and Harris, 1990). Farther to the southwest, in the Fourth Range and at Plunge Creek (fig. 2), this contact is gradational (Gruzlovic, 1991).

Most of the upper member of the Wahoo Limestone represents a TR sequence containing many parasequences (each 3–9 m thick) related to relative sea-level changes and the migration of ooid shoals. The ooid shoals formed a

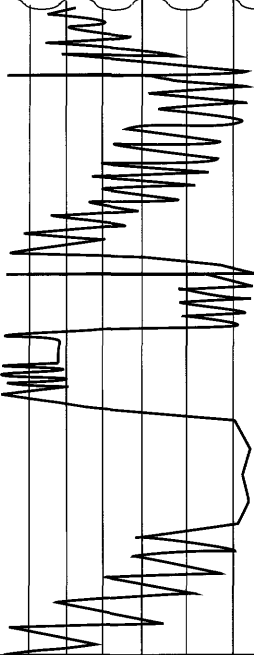
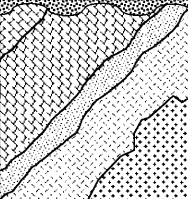
SYSTEM	GROUP	STRATIGRAPHIC UNIT	LITHOLOGY	DESCRIPTION	DEPOSITIONAL ENVIRONMENT									
					INTERTIDAL	PLAT-FORM		OPEN PLATFORM TO OPEN MARINE	SHOAL	OPEN MARINE				
						RESTRICTED	OPEN			WAVE BASE	ABOVE	BELOW		
PERMIAN	TRIASSIC	SADLEROCHIT GROUP	Ivishak Formation (part)	Quartzose sandstone and shale										
			Echooka Formation	Siltstone and glauconitic sandstone										
PENNSYLVANIAN	LISBURNE GROUP	Wahoo Limestone	upper member	Oncolitic and peloid packstone and grainstone Ooid and (or) <i>Donezella</i> packstone and grainstone Ooid grainstone Cryptalgal and (or) dolomitized mudstone	Cyclical, alternating with bryozoan-pelmatozoan limestone									
			lower member	Bryozoan-pelmatozoan grainstone and packstone										
		Alapah Limestone	upper member	Spiculitic dolostone and dolomitic lime mudstone-wackestone, cryptalgal laminite										
			middle member	Bryozoan-pelmatozoan limestone										
			lower member	Cyclical, crossbedded, skeletal grainstone alternating with peloidal skeletal packstone. Algal limestone and spiculitic dolostone and limestone in lower part										
			ENDICOTT GROUP	Itkilyariak Formation									Sandy limestone	Fluvial to marginal marine
		Kayak Shale		Black shale, containing some sandstone and limestone										
		Kekiktuk Conglomerate		Quartzose sandstone and conglomerate										
		PRE-MISSISSIPPIAN		Mount Copleston Limestone									Sedimentary, metamorphic, and igneous rocks	Variously deformed, relatively south-dipping rocks
				Nanook Limestone										
Katakturuk Dolomite														
Sedimentary, metamorphic, and igneous rocks, undivided														

Figure 4. Stratigraphic relationships, lithologies, and inferred depositional environments of the Lisburne Group, northeast Brooks Range. At the study section, the Endicott Group is absent, and the Alapah Limestone rests with angular discordance on

pre-Mississippian rocks (fig. 5). Only the Wahoo Limestone was systematically analyzed for this study. See fig. 3 for explanation. (Modified from Carlson, 1987; Watts, 1990; and Gruzlovic, 1991.)

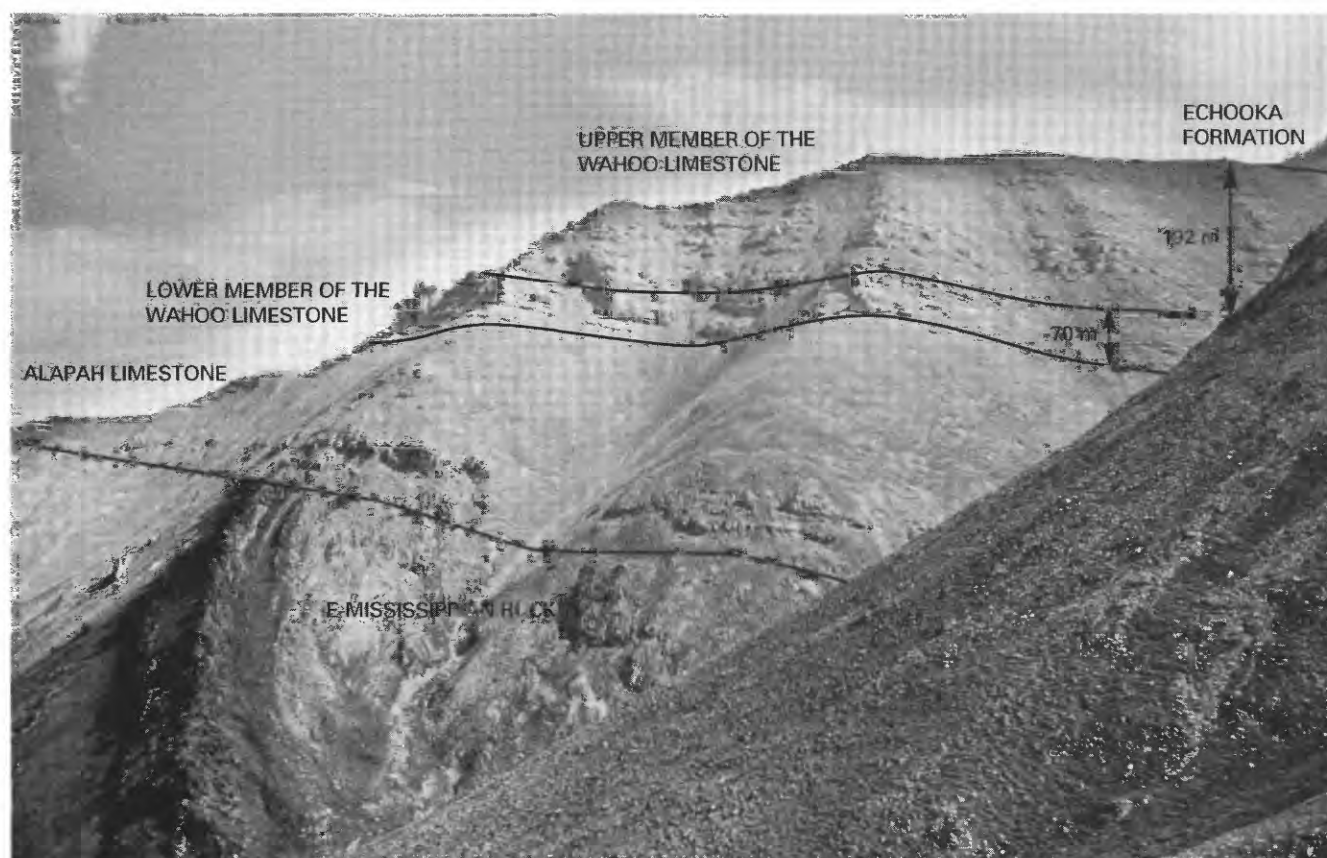


Figure 5. View of study section looking northeast, eastern Sadlerochit Mountains (see fig. 2 for location). Measured section follows ridgeline and includes upper 3 m of the Alapah Limestone, the entire Wahoo Limestone, and lower 1 m of the Echooka Formation. Note that the Endicott Group is absent and a marked angular unconformity separates the Alapah from underlying pre-Mississippian rocks.

broad, discontinuous belt trending westward from the northern British Mountains, near the Canadian border, to the Canning River and then possibly northwestward toward Prudhoe Bay (fig. 1). The shoals pinch out southwestward, down the depositional dip of the carbonate ramp (Gruzlovic, 1991). The lithology of the upper member varies vertically and laterally as a consequence of ooid shoal migration through time (Carlson, 1987; Watts, 1990; Gruzlovic, 1991).

A disconformity of considerable magnitude (~40 m.y.) separates the Lisburne Group from the overlying Echooka Formation of Permian age (fig. 4). Regionally, this disconformity is an irregular surface having as much as 200 m of section removed by erosion locally and as much as 20 m of local erosional relief (Crowder, 1990). The contact between the Lisburne Group and Echooka Formation is typically planar; carbonate rocks of the Lisburne Group are overlain by terrigenous siltstone, shale, and (or) glauconitic quartzose sandstone of the Echooka Formation (Crowder, 1990). Locally, erosional relief is most apparent beneath channelized conglomerates in the basal part of the Echooka Formation. Clasts in the conglomerates include limestone and chert derived from the Lisburne Group providing additional

evidence of erosion. Even though the Lisburne Group platform was subaerially exposed, karst features are rare (Carlson, 1990; Watts, 1990; Watts and others, 1992). Erosion along the disconformity produced some of the variation in thickness of the Wahoo Limestone and significantly influenced the age of the uppermost part of the formation. At the study section, the formation is not as thick as at the type section (262 m versus >330 m in thickness), but the uppermost part of the formation is as young as or younger than the highest beds at and near the type section (app. 1, locs. 4E, D). In some areas, such as near the Trans-Alaska Pipeline (fig. 1), the upper part of the Lisburne Group is no younger than latest Mississippian (Watts, 1991).

LITHOSTRATIGRAPHY OF THE WAHOO LIMESTONE, EASTERN SADLEROCHIT MOUNTAINS

The study section is near the eastern limit of outcrops of the Wahoo Limestone in the Sadlerochit Mountains (fig. 2). The base of the section is in the SE1/4SW1/4 sec. 5, T. 3 N., R. 31 E. (lat 69°38'24" N., long 144°34'45" W.), and the

top is in the center NW1/4 sec. 8, T. 3 N., R. 31 E. (lat 69°38'03" N., long 144°34'45" W.), Mt. Michelson C-1 quadrangle. This section was chosen because of (1) accessibility by helicopter (65 km southwest of Kaktovik; fig. 1), (2) proximity to measured sections described by previous workers (Armstrong and others, 1970; Wood and Armstrong, 1975; and Carlson, 1987) that were less accessible for conodont sampling, (3) excellent exposures of the Wahoo Limestone (95 percent) and its boundaries (fig. 5), and, in particular, (4) the relatively thick interval of upper Morrowan and Atokan strata.

Our measured section includes the upper 3 m of the Alapah Limestone, the entire Wahoo Limestone (262 m), and the basal 1 m of the succeeding Echooka Formation (pl. 6). The lower 3 m of the Wahoo Limestone is massive-bedded dolomitized bryozoan packstone that overlies a 0.5-m-thick interval of light-gray, fenestral, dolomitic mudstone at the top of the Alapah Limestone. The lower and upper members of the Wahoo Limestone are readily distinguished; their boundary is placed at the change from cliff-forming, light-gray packstone below to orange-weathering, silty, cryptalgal(?) dolostone above (fig. 5). The contact with the overlying Echooka Formation forms a rubble-covered dip slope, but only a few meters of section are concealed. The section was systematically sampled for microlithofacies at 2-m intervals. Additional samples were taken to document obvious lithologic changes and at all conodont sample sites (table 1; pl. 6).

LOWER MEMBER OF THE WAHOO LIMESTONE

The lower member (Mississippian and Pennsylvanian) of the Wahoo Limestone is 70 m thick and is chiefly bryozoan-pelmatozoan grainstone and packstone. Rare beds of wackestone and skeletal packstone occur particularly in the basal part of the lower member and near the Mississippian-Pennsylvanian boundary and contain minor sponge spicules. Peloids, including completely micritized bioclasts, are a common constituent of the lower member and become abundant near the boundary. An interval of oolitic grainstone, 62 to 64 m above the base of the lower member, is the lowest occurrence of a lithology that typifies the upper member. Dark-gray replacement chert nodules are common throughout (pl. 6).

The lower member of the Wahoo Limestone formed on a predominantly open-marine platform that developed above restricted-platform carbonate deposits of the upper part of the Alapah Limestone (see fig. 9). Muddy and spiculitic limestone in the lower several meters of the Wahoo Limestone formed in partly restricted conditions during the early phase of a major transgression. The upper 25 m of the lower member primarily formed in normal-marine conditions, but common to abundant peloids and minor spicules suggest intermittent restriction; locally abundant ooids

imply proximity to shoals. These grain types indicate the onset of regression.

Just below the Mississippian-Pennsylvanian boundary, at 56 m above the base of the lower member of the Wahoo Limestone, a distinct interval of peloidal-spiculitic wackestone is partly replaced by reddish-brown and gray nodular chert. This chert-bearing interval has variable thickness (<0.5 to 1 m), sharp lower and upper contacts, and appears to have been deposited above an irregular surface with as much as 1 m of relief (fig. 6). The surface has been interpreted to have formed during subaerial exposure (Carlson, 1990; Watts, 1990). The chert-bearing interval overlies a skeletal grainstone that contains definitive Mississippian conodonts within 10 cm of the contact and, in turn, is overlain by a peloidal-skeletal grainstone, the base of which produced the lowest definitive Pennsylvanian conodonts in the study section (fig. 6). The chert-bearing interval was traced 1 km west to Carlson's (1987) section where *Declinognathodus noduliferus japonicus*, an index to the Pennsylvanian, occurs 1.5 m **below** the chert (app. 1, loc. 1B1b), suggesting at least 1.5 m of erosion at the study section.

A comparable chert-rich interval was noted in Lower Pennsylvanian rocks (based on foraminiferan biostratigraphy) in the western Sadlerochit Mountains (Clough and Bakke, 1986; Imm, 1986). Correlation of this interval with the eastern Sadlerochit Mountains, however, has not been verified with conodonts. A chert-rich interval has not been noted in a similar stratigraphic position in sections to the south or east.

The contact between the lower and upper members of the Wahoo Limestone appears planar. Redeposited, latest Mississippian conodonts occur sporadically in the Pennsylvanian part of the lower member and increase in abundance a meter below the contact with the upper member (table 1). The redeposited conodonts indicate intermittent reworking of slightly older deposits of the Wahoo Limestone.

UPPER MEMBER OF THE WAHOO LIMESTONE

The upper member of the Wahoo Limestone is 192 m thick at the study section and contains many shallowing-upward parasequences. These parasequences are superimposed on a major TR sequence.

The lower 24 m of the upper member is dominated by peloidal-bryozoan packstone, dolomitized silty mudstone, and wackestone. Cryptalgal laminites are poorly developed in the study section but are present in nearby exposures. Shallowing-upward parasequences in this interval begin with peloidal-bryozoan packstone (minor grainstone) and pass upward into dolomitized, silty, locally spiculitic, lime mudstone. Detrital quartz is relatively abundant (as much as 40 percent), particularly in dolomitic mudstone. Significantly, quartz sand increases from 3 to 4.5 percent in the upper meter of the lower member and then abruptly rises to

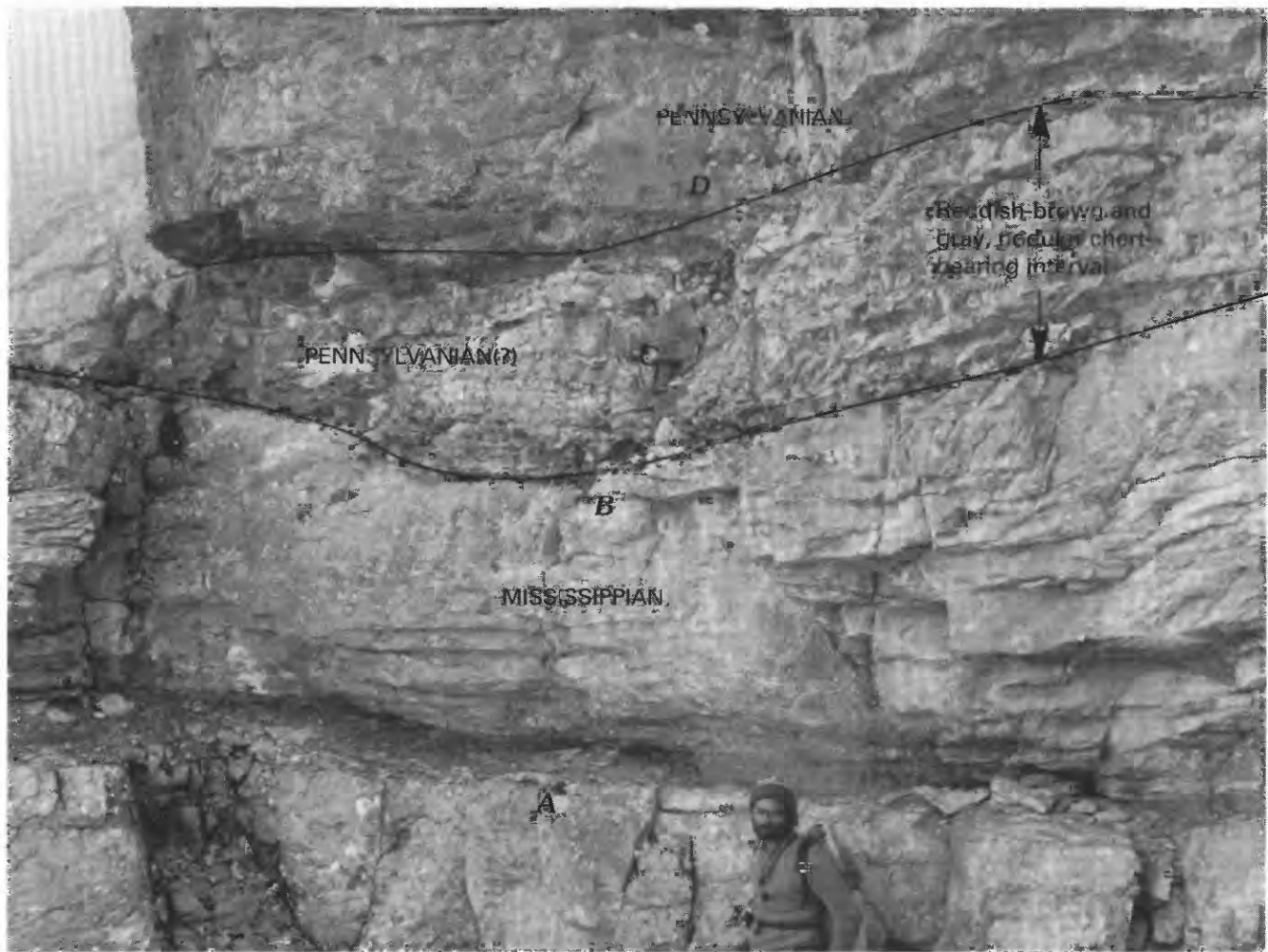


Figure 6. Mississippian-Pennsylvanian boundary beds in upper part of lower member of the Wahoo Limestone at the study section showing the distinct reddish-brown and gray, nodular chert-bearing interval (arrows mark its top and bottom). Thickness of beds shown is approximately 4 m. Conodont samples at locations A–D. Sample A, 53 m above base of the Wahoo (table 1, USGS colln. 30757–PC), contains *Gnathodus girtyi girtyi*, *G. g. simplex*, and forms transitional to *Declinognathodus* spp. as well as *G. bilineatus bilineatus*, *Hindeodus minutus*, *Vogelgnathus postcampbelli*, and *Kladognathus* sp. Sample B, 54.9 m above base of formation (table 1, USGS colln. 31698–PC), contains Mississippian species including *G. g. girtyi*, *Kladognathus* spp., and *Lochriea commutata* as well as subadult Pa elements of *G. g. simplex* transitional to *D. noduliferus japonicus* and abundant *Cavusg-*

nathus? tyttus of Mississippian and Pennsylvanian age. Sample C, 55.5 m above the base and within the cherty interval (table 1, USGS colln. 31699–PC), produced only a few conodonts, chiefly *C. ? tyttus* of Mississippian and Pennsylvanian age. In sample D, 56 m above base of formation, *D. n. japonicus* (pl. 3, figs. 4–8), an index to the Pennsylvanian, occurs with several other species known to range across the Mississippian-Pennsylvanian boundary (table 1, USGS collns. 30758–PC and 31700–PC). Collections 1 km to the west yielded Pennsylvanian conodonts 1.5 m below reddish-brown and gray chert-bearing interval suggesting that the irregular surface at base of chert is a disconformity that probably marks the Mississippian-Pennsylvanian boundary at the study section.

an average of 12 percent in the lower 20 m of the upper member (percent quartz determined from acid-insoluble residues of conodont samples). This sudden increase of terrigenous sediment at and above the lower member-upper member contact suggests considerable regression and some exposure of the Wahoo platform. Indeed, exposure surfaces in the lower part of the upper member and local channeliza-

tion of cryptalgal laminites at the lower member-upper member contact have been described in the eastern Sadlerochit Mountains here and 1 km to the west (Carlson, 1987, 1990; Watts, 1991). In addition, relatively few conodonts and foraminifers are found in this part of the upper member, possibly due to inhospitable environmental conditions. The lower 24 m of the upper member formed on a

predominantly restricted platform during a major regression and contain some of the shallowest water deposits in the Wahoo Limestone (Gruzlovic, 1991).

The succeeding 120 m of the upper member of the Wahoo Limestone are characterized by oolitic grainstones, particularly the upper part of the member (pl. 6). Bioclasts and peloids are common and grapestone lumps, intraclasts, and *Archaeolithophyllum* sp. (algae) are rare to minor in these high-energy grainstones and associated packstones. Oncolites are most common in the lower part of this interval whereas *Donezella* sp. (algae) occur in the upper part, first appearing at 167 m above the base of the Wahoo (P.L. Brenckle, written commun., 1991) suggesting some environmental restriction up section. Shallowing-upward parasequences typically begin with dolomitic bryozoan wackestone and pass upward into dominantly skeletal and oolitic grainstone that may be capped by dolomitized, locally spiculitic, lime mudstone. Repeated intervals of oolitic grainstone represent migration of shoals across the Wahoo platform. Oncoids, peloids, grapestone lumps, and algae indicate that open-platform depositional environments developed shoreward of the shoals. Rare, isolated colonial and solitary corals also occur and are locally associated with spiculitic mudstone and peloids that suggest proximity to partly restricted conditions. The abundant ooid-shoal deposits in the upper part of this interval correspond with the maximum transgression during deposition of the upper member of the Wahoo (Watts, 1990; Gruzlovic, 1991).

The upper 48 m of the upper member of the Wahoo Limestone are chiefly peloidal-oncolitic and bryozoan-pelmatozoan packstone and grainstone (pl. 6). Ooids and superficial ooids occur in the lower part of the member, representing the last ooid-shoal deposits of the Wahoo. Peloidal-spiculitic-oncolitic wackestone and spiculitic mudstone become prevalent approximately 13 m below the top of the formation, marking a shift from primarily open-platform to restricted-platform environments.

Persistent sea-level fluctuations during deposition of the Wahoo Limestone produced a mosaic of shifting environments that controlled biotic distribution. Conodont and foraminiferan biofacies (species associations) reflect these environmental changes. Biofacies, as well as postmortem transport of skeletal remains, controlled the occurrence of biostratigraphically significant species and, ultimately, the biozonation of the Wahoo Limestone.

CONODONT BIOSTRATIGRAPHY OF THE WAHOO LIMESTONE, EASTERN SADLEROCBIT MOUNTAINS

The conodont zonation proposed by Lane and Straka (1974) and subsequently revised by Lane (1977) and Baesemann and Lane (1985) for uppermost Mississippian and

STUDY SECTION				CONODONT ZONATION (Baesemann and Lane, 1985)	
SYSTEM	SERIES	FORMATION/ MEMBER	CONODONT ZONE/ FAUNA		
PENNSYLVANIAN	PERMIAN	ECHOOKA FORMATION			
	LOWER ATOKAN	WAHOO LIMESTONE	(262 m) First appearance of <i>Idiognathodus incurvus?</i> (246 m)	Unzoned	
	UPPER MORROWAN AND (OR) LOWER ATOKAN		<i>Idiognathodus</i> Fauna	<i>Idiognathoides ouachitensis</i>	
				<i>Idiognathoides convexus</i>	
				<i>Idiognathodus klapperi</i>	
				<i>Idiognathodus sinuosus</i>	
	MORROWAN		<i>minutus</i> Fauna	(177 m) First appearance of <i>Pseudostaffella</i> (171 m)	<i>Neognathodus bassleri</i>
				(162 m) lower <i>minutus</i> Fauna	<i>Neognathodus symmetricus</i>
				(84 m) <i>noduliferus - primus</i> Zone	<i>Idiognathoides sinuatus-Rhachistognathus minutus</i>
					<i>Declinognathodus noduliferus-Rhachistognathus primus</i>
	MISSISSIPPIAN		CHESTERIAN (PART)	ALAPAH LIMESTONE (PART)	(56 m) First appearance of <i>G. bulloides</i> (43 m)
(0 m) <i>Upper muricatus</i> Subzone					

Figure 7. Conodont zonation/faunal succession recognized in the Wahoo Limestone at study section compared to the North American middle Carboniferous conodont zonation of Baesemann and Lane (1985). Zonal indicators of Baesemann and Lane not found at study section include *Neognathodus symmetricus*, *N. bassleri*, *Idiognathodus klapperi*, and *Idiognathoides convexus*. *Declinognathodus noduliferus* first appears 13 m above *Globivalvulina bulloides*, the foraminiferan secondary guide to the mid-Carboniferous boundary (Lane and Manger, 1985). See figure 6 and table 1 for detailed information on the Mississippian-Pennsylvanian boundary. *Idiognathodus sinuosus* first appears 6 m above *Pseudostaffella* sp., a foraminiferan guide to the Morrowan-Atokan boundary in the Midcontinent and Cordillera of the conterminous United States (Lane and Manger, 1985; Groves, 1986). The Morrowan-Atokan boundary is poorly constrained by conodonts and foraminifers. The foraminifer *Pseudostaffella* sp. appears well below the lowest definitive Atokan conodont, *Idiognathodus incurvus?* (table 1). *G. Globivalvulina*.

Pennsylvanian (Morrowan) rocks in North America only applies to the conodont succession in the upper part of the Alapah Limestone and the succeeding 84 m of the Wahoo Limestone (fig. 7). The Upper *muricatus* Subzone (uppermost Mississippian), the *noduliferus-primus* Zone (lowermost Pennsylvanian), and the lower part of the succeeding

minutus Fauna (= *sinuatus-minutus* and *symmetricus* Zones of Baesemann and Lane, 1985) are well documented in this part of the section (table 1 and pl. 6). The remaining Pennsylvanian strata, however, could not be precisely dated by using existing conodont zonal schemes (for example, Baesemann and Lane, 1985; Grayson, 1990) because of a persistent, chiefly rhachistognathid biofacies (high-energy, shoal to near-shoal environments) in which most zonal indicators are rare or absent. We have, instead, used a faunal designation for this part of the Wahoo Limestone based on possible local ranges of some rhachistognathids and what is almost certainly a relatively late migration of *Idiognathodus* into northeast Alaska. Some of the rhachistognathids that appear before or originate in the lower 84 m of the Wahoo Limestone disappear before the lowest occurrence of *Idiognathodus* in the northeast Brooks Range; other rhachistognathids persist to the major unconformity that truncates the formation (pl. 6). Rare, sporadic occurrences of generally poorly preserved, nonrhachistognathid species are not originations but are clearly the result of postmortem hydraulic admixture from other biofacies and can be used to roughly tie the northeast Alaskan succession to successions in other parts of North America.

Species diversity is rather low for a section that spans at least 10 million years, from the latest Chesterian to at least early Atokan. Only 24 species, distributed among 14 genera, were identified in 72 productive samples. Further complicating establishment of a reliable conodont succession for part of the Wahoo Limestone is the menace of redeposition. Several samples from the post-Mississippian part of the study section (table 1 and pl. 6), as well as many other spot samples from the uppermost part of the Wahoo Limestone in the northeast Brooks Range, produced redeposited Mississippian and earliest Pennsylvanian conodonts that cast some doubt on the biostratigraphic integrity of species distribution in the upper part of the formation.

The conodont zones of Baesemann and Lane (1985) and the conodont faunal succession established in the Wahoo Limestone and upper part of the Alapah Limestone at the study section and elsewhere in the northeast Brooks Range are described below.

MURICATUS ZONE

The *muricatus* Zone is defined by the first appearance of *Rhachistognathus muricatus* below the occurrence of either *Declinognathodus noduliferus* or *R. primus* (Lane and Straka, 1974; Baesemann and Lane, 1985). Baesemann and Lane (1985) proposed a phylogeny for the rhachistognathids of the middle Carboniferous in which *R. prolixus* is the inferred ancestor. They suggested that *R. prolixus* probably gave rise to *R. muricatus* after the appearance of *Adetognathus unicornis* (= *Cavusgnathus monocerus* [Rexroad and Burton] of Brown and others, 1990) the name

bearer of the preceding conodont zone. Baesemann and Lane (1985) subdivided the *muricatus* Zone into lower and upper subzones. The *muricatus* Zone is the most widely recognized conodont zone in the Chesterian part of the Lisburne Group in the northeast Brooks Range. It is represented by a very thick sequence that may include much of the Alapah Limestone and part of the Wahoo Limestone and is well documented in nine sections between Atigun River gorge and the Clarence River (fig. 1; A.G. Harris and A.P. Krumhardt, unpub. data). At and near the study section, the *muricatus* Zone is at least 155 m thick and ranges from about 24 m above the base of the Alapah Limestone (app. 1, loc. 1A2) to 55.5 m above the base of the Wahoo Limestone (table 1, USGS colln. 30757-PC). It is apparently thickest (250 m) in the Romanzof Mountains (app. 1, locs. 9B1a, b). In the area of the type section of the Wahoo Limestone, the upper 70 m of the Alapah Limestone and lower 140 m of the overlying Wahoo Limestone are within the *muricatus* Zone (app. 1, locs. 4A1a, c).

LOWER MURICATUS SUBZONE

The Lower *muricatus* Subzone is defined by the first appearance of the zonal indicator below the occurrence of *Adetognathus lautus*. This subzone has not yet been identified at the study section or in our other collections from northern Alaska but may be present in the Alapah Limestone. As proposed (Baesemann and Lane, 1985), the subzone can be identified only in closely sampled sections of appropriate shallow-water, relatively normal-marine biofacies. Virtually all common associates of this biofacies in the Lower *muricatus* Subzone, with the possible exception of *Hindeodus cristulus* (Youngquist and Miller), extend or likely extend into the Upper *muricatus* Subzone (table 1; Weibel and Norby, 1992). Thus, the only guide to this zone is the presence of *A. lautus* in definitive pre-Pennsylvanian strata above the occurrence of *Rhachistognathus muricatus* with *H. cristulus*.

UPPER MURICATUS SUBZONE

This subzone is defined by the overlapping ranges of *Rhachistognathus muricatus* and *Adetognathus lautus* below the appearance of *Declinognathodus noduliferus* or *R. primus*. As yet, *R. muricatus* has not been found in the upper 64 m of the Alapah Limestone or the succeeding lower 5 m of the Wahoo Limestone in the eastern Sadlerochit Mountains. Representatives of the species were recovered 6 m above the base of the formation and well below *D. noduliferus* (table 1). *Adetognathus lautus*, although not found in the lower 84 m of the Wahoo Limestone, was recovered from the Alapah Limestone at 72 and 65 m below the base of the Wahoo Limestone at the study section (app. 1, locs. 1A1a, b). Thus, the Upper *muricatus* Subzone is

present at a level considerably below the base of the Wahoo Limestone and is at least 127 m thick (from 72 m below the top of the Alapah Limestone to 56 m above the base of the Wahoo Limestone).

Species that occur within the Upper *muricatus* Subzone in the Alapah and Wahoo Limestones in the study section include, in order of decreasing abundance, *Cavusgnathus unicornis* Youngquist and Miller, *Kladognathus* spp., *Gnathodus girtyi simplex* Dunn, *G. g. girtyi* Hass, *Hindeodus minutus* (Ellison), *Rhachistognathus muricatus* (Dunn), *Vogelgnathus postcampbelli* (Austin and Husri), *C. ? tythius* Brown and Rexroad, *G. bilineatus bilineatus* (Roundy), *Idioproniodus* spp., *Adetognathus lautus* (Gunnell) (see app. 1, locs. 1A1a, b), *Lochriea commutata* (Branson and Mehl), *G. girtyi* subsp. transitional to *Declinognathodus* spp., *C. altus* Harris and Hollingsworth, *R. prolixus* Baesemann and Lane?, and *Gnathodus defectus* Dunn?.

Cavusgnathus monocerus (Rexroad and Burton), a relatively common component of the *R. muricatus* Zone as well as the name bearer of the preceding conodont zone, is notably absent in the Brooks Range.

The Upper *muricatus* Subzone is recognized in the upper part of the Alapah Limestone and lower part of the Wahoo Limestone in six sections (including the study section) between Wahoo Lake and the Clarence River. The subzone is thickest (at least 133 m) at Clarence River and includes at least the upper 53 m of the Alapah Limestone and the lower 80 m of the Wahoo Limestone (app. 1, locs. 10A1a-e) and at least 124.5 m near Wahoo Lake (app. 1, locs. 4A1b, c). The only other species found in the subzone in the northeast Brooks Range, but not in the study section, is *Rhachistognathus websteri* Baesemann and Lane (app. 1, loc. 4A1c).

NODULIFERUS-PRIMUS ZONE

Baesemann and Lane (1985) modified the *primus* Zone of Lane and Straka (1974) to the *noduliferus-primus* Zone, the lower boundary of which marks the base of the Morrowan Series and the Pennsylvanian System. Whereas *Rhachistognathus primus* has not been found outside of North America, *Declinognathodus noduliferus* has a worldwide distribution and has been recommended as the primary micropaleontologic guide for the base of the Pennsylvanian (Lane and Manger, 1985). The *noduliferus-primus* Zone is recognized by the occurrence of either *D. noduliferus* or *R. primus* below the appearance of *R. minutus* or *Idiognathoides sinuatus* Harris and Hollingsworth. The zone was subdivided into lower and upper subzones by Brenckle and others (1977). The lower subzone is characterized by "the overlap in the upper ranges of *Gnathodus girtyi simplex* and *G. cf. G. bollandensis* with the lower ranges of *R. primus* and *D. noduliferus*" (Baesemann and Lane, 1985, p. 100).

We assume that *G. cf. G. bollandensis* of Baesemann and Lane (1985) is *G. bilineatus bollandensis* of other workers or a form close to it. *Gnathodus girtyi simplex* has been reported together with *D. noduliferus* in Nevada (Baesemann and Lane, 1985). In our study section, *G. g. girtyi* and *G. g. simplex* occur relatively consistently in the lower 54.9 m of the Wahoo Limestone, 1.1 m below the first occurrence of *D. noduliferus japonicus* (table 1). Neither subspecies has been recovered from the succeeding 10 m, but 4 and 5 m higher *G. g. girtyi* reappears together with *G. b. bilineatus* and *Kladognathus* spp. as well as other species (table 1). We believe that these typical Mississippian forms are redeposited. Significantly, Carlson (1987) reported channelization at this level about 1 km to the west. It is possible that other Pennsylvanian occurrences of *G. g. girtyi* are also redeposited, as shown for the Granite Mountain, Utah section, by Wardlaw (1984). *Gnathodus bilineatus bollandensis* has not been recognized in the study section and *G. g. simplex* does not occur in the *noduliferus-primus* Zone here. Thus, we cannot recognize the subdivisions of the *noduliferus-primus* Zone at the study section. Elsewhere in the northeast Brooks Range, *G. g. simplex* is a rare, possibly indigenous constituent of the *noduliferus-primus* Zone (app. 1, locs. 5b, 1B1e).

Species that occur in the *noduliferus-primus* Zone in the study section include, in order of decreasing abundance, *Cavusgnathus ? tythius*, *Declinognathodus noduliferus japonicus* (Igo and Koike), *Rhachistognathus muricatus*, *Hindeodus minutus*, *D. n. noduliferus* (Ellison and Graves), *Vogelgnathus postcampbelli*, *Idioproniodus conjunctus* (Gunnell)?, *R. websteri*, and *Gnathodus girtyi* subsp. transitional to *Declinognathodus* spp. *Rhachistognathus primus* has not been identified in this zone in our section but has been found elsewhere in the zone in the northeast Brooks Range (app. 1, loc. 4B). Additional guides for the *noduliferus-primus* Zone in the northeast Brooks Range are *Cavusgnathus ? tythius* and *Vogelgnathus postcampbelli* with or above *D. noduliferus* (table 1). *Cavusgnathus ? tythius* extends to near the top of the zone, is common, and appears to occupy the habitat of *Adetognathus lautus*, which is notably absent in this zone in collections in the northeast Brooks Range; *V. postcampbelli* has a similar range but is rare in the study section. Only 1 km to the west, *V. postcampbelli* is relatively abundant (app. 1, loc. 1B1g). Other species found in the zone in the northeast Brooks Range, but not in the study section, are *G. girtyi simplex* (app. 1, locs. 4B, 4A1d, 5a) and *R. prolixus* (app. 1, loc. 5a).

Beds 56 to 84 m above the base of the Wahoo Limestone in the study section are representative of the *noduliferus-primus* Zone (table 1). The zone is recognized within the lower member of the formation in three other sections, as far west as Wahoo Lake. These are (1) the Sunset Pass section (app. 1, locs. 1B1b-g); (2) the Pogopuk Creek section (app. 1, locs. 5a, b), where the zone is thickest in the northeast Brooks Range (at least 80 m) and where the

highest sample in the zone contains *Gnathodus girtyi simplex* suggesting a level presumably within the lower part of the zone; and (3) in the vicinity of the type section near Wahoo Lake (app. 1, locs. 4A1d, 4B).

MINUTUS FAUNA

Considerable controversy surrounds the time of origin of *Rhachistognathus minutus*. Baesemann and Lane (1985) proposed a phylogeny for rhachistognathids in which *R. minutus* evolved from *R. muricatus* some time after the appearance of *R. primus* and *Declinognathodus noduliferus*. Lane and others (1985b) noted that Higgins (1975) reported *R. minutus* below the first appearance of *D. noduliferus* in the Craven basin, northern England. In order to explain the succession of rhachistognathids in chiefly shallow-water carbonate rocks of North America, a hiatus was inferred in the Craven basin succession encompassing the interval of the North American *unicornis*, *muricatus*, *noduliferus-primus*, and most of the *sinuatus-minutus* Zones (Lane and others, 1985b). However, Riley and others (1987) demonstrated persuasively that *R. minutus* appears substantially later in North America than in northern England. Manger and Sutherland (1992) support the interpretation of Riley and others (1987) in their comprehensive summary of this controversy. We agree that the appearance of *R. minutus* in many areas of North America is a migration event, so that the lower boundary of the *sinuatus-minutus* Zone (based on *R. minutus*) is diachronous from England to North America. *Rhachistognathus minutus* has a very short range in England but is relatively long ranging and widespread in the Cordillera of North America (including Alaska) where it is most abundant in high-energy, shallow-water deposits. According to Baesemann and Lane (1985), *R. minutus* extends into at least the lower Atokan.

We are introducing a *minutus* Fauna to identify the local range of *Rhachistognathus minutus* subsp. below the range of *Idiognathodus* spp. The lower boundary of this fauna undoubtedly varies within the northeast Brooks Range because its distribution is biofacies dependent. The *sinuatus-minutus* Zone of Baesemann and Lane (1985) is not used because *Idiognathoides sinuatus* (as defined by Grayson and others, 1990) was found in only a single sample high in the study section (table 1). Furthermore, the succeeding *symmetricus* Zone (as used by Lane and Straka, 1974) cannot be recognized because of the apparent absence of the zonal indicator in the Brooks Range. In the western Canada sedimentary basin of the Canadian Cordillera, Higgins and others (1991) recognize a *minutus* Zone that includes the *sinuatus-minutus* and *symmetricus* Zones of Baesemann and Lane (1985) because of the absence of *Idiognathoides sinuatus* and *Neognathodus symmetricus* in their sections. The *minutus* Zone of western Canada contains diverse rhachistognathids and is probably equivalent

to the lower part of our *minutus* Fauna. Indeed, we recognize a lower subdivision of the *minutus* Fauna by the overlapping ranges of *R. minutus* subsp. and *R. websteri*. In our section, *R. websteri* ranges slightly higher than *R. muricatus*. Baesemann and Lane (1985) indicate that *R. websteri* does not occur above their *symmetricus* Zone in North America, and they show *R. muricatus* extending into the lower Atokan. According to J.F. Baesemann and H.R. Lane (oral commun., 1992), *R. muricatus* may be absent from the upper Morrowan part of the Wahoo Limestone and is rare in the post-Morrowan part. These late forms of the species are small and atypical of early *R. muricatus*. The only small rhachistognathids from the highest part of the Wahoo Limestone are juveniles of *R. minutus* that occur with adults of *R. minutus* subsp. (table 1, USGS colln. 30800-PC).

In our section, the upper limit of the *minutus* Fauna is defined by the first appearance of *Idiognathodus* sp., 177 m above the base of the Wahoo Limestone (15 m above the disappearance of *Rhachistognathus websteri*; table 1). The upper 15 m of the *minutus* Fauna contains few conodonts; most samples have a few specimens each of *Declinognathodus noduliferus* subsp., *R. minutus* subsp., and *Adetognathus lautus*. These upper 15 m may be equivalent to part of the *Idiognathodus* Fauna. Similarly, many other collections from single-sample localities or partial sections in the northeast Brooks Range contain *R. minutus* subsp. above or with *D. noduliferus* subsp. and (or) *R. primus* and lack *R. muricatus*, *R. websteri*, and idiognathodids. Such collections have been assigned to the *minutus* Fauna although, similar to the upper 15 m of the *minutus* Fauna in the study section, they could be equivalent to the *Idiognathodus* Fauna. For example, about 10 km north of Wahoo Lake, samples from the upper 132 m of the Wahoo Limestone contain *R. minutus* subsp., *R. primus*, *D. n. noduliferus*, adetognathids, and idioprioniodids and are assigned to the *minutus* Fauna (app. 1, locs. 4C1a-c).

In the northeast Brooks Range, the *minutus* Fauna is thickest (93 m) in the eastern Sadlerochit Mountains (table 1) and is at least 70 m thick at Katakaturuk gorge, western Sadlerochit Mountains (app. 1, locs. 2a-g).

The foraminifers *Pseudostaffella* sp. and *Eoschubertella* sp. first appear in the upper part of the *minutus* Fauna at 171 m and 175 m above the base of the Wahoo Limestone, respectively (P.L. Brenckle, written commun., 1991). These species are used to approximate the base of the Atokan in much of North America (Groves, 1986). Their first occurrence in Alaska relative to the Morrowan-Atokan boundary remains uncertain, and conodonts provide no additional control.

LOWER MINUTUS FAUNA

The lower subdivision of the *minutus* Fauna is defined by the local overlapping ranges of *Rhachistognathus*

muricatus, *R. websteri*, and *R. minutus* subsp. below the range of *Idiognathodus* spp. (pl. 6). In the northeast Brooks Range, this faunal interval contains the greatest diversity and abundance of rhachistognathids. Associated conodonts within the lower *minutus* Fauna in the study section include, in order of decreasing abundance, *Rhachistognathus muricatus*, *R. minutus minutus* (Higgins and Bouckaert), *Adetognathus lautus*, *R. m. havlenai* Baesemann and Lane, *R. websteri*, *Declinognathodus noduliferus noduliferus*, *R. m. declinatus* Baesemann and Lane, *A. spathus*, *D. n. japonicus*, *Idioproniodus* spp., *Hindeodus minutus*, *Gnathodus defectus*, and *R. prolixus*?. The interval contains a few specimens of *Kladognathus* spp. in one sample, which we consider redeposited. No additional species have been recognized within the lower *minutus* Fauna in our many collections from the northeast Brooks Range.

Rhachistognathus websteri and *R. muricatus* do not occur above the lower *minutus* Fauna in the study section (table 1). Rhachistognathids generally maintain their dominance higher in the section, but with reduced diversity; *R. m. declinatus* is the most abundant rhachistognathid above the lower *minutus* Fauna. The lower *minutus* Fauna is likely Morrowan in age because the foraminiferan guides to the base of the Atokan occur in the upper part of the *minutus* Fauna. The lower *minutus* Fauna roughly correlates with the *sinuatus-minutus* to *symmetricus* Zones of Baesemann and Lane (1985; fig. 7, this report).

Rhachistognathus minutus appears 84 m above the base of the Wahoo Limestone (14 m above the base of the upper member) and *R. websteri* disappears 78 m higher in the study section (table 1). At Katakturuk River gorge, in the western Sadlerochit Mountains (fig. 2, loc. 2), at least 34.5 m of the Wahoo Limestone contain the lower *minutus* Fauna (app. 1, locs. 2a–d). The fauna is also present in a 43.5-m-thick interval in the lower member of the formation at Pogopuk Creek (app. 1, locs. 5c–e) and in a single sample from the upper member in the Clarence River area (app. 1, loc. 10A1f).

IDIOGNATHODUS FAUNA

This fauna is characterized chiefly by the association of *Idiognathodus* spp., *Rhachistognathus minutus* subsp., and *Adetognathus lautus*; the first appearance of *Idiognathodus* spp. in the Wahoo Limestone marks its lower boundary. The upper boundary cannot be defined biostratigraphically but is placed at the unconformity that separates the Wahoo Limestone from the overlying Echooka Formation (Permian). The lower boundary could be as old as the *sinuosus* Zone (late Morrowan) of Baesemann and Lane (1985) or as young as early Atokan. At least half the idiognathodids in our collections from the northeast Brooks Range cannot be determined to species because of poor preservation. Many of the rocks that produce abundant

Idiognathodus are high-energy oolitic to skeletal grainstones resulting in incomplete and moderately to extremely abraded specimens. Most of the better preserved specimens are assigned to *I. sinuosus* Ellison and Graves following the species concept of Grayson and others (1989; 1990). This species ranges from the base of the *sinuosus* Zone (upper Morrowan) to at least the Upper Pennsylvanian; it ranges from 187 to 243 m above the base of the Wahoo Limestone in our section (table 1) and above the lowest occurrence of *Pseudostaffella* sp. (fig. 7). If the latter approximates the base of the Atokan in Alaska, then the first occurrence of *I. sinuosus* (16 m higher in the study section) is in the early Atokan and considerably later than its debut in the type Morrowan in Arkansas. Two specimens from 246 to 250 m above the base of the Wahoo Limestone are assigned to *I. incurvus* Dunn? sensu Grayson and others (1989) (table 1). *Idiognathodus incurvus* is restricted to the Atokan and lower Desmoinesian (Grayson and others, 1989); therefore, the upper 16 m of the *Idiognathodus* Fauna in the study section is probably no older than Atokan. In addition, *R. minutus* subsp., identified in samples from the uppermost part of the Wahoo Limestone, is not known to extend above the lower Atokan (Baesemann and Lane, 1985). Therefore, the top of the *Idiognathodus* Fauna in our section is considered no younger than early Atokan in age.

Conodonts that occur in the *Idiognathodus* Fauna in the study section include, in order of decreasing abundance, *Rhachistognathus minutus declinatus*, *Declinognathodus noduliferus noduliferus*, *Idiognathodus sinuosus*, *Adetognathus lautus*, *D. n. japonicus*, *R. m. havlenai*, *R. m. minutus*, *A. spathus*, *Idioproniodus* spp., *Hindeodus minutus*, *Idiognathoides sinuatus* (Harris and Hollingsworth), *Idiognathodus incurvus*?, *Diplognathodus?* *ellesmerensis*?, and *Neognathodus?* sp. indet. Taken together, our many collections from the *Idiognathodus* Fauna from elsewhere in the northeast Brooks Range have fewer species than the study section (see app. 1).

The *Idiognathodus* Fauna is widespread in the uppermost part of the Wahoo Limestone across the northeast Brooks Range, from the Philip Smith Mountains to the Yukon (fig. 1). Some of the localities (see app. 1) that produced this fauna include [samples are from the upper 1 m of the Wahoo Limestone, except as noted] (1) northwestern Philip Smith Mountains (locs. 3A, B), (2) 4.5 m below the top of the Wahoo Limestone near its type section, Philip Smith Mountains (loc. 4D), (3) Pogopuk Creek, Franklin Mountains (loc. 5f), (4) central Fourth Range (loc. 7b), (5) central Shublik Mountains (loc. 8), (6) 6-m-thick interval in upper part of the Wahoo Limestone (locs. 2h, i) and the uppermost (loc. 2j) beds, Katakturuk River gorge, western Sadlerochit Mountains, (7) eastern Sadlerochit Mountains (loc. 1C), (8) central Romanzof Mountains (loc. 9A), (9) upper 45 m of the Wahoo Limestone, Clarence River, northern British Mountains, Alaska (locs. 10A1g, h), and (10) near the top of Wahoo Limestone, northern British Moun-

tains, Alaska-Yukon border (loc. 10B; figs. 1, 2). The *Idiog-nathodus* Fauna may extend lower at localities that represent single collections

THE MID-CARBONIFEROUS BOUNDARY—AN APPROXIMATION OF THE MISSISSIPPIAN- PENNSYLVANIAN BOUNDARY

BIOSTRATIGRAPHIC CRITERIA

Three major fossil groups, ammonoids, foraminifers, and conodonts, have been used for zoning the Carboniferous and as guides to the mid-Carboniferous boundary (Sutherland and Manger, 1984b; Manger and Sutherland, 1992). In 1983, the Subcommittee on Carboniferous Stratigraphy (SCCS) approved several recommendations regarding the various biostratigraphic criteria for establishing an international mid-Carboniferous boundary (Lane and Manger, 1985). These include—

- (1) The transition between the *Eumorphoceras* and *Homoceras* ammonoid zones. *Homoceras*, however, is geographically restricted and not useful for global correlations.
- (2) The first appearance of the conodont *Declinognathodus noduliferus*, preferably together with its ancestor *Gnathodus girtyi simplex*.

Secondary guides to the boundary include the first appearance of the conodonts *Adetognathus lautus*, *Rhachistognathus primus*, and *R. minutus* and the foraminifers *Globivalvulina* sp. D of Brenckle (= *G. moderata* = *G. bulloides*; P.L. Brenckle, oral commun., 1991), *Millerella pressa* Thompson, and *M. marblensis* Thompson.

These recommendations are not yet ratified because a stratotype has not been selected. Nevertheless, the recommendations of the SCCS are useful for defining the mid-Carboniferous boundary in marine successions (Lane and others, 1985b; Riley and others, 1987) and are followed here.

The faunal succession across the mid-Carboniferous boundary in North America and elsewhere has been extensively documented (for example, Ziegler and Lane, 1985; Brenckle and Manger, 1990; Sutherland and Manger, 1992). The lithofacies and conodont succession in our section are most like those described from Nevada, Utah, and Montana (Wardlaw, 1984; Baesemann and Lane, 1985; Davis and Webster, 1985; Morrow and Webster, 1991, 1992). These studies, however, indicate significant inconsistencies in conodont distribution and possible misinterpretations of depositional continuity that affect zonal schemes. For example, in the Arrow Canyon section, Nevada, Baesemann and Lane (1985) place the Mississippian-Pennsylvanian boundary at the simultaneous first occurrence of *Declinognathodus noduliferus*, *Rhachistognathus primus*, and *R.*

websteri immediately above beds containing *Adetognathus lautus*, *R. muricatus*, and *Gnathodus girtyi simplex*. *Gnathodus girtyi simplex* occurs in 10 samples taken through a 6-m-thick interval above the boundary (Baesemann and Lane, 1985, fig. 2). Thus, beds representing the Upper *muricatus* Subzone are overlain by beds representing the Lower *noduliferus-primus* Zone. Their lithic column shows a 2-m-thick clastic-rich interval less than 1 m above the boundary that occurs in a limestone. According to field observations made by K.F. Watts in 1989, the systemic boundary lies at a lithic change from crinoidal packstone-grainstone to packstone having a greenish matrix and sand-filled burrows in its uppermost part. The clastic interval less than 1 m above the boundary contains a variety of lithologies including mixed-pebble conglomerate in a carbonate and lesser quartz sand matrix and flat-pebble conglomerate. These features suggest a change in depositional regime, possibly beginning at the boundary but certainly occurring less than 1 m above it. The first appearance of *Declinognathodus* and new species of *Rhachistognathus* may be a migration event related to changing environmental factors associated with the lithic changes. Conodont collections made by B.R. Wardlaw and R.G. Stamm (U.S. Geological Survey, unpub. data), at 0.5-m intervals from 14.5 m below to 2 m above the boundary as designated by Baesemann and Lane (1985) reveal additional problems. In these collections, *R. primus* is limited to one sample 4 m below the only sample containing *D. noduliferus* (taken at the systemic boundary). Thus, in Arrow Canyon, *R. primus* appears before, rather than together with, *D. noduliferus*.

At Granite Mountain, Utah, Morrow and Webster (1992) report the appearance of *Rhachistognathus primus* 9 m below the first *Declinognathodus noduliferus*. They place the Mississippian-Pennsylvanian boundary at the first occurrence of *D. noduliferus* on the basis of comparisons to other localities where *R. primus* occurs below *D. noduliferus*. We agree with Morrow and Webster (1991) that the rarity of *D. noduliferus* and gnathodids at Granite Mountain is biofacies related and that the first appearance of *D. noduliferus* is a migration event. We do not, however, agree with their placement of the *primus* Zone interval in the Mississippian (Morrow and Webster, 1992), as it could just as well be partly or entirely Pennsylvanian in age.

As documented above, our own and published data suggest *Rhachistognathus primus* evolved shortly before *Declinognathodus noduliferus*. *Rhachistognathus primus* is relatively rare in the northeast Brooks Range. Only one collection contains *R. primus* not constrained by *D. noduliferus*; it is assigned to the *noduliferus-primus* Zone (app. 1, loc. 4B).

The ancestry of *Declinognathodus noduliferus*, the micropaleontologic guide to the base of the Pennsylvanian, remains controversial with conflicting evidence indicating ancestry from either *Gnathodus girtyi simplex* or *G. bilineatus*. Grayson and others (1985b), Grayson and others

(1990), and Grayson (1990) consider *G. bilineatus* ancestral to *D. noduliferus* on the basis of apparatus comparisons. Indeed, examination of chiefly Pa elements from a proposed mid-Carboniferous stratotype section in middle Asia strongly supports the *G. bilineatus* ancestry (Nigmatdjanov and Nemirovskaya, 1992a, 1992b; Nemirovskaya and Nigmatdjanov, 1994). Our data, however, are equally convincing for a *G. g. simplex* ancestry (see below). The controversy concerning the ancestry of *D. noduliferus* may be the result of homeomorphy. Pa elements documenting the evolution of *G. bilineatus bollandensis* to *G. postbilineatus* to *D. praenoduliferus* and, finally, to *D. noduliferus noduliferus* (Nigmatdjanov and Nemirovskaya, 1992a; Nemirovskaya and Nigmatdjanov, 1994) are just as convincing as those documenting the evolution of *G. girtyi simplex* to *D. n. japonicus* and (or) *D. n. noduliferus* (Dunn, 1970b; this report). It may be that the Pa elements presently recognized as those of *D. noduliferus* are polyphyletic.

Presently, the leading candidate section for the mid-Carboniferous boundary stratotype is in Arrow Canyon, Nev. (Baesemann and Lane, 1985). The first appearance of *Declinognathodus noduliferus inaequalis*, *D. n. japonicus*, or *D. n. noduliferus* in the section marks the mid-Carboniferous boundary and will be used to mark the base of the Pennsylvanian System.

CONODONT-BASED BOUNDARY IN THE EASTERN SADLEROCHIT MOUNTAINS

Gnathodus girtyi simplex transitional to *Declinognathodus noduliferus japonicus* first appears at 53 m above the base of the Wahoo Limestone (table 1). Additional specimens were found at 54.9 m above the base of the formation, immediately below a reddish-brown and gray chert-bearing peloidal spiculitic wackestone interval (fig. 6). *Declinognathodus noduliferus japonicus* first appears immediately above the chert-bearing interval, at 56 m above the base of the Wahoo Limestone (table 1). The mid-Carboniferous boundary may be no higher than 55 m above the base of the Wahoo Limestone and below the chert-bearing interval at the study section because 1 km to the west (app. 1, locs. 1B1a–g) *D. n. japonicus* is common in a 1.5-m interval below a reddish-brown and gray chert-bearing peloidal spiculitic wackestone. The chert-bearing interval can be traced between the two localities. Collections from within it contain similar conodont faunules (app. 1, loc. 1B1f; table 1, USGS colln. 31699–PC). Its base is a discontinuity and has a relief of at least 1 m. It may be that the 1.5-m interval containing *D. n. japonicus* below the discontinuity to the west was cut out at the study section.

Other, less diagnostic guides to the mid-Carboniferous boundary are either rare or absent in the boundary interval. *Adetognathus lautus* does not occur in this interval for environmental reasons but does occur 121 m below it (app. 1, loc. 1A1b) and 28 m above it (table 1), and *Rhachisto-*

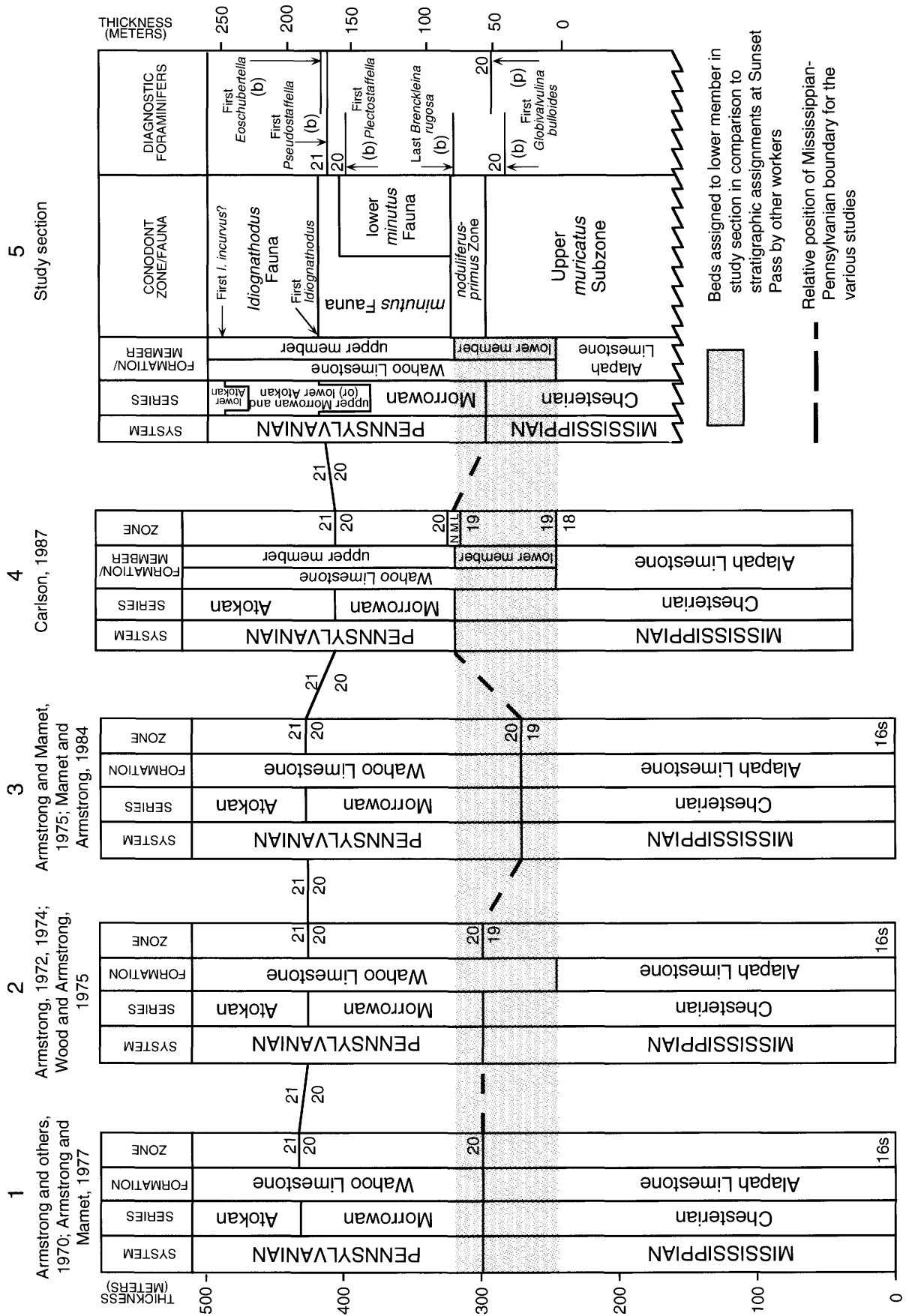
gnathus primus has not been recognized. Additional guides include the last appearance of *Cavusgnathus* spp. at 3 m below the boundary and the continuation of *C. ? tyttus* and *Vogelgnathus postcampbelli* to 20.5 m above the boundary. A few representatives of species believed to be restricted to the Mississippian occur sporadically above the boundary; these are shown in table 1 as redeposited.

FORAMINIFERAN-BASED BOUNDARY IN THE EASTERN SADLEROCHIT MOUNTAINS

The Mamet and Skipp (1970) foraminiferan zonation has been used extensively to correlate the Lisburne Group in northern Alaska (for example, Armstrong and others, 1970, Armstrong and Mamet, 1975, 1977; Dutro, 1987). Mamet and Skipp (1970) and subsequent publications by Mamet and his co-workers place the mid-Carboniferous (Mississippian-Pennsylvanian) boundary coincident with the boundary between foraminiferan Zones 19 and 20. The base of Zone 20 is defined by the appearance of the *Lipinella-Millerella sensu stricto* assemblage (Armstrong and others, 1970). Later, Mamet (1975) amended Zone 20 to include the first diaphanotheca-bearing *Globivalvulina*.

Studies in the eastern Sadlerochit Mountains show inconsistencies in lithostratigraphic and chronostratigraphic boundaries with the foraminiferan zonation (fig. 8). Armstrong's (1972) boundary between the Alapah Limestone

Figure 8. Comparison of lithostratigraphic, biostratigraphic, and time-rock boundaries between study section and the nearby Sunset Pass section analyzed in previous reports. Prior to Carlson (1987; column 4), all interpretations for the Sunset Pass section (fig. 2, loc. 1B) were based on one composite section (Armstrong and others, 1970, sections 68A–4A, 4B); Carlson's section is along the same traverse. The Alapah Limestone-Wahoo Limestone boundary is at the same stratigraphic level in columns 2, 4, and 5 but differs from that in columns 1 and 3. Foraminiferan zonal boundaries in columns 1–4 were determined by B.L. Mamet; foraminiferan data for column 5 are from P.L. Brenckle (b; written commun., 1991) and Sylvie Pinard (p; written commun., 1991). In column 5, the first occurrence of the diagnostic foraminifer that approximates the base of the Pennsylvanian, *Globivalvulina bulloides*, is at least 13 m below the first *Declinognathodus noduliferus*. P.L. Brenckle (written commun., 1991) also noted the last occurrence of *Brenckleina rugosa* well above its known range in the conterminous United States (at or very slightly above the base of the Pennsylvanian). See figure 6 and table 1 for specific information on the Mississippian-Pennsylvanian boundary. The Morrowan-Atokan boundary is poorly constrained by conodonts. *Pseudostaffella* sp. is used to approximate this boundary in the Midcontinent and Cordillera of the conterminous United States (Lane and Manger, 1985; Groves, 1986). In the study section, it appears 14 m above the lowest occurrence of its plectostaffellid ancestor and 75 m below the first definitive Atokan conodont. NML, "No Man's Land" as used by B.L. Mamet in Carlson (1987) and Gruzlovic (1991).



and Wahoo Limestone and his systemic boundary are similar to our results; however, Armstrong and Mamet (1975, 1977) subsequently changed the position of both boundaries (fig. 8). Most of the reports cited in figure 8 use the original section measurements and thin sections that were first used by Armstrong and others (1970). Carlson's (1987) section is at or immediately adjacent to Armstrong's original section but was sampled in more detail. Analysis of Carlson's samples by Mamet (*in* Carlson, 1987) produced results different than those in previous reports. The reasons for changing lithostratigraphic and chronostratigraphic boundaries, however, were not explained. It is likely that biostratigraphic criteria changed, and the formation boundary was moved to approximate the systemic boundary.

In the northeast Brooks Range, Mamet and Armstrong (1984, p. 435) recognized an "...undetermined interval between Zones 19 and 20 [which] represents a very small amount of the sedimentation column but is a stratigraphic break lacking any characteristic paleontologic association." Mamet called this interval "No Man's Land" or NML (*in* Carlson, 1987; *in* Gruzlovic, 1991; this report, fig. 8). According to Mamet (*in* Clough and Bakke, 1986; *in* Carlson, 1987), the NML interval is correlative with the Mississippian-Pennsylvanian regional unconformity of the Midcontinent of North America.

Because foraminifers have been the principal fossils used for correlating the Lisburne Group, we were eager to tie our conodont biostratigraphy to Mamet's foraminiferan zonation. Unfortunately, the original Sunset Pass section was not logistically suitable for conodont sampling, but our study section, 1 km to the east, is close enough to assure lithologic correlation and thus permit comparison of conodont and foraminiferan data. Microlithofacies samples were taken every 2 m or less to coincide with conodont samples and lithologic changes and were also used for foraminiferan analyses. The conodont-based Mississippian-Pennsylvanian boundary generally does not agree with the boundary determined by foraminifers. Figure 8 shows the conodont-based boundary at about the same stratigraphic level as given in columns 1 and 2, but about 25 m higher than in column 3, and about 17 m lower than in column 4 (see fig. 8 caption for details). If the first appearance of the foraminifer *Globivalvulina bulloides* is used as a guide to the base of the Pennsylvanian in our section, the mid-Carboniferous boundary would be 13 m lower than the conodont-based boundary but would still not match other levels determined by Mamet using his own zonation (foraminiferan analysis by P.L. Brenckle, Amoco Production Company, written commun., 1991). Sylvie Pinard (Geological Survey of Canada) analyzed the foraminifers (written commun., 1991) in the same thin sections as those examined by P.L. Brenckle and placed the boundary 9 m higher than his determination (fig. 8; 4 m below the conodont-based boundary).

The last appearance of the foraminifer *Brenckleina rugosa* may be an additional guide to the mid-Carboniferous boundary in the Cordillera of the conterminous United States where the species disappears at, or slightly above, the base of the Pennsylvanian and before the first occurrence of *Globivalvulina* (Brenckle and others, 1982). At the study section (fig. 8), however, *B. rugosa* extends at least 25 m above the first appearance of *D. noduliferus* and 38 m above the first *Globivalvulina* (P.L. Brenckle, written commun., 1991).

It is obvious that taxonomic interpretations, biostratigraphic models, and paleobiogeography, as well as spacing and selection of foraminifer and conodont samples, control boundary placements. As taxonomic interpretations stabilize and global biostratigraphic data increase for both foraminifers and conodonts, correlations should improve the usefulness these groups separately and in concert.

MORROWAN-ATOKAN BOUNDARY

The foraminiferan zonation of Mamet and Skipp (1970) has been used extensively to correlate the Lisburne Group and to approximate the position of the standard North American Midcontinent series boundaries within it. Armstrong and Mamet (1977, p. 18) place the base of the Atokan Series at the boundary between foraminiferan Zones 20 and 21. They define the base of Zone 21 as the "outburst of abundant *Eoschubertella*, *Pseudostaffella*, and *Globivalvulina* of the group *G. bulloides*." Groves (1986) also uses *Eoschubertella* and (or) *Pseudostaffella* to define the base of the Atokan in the southern Midcontinent and Cordillera of the conterminous United States and to approximate this boundary in northeast Alaska. Sutherland and Manger (1984b) recommended that the base of the Atokan Series in the southern Midcontinent be marked by the appearance of the foraminifer *Eoschubertella* spp. and the conodont *Diplognathodus* spp.

Diplognathodus? was found in only one sample in our section (pl. 5, figs. 18, 19; pl. 6; table 1) and is rare in the Lisburne Group in northern Alaska. Moreover, the proposal to use *Diplognathodus* as a guide to the base of the Atokan preceded the recognition of Morrowan diplognathodids (von Bitter and Merrill, 1990). For now, *Diplognathodus*? *orphanus* appears to be the only known diplognathodid restricted to the Atokan. Consequently, other conodonts or groups are needed to identify rocks of Atokan age. Grayson (1990) and Whiteside and Grayson (1990), in their revision of *Idiognathodus sinuosus*, *I. klapperi*, and *I. incurvus*, suggest that the appearance of *I. incurvus* indicates an Atokan or slightly younger Pennsylvanian age in the southern Midcontinent, including the type area of the Atokan. Additionally, *I. incurvus* probably overlaps the upper range of its ancestor *I. klapperi* within the lower Atokan (Grayson and others, 1989). We were unable to confirm the phylogeny

proposed by Grayson and his co-workers. Nearly all of the idiognathodids recovered from our section are either too poorly preserved for specific identification or are representatives of the long-ranging species, *I. sinuosus*. Two specimens of *I. incurvus*? were identified. The first appearance of *I. sinuosus* in the study section is probably unrelated to its origin and could represent any level within the lower part of its stratigraphic range. The occurrence of *I. incurvus*? with *Rhachistognathus minutus* subsp. suggests an age no younger than early Atokan for the uppermost part of the Wahoo Limestone in the study section.

Foraminiferan data suggest that the first appearance of *Idiognathodus sinuosus* in the study section is within the Atokan (figs. 7, 8). The foraminiferan guides to the Atokan, *Pseudostaffella* and *Eoschubertella*, first appear 16 m and 12 m, respectively, below *I. sinuosus* (171 and 175 m above the base of the Wahoo Limestone, P.L. Brenckle, written commun., 1991). Furthermore, *Plectostaffella*, the ancestor of *Pseudostaffella*, first appears 14 m below its descendant (157 m above the base of the Wahoo Limestone) and continues to 183 m above the base of the Wahoo Limestone. *Plectostaffella* is unknown in North America except from northern Alaska (Groves, 1986, 1988). The sudden appearance of its descendant, *Pseudostaffella*, at the base of the Atokan in the North American Midcontinent indicates its migration from the Eurasian-Arctic Faunal Realm to the Midcontinent-Andean Faunal Realm (Groves, 1988). Thus, *Pseudostaffella* probably is not a reliable guide to the base of the Atokan in northern Alaska. The base of the Atokan could lie at some level between the first appearance of *Pseudostaffella* and *I. incurvus*?. Figures 7 and 8 show the relative position of the lower boundary of the Atokan on the basis of conodonts versus foraminifers. A third fossil group may be needed to distinguish evolutionary from migratory patterns in foraminifers and conodonts.

CONODONT BIOFACIES

The distribution of conodonts was chiefly controlled by the physical and chemical characteristics of the water mass and its trophic resources and, on a grander scale, by paleogeography. These factors influence biostratigraphic analyses because most zonation is based on first appearances. Thus, the presence or absence of a species is not only related to evolution but also to a wide range of paleogeographic, paleoenvironmental, and postmortem factors (Merrill and von Bitter, 1976; Rexroad and Horowitz, 1990; Pohler and Barnes, 1990).

Studies that are useful for conodont biofacies analysis of the Wahoo Limestone include Webster (1969), Merrill (1973a), Merrill and Martin (1976), Merrill and von Bitter (1976, 1979, 1984), Driese and others (1984), Davis and Webster (1985), Wilson (1985), Sweet (1988), Rexroad and Horowitz (1990), and Morrow and Webster (1991, 1992).

Of these, Davis and Webster (1985) and Morrow and Webster (1991, 1992) best approximate the age, paleoenvironmental conditions, and species associations found in the Wahoo Limestone. Davis and Webster (1985) proposed four conodont biofacies for middle Carboniferous, shallow-water, carbonate-shelf deposits in central Montana: *Declinognathodus-Idiognathoides*, *Rhachistognathus*, *Adetognathus*, and *Neognathodus* biofacies. Morrow and Webster (1991) recognized only the *Rhachistognathus* and *Adetognathus* biofacies in offshore barrier-shoal and nearshore-lagoon environments through the mid-Carboniferous boundary interval in the Ely Limestone of west-central Utah. All but the *Neognathodus* biofacies have been recognized, with some modifications, in the Wahoo Limestone. According to Davis and Webster (1985), the *Declinognathodus-Idiognathoides* biofacies (= *Idiognathodus-Streptognathodus* biofacies of Merrill, 1973a, and Merrill and von Bitter, 1976, 1979) represents an offshore, shallow, open-marine environment. The *Rhachistognathus* biofacies represents a higher energy regime that is associated with shoals transitional between the open-platform and open-marine environments (see fig. 10C). The *Adetognathus* biofacies (= *Cavusgnathus* biofacies of Merrill and von Bitter, 1976, 1979) occupies the open- to restricted-platform area behind a shoal, an area of variable salinities represented by a variety of lithologies.

Like Morrow and Webster (1991, 1992), we relied on regional stratigraphic relationships, field observations, such as stratigraphic sequence and bedding characteristics, and, most heavily, on microlithofacies to confirm and constrain conodont paleoenvironmental interpretations.

CONODONT BIOFACIES AND ASSOCIATED MICROLITHOFACIES, WAHOO LIMESTONE, EASTERN SADLEROCHIT MOUNTAINS

Conodont biofacies and depositional environments of the Wahoo Limestone in the eastern Sadlerochit Mountains are intermediate between those presented by Davis and Webster (1985) and Morrow and Webster (1991, 1992) for sections in Montana and Utah. *Rhachistognathus* and *Adetognathus*, however, are distributed across a wider range of depositional environments in the Wahoo Limestone. This probably resulted from hydraulic mixing of conodont elements from adjacent environments during periodic high-energy conditions on the Wahoo carbonate platform. The predominance of grainstone (65 percent, including oolitic grainstone) in the Wahoo indicates deposition on the shallow inner part of a carbonate ramp. Lacking reefal barriers, carbonate ramps are particularly susceptible to reworking and redistribution of sediment by waves and storm surges (Oslenger, 1991). Conodont elements in our section are commonly abraded, further evidence of hydraulic transport.

Our data are from 72 samples. Initially, samples were collected at about 5-m intervals. Subsequently, intervals containing important biostratigraphic boundaries and (or) few conodonts were resampled at closer spacing. Because the main focus of this study was biostratigraphic, some lithologies, representing environments unfavorable for conodonts, were avoided. For example, rocks representing restricted-marine and oolitic and oncolitic shoal environments were not sampled initially. After preliminary biostratigraphic analysis, however, even rocks known or inferred to be unfavorable for conodont recovery were collected near lithostratigraphic and biostratigraphic boundaries. None of these samples were devoid of conodonts, but predictably, they produced few if any biostratigraphically significant species and, even worse, too few for biofacies analysis (for example, tables 1 and 2; 62–80.8 m and 167–182 m above the base of the Wahoo Limestone). Consequently, 26 samples could not be used for biofacies analysis. Ten of these contain common to abundant peloids and (or) spicules, and another 12 contain common to abundant ooids, superficial ooids, and (or) oncoids. Five samples that contain common but not abundant ooids, superficial ooids, and (or) oncoids did qualify for biofacies analysis. The positive aspect of these largely negative results is that most of our prejudices about “offensive” rock types were reinforced, but, in a few cases, we learned not to suggest depositional environments using minimal conodont data (see table 2, samples not qualifying for biofacies analysis).

Only generically identifiable conodonts, including all apparatus elements, were used for biofacies analysis. Samples with fewer than 20 elements identifiable to genus and genera represented by less than 5 elements were not used for analysis. *Cavusgnathus? tyttus*, listed separately on table 2, is combined with cavusgnathids in Mississippian collections and adetognathids in Pennsylvanian collections. Following Ziegler and Sandberg (1990), conodont biofacies are designated using the name of one or two generic components that make up about 70 percent of the fauna. If the two most abundant genera do not reach this percentage, the conodont association is, with some exceptions, considered the result of postmortem hydraulic transport, bioturbation, and (or) unfortunate sampling. Although most of the samples analyzed show evidence of some hydraulic transport and mixing, those dominated by one or two genera are interpreted to represent a living association or an association derived from laterally adjacent environments.

For the most part, biofacies are closely related to specific paleoenvironments. In some instances, however, the associated biota and (or) degree of abrasion of conodonts and grain types influenced environmental interpretations (table 2). Biofacies and microlithofacies environmental analyses agree in general but may differ in some details.

Paleoenvironments (fig. 9) were interpreted from regional and local and vertical and lateral stratigraphic relationships, bedding characteristics, sedimentary structures,

carbonate lithology (megascopic and microscopic textural classification of Dunham, 1962), carbonate grain types, and fossil assemblages. The data set for this study is given in tables 1 and 2 and plate 6.

MISSISSIPPIAN PART OF THE WAHOO LIMESTONE

Regional relationships suggest that the Mississippian part of the lower member of the Wahoo Limestone was deposited in a predominantly open-platform to open-marine setting. Three major environments were sampled in this part of the section: (1) near-restricted open platform⁴ to open platform, (2) moderate- to high-energy (above wave base) open marine, and (3) low-energy (below wave base) open marine. The general characteristics and paleogeographic setting of each are given in figure 9.

CAVUSGNATHID BIOFACIES

NEAR-RESTRICTED TO OPEN-PLATFORM ENVIRONMENTS

Six collections from the Mississippian part of the lower member of the Wahoo Limestone represent the cavusgnathid biofacies. The samples are from moderate- to well-sorted bryozoan grainstone, commonly containing fenestrate bryozoans and fewer pelmatozoans. Minor to rare grains include peloids, intraclasts, and bioclasts of algae, foraminifers, brachiopods, gastropods, and trilobites (table 2). Macrofossils, which are typically incomplete, occur as abraded and commonly micritized bioclasts. Beds are generally massive, bioturbated and, where preserved, parallel bedded. Grainstones are better washed and slightly coarser grained than those in the adjacent, lower energy cavusgnathid-kladognathid biofacies. A seventh collection qualified for biofacies analysis (table 1, USGS colln. 31698-PC) but could not be included here because no microlithofacies sample was saved.

Conodonts are rare (<10/kg) to common (10–25/kg) and average 11/kg in this biofacies. Only 43 percent of the conodonts, however, are generically determinate, and rami-form elements are rarely identifiable to genus or even element type reflecting a relatively high-energy regime. Most smaller and lighter elements were probably carried into nearby lower energy regimes.

Cavusgnathus, dominantly *C. unicornis*, makes up 69 to 100 percent, averaging 84 percent, of all conodonts from this biofacies (fig. 10A); *C.? tyttus* makes up less than 4 percent of the cavusgnathids. *Kladognathus* and *Gnathodus* average 9 and 2 percent, respectively, and hindeodids, lochrieids, and rhachistognathids, together, make up less than 5 percent of conodonts from this biofacies. One sample

⁴We use near restricted to indicate proximity to restricted environments such as back shoals and tidal flats (see fig. 9).

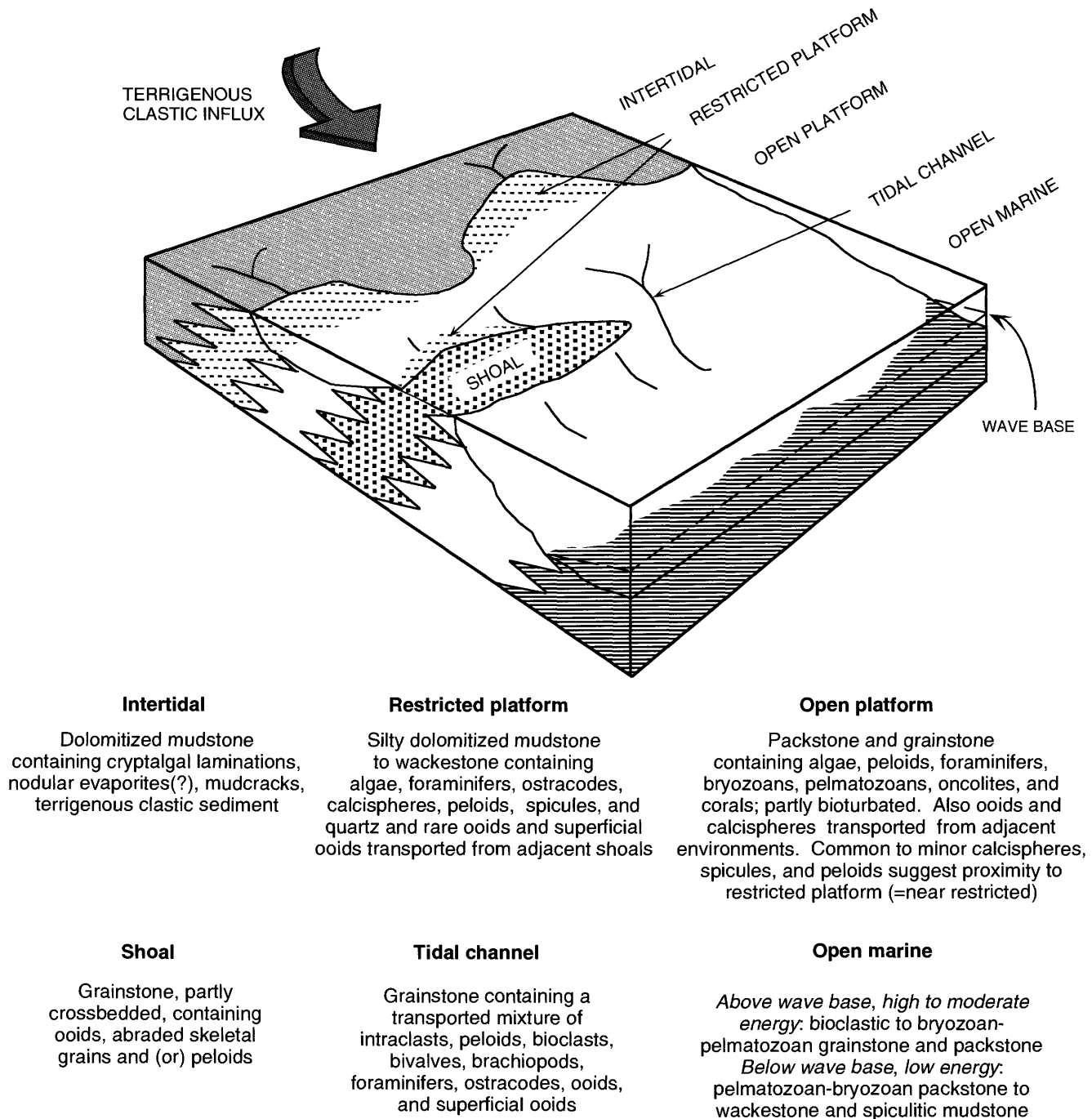
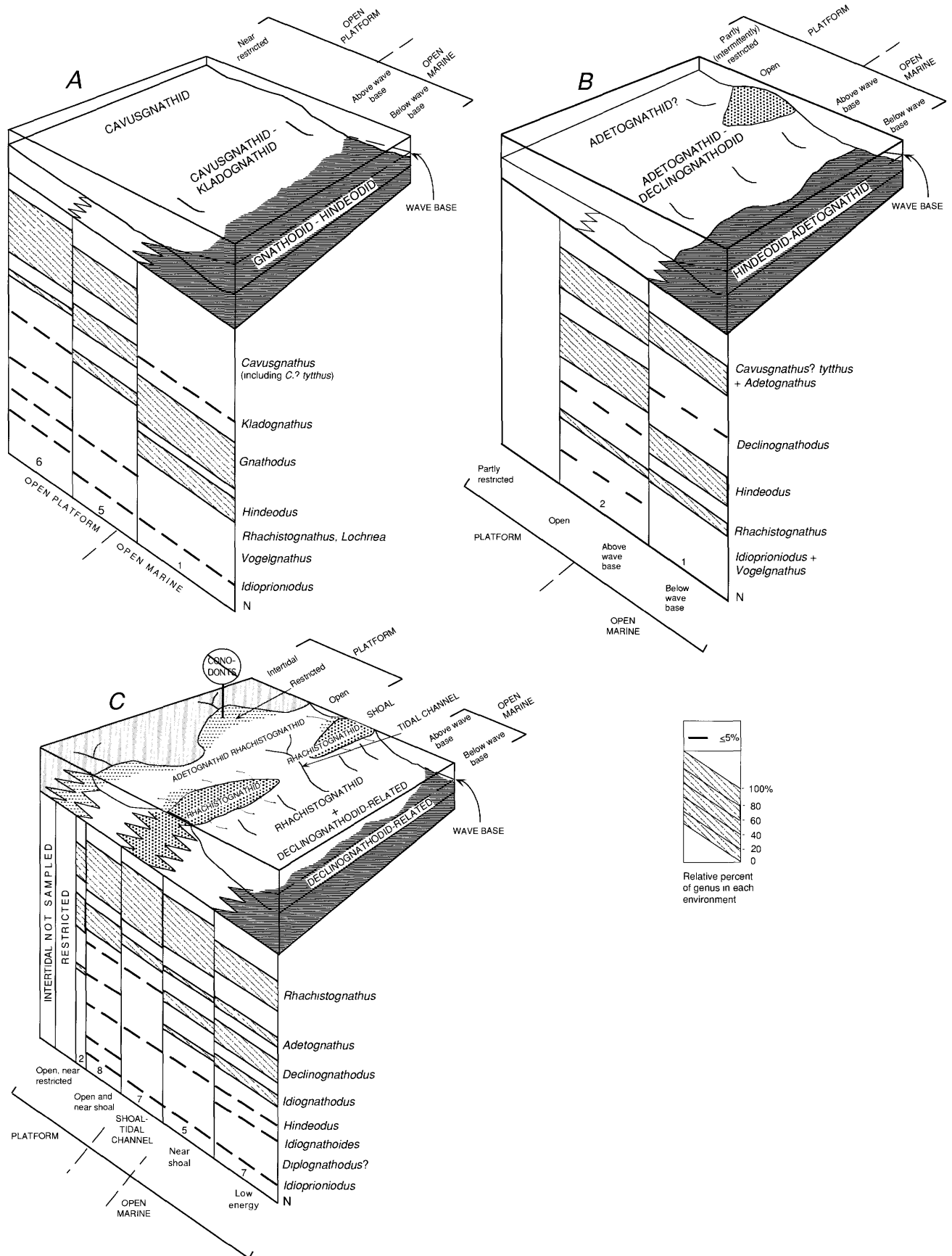


Figure 9. Depositional model for and sediment characteristics of the Wahoo Limestone. Terminology modified from Scoffin (1987) and Wilson (1975). Carbonate platform upon which the Wahoo Limestone was deposited was probably a southward-dipping homoclinal ramp (for example, Read, 1982).

contains 12 percent *Vogelgnathus* and 11 percent *Rhachistognathus* (table 1, 13.2 m above the base of the Wahoo Limestone). The presence of rhachistognathids is compatible with the high-energy, well-sorted microlithofacies interpretation. All other collections from this biofacies are from moderately sorted, lower energy grainstones and lack rhachistognathids.

Cavusgnathus dominated this and, less commonly, adjacent offshore environments. Most other genera were minor components of the population and (or) postmortem additions. We have not been able to identify the ecologic preference of *Vogelgnathus* in the study section because of its scarcity. Elsewhere, this genus is associated with restricted marine environments (Purnell and von Bitter,



← **Figure 10.** Generalized paleogeography, biofacies, and distribution of conodont genera at the study section, Wahoo Limestone, eastern Sadlerochit Mountains (fig. 2, loc. 1A). A, Mississippian part of lower member. B, Pennsylvanian part of lower member. High-energy oolitic shoals that dominate the upper member of the Wahoo had not fully developed during the earliest Pennsylvanian. Instead, lithologies and biofacies of this time period reflect the normal-marine, low- to moderate-energy conditions characteristic of an open-platform environment. C, upper member (Pennsylvanian). N, number of samples.

1992). Most of the rocks in our section that might represent the habitat of *Vogelgnathus* were either not sampled or formed in moderate- to high-energy regimes from which the small skeletal elements of *Vogelgnathus* were probably winnowed. *Vogelgnathus* is abundant in a poorly washed peloidal grainstone containing minor echinoderm debris and spicules.

The conodont species association and taphonomy suggest that the cavusgnathid biofacies occupied a near-restricted to moderate-energy open-platform setting. The predominance of *Cavusgnathus* strongly favors a nearshore, relatively variable environment (Merrill and von Bitter, 1976, 1979). In addition, minor kladognathids and rare hindeodids, gnathodids, and lochrieids support an open-platform rather than an open-marine interpretation.

The Mississippian part of the lower member of the Wahoo Limestone formed during the early phase of a major TR sequence. Initially, circulation and depositional patterns were not well established so that shoal facies and associated environmental partitioning are absent. Without intervening shoals, the depositional setting (open platform versus open marine) of fossiliferous packstones and grainstones cannot be reliably interpreted. Microlithofacies and conodont-based interpretations of the environmental setting for samples from the cavusgnathid biofacies differ. The overwhelming dominance of *Cavusgnathus* and the virtual absence of open-marine conodont species point to an open- to near-restricted platform environment. In contrast, microlithofacies favor a moderate- to high-energy, open-marine or open-platform environment containing a diverse marine fauna. We believe that the conodonts **favor** the open-platform interpretation because of the low-diversity conodont fauna.

CAVUSGNATHID-KLAGDOGNATHID BIOFACIES

OPEN-PLATFORM TO OPEN-MARINE ENVIRONMENT

Five samples from the lower 37 m of the Wahoo Limestone contain subequal mixtures of *Cavusgnathus* and *Kladognathus*. These samples are primarily from moderately sorted grainstone and poorly sorted packstone that contain

bryozoans and pelmatozoans, minor peloids, and rare intraclasts. Other bioclasts include minor algae, brachiopods, sponge spicules, and foraminifers and rare gastropods, calcispheres, and ostracodes (table 2). Grains are moderately abraded and variably micritized. The rocks are less well sorted and slightly finer grained than those of the cavusgnathid biofacies. Massive bedding may have resulted from extensive bioturbation, indicating oxygenated bottom waters and (or) low sedimentation rates. Bryozoans and pelmatozoans probably lived within or near this environment, indicating normal-marine conditions. Mud-rich laminae and burrow fills commonly contain peloids, spicules, and (or) ostracodes that indicate partial derivation from adjacent restricted-platform environments. The three samples in the lower 7 m of the Wahoo Limestone are packstone and grainstone-packstone interbedded with dolomitic spiculitic mudstone; this association of lithologies further indicates proximity to low-energy, intermittently-restricted platform environments.

Samples from the cavusgnathid-kladognathid biofacies contain relatively abundant conodonts (26/kg), but about 60 percent are generically indeterminate fragments, suggesting considerable postmortem movement. Many elements, including ramiforms, are complete; thus, postmortem movement was probably within this and (or) from nearby biofacies.

Four samples from the open-platform to open-marine environment contain 40 to 57 percent *Cavusgnathus unicornis*, 21 to 40 percent *Kladognathus* spp., and 9 to 24 percent *Gnathodus girtyi*. *Rhachistognathus*, chiefly *R. muricatus*, makes up as much as 9 percent of two samples and idiopriodontids, lochrieids, and vogelgnathids together make up less than 5 percent (table 1). *Cavusgnathus* probably lived within this environment, but many elements may have been transported from the adjacent higher energy cavusgnathid biofacies (fig. 10A). The ecologic preference of *Cavusgnathus* for nearshore, relatively variable environments (Merrill and von Bitter, 1976, 1979) is consistent with its distribution in the Wahoo Limestone. *Kladognathus* also lived in this environment, as nearly all the components of its apparatus are present (table 1). The percentage of *Kladognathus* diminishes rapidly shoreward toward the cavusgnathid biofacies (fig. 10A). *Gnathodus girtyi* may have lived in this environment in low to moderate numbers. Most of our specimens, however, are incomplete and poorly preserved suggesting postmortem transport from the more offshore gnathodid-hindeodid biofacies (fig. 10A). During this time interval, *Gnathodus girtyi* subsp. is the dominant gnathodid in collections from normal-marine, relatively shallow-water deposits in the Brooks Range and elsewhere in the Cordillera of the United States (unpub. USGS collections). This species had a variety of ecophenotypes (included here in *G. g. simplex*) that successfully competed in shallow water. Rhachistognathids, in addition to other genera that make up less than 5 percent of the conodonts

from this environment, are considered postmortem admixtures. Rhachistognathids were probably transported from nearby higher energy regimes as representatives of the genus generally occupy near-shoal and shoal-water environments.

A sample from 37 m above the base of the Wahoo Limestone contains conodonts of the *cavusgnathid*-*kladognathid* biofacies and represents an open-marine environment. *Cavusgnathus* and *Kladognathus* are equally abundant (36 percent) and gnathodids make up 27 percent of the faunule, a higher proportion than other samples in this biofacies. On the basis of conodonts, we would interpret the environment as open platform or possibly open marine. Microlithofacies suggest an open-marine to open-platform, moderate-energy environment, but the low diversity and absence of shallow-water grain types favor the open-marine setting. The gnathodids and grain types together with slightly muddier lithologies convinced us to extend the *cavusgnathid*-*kladognathid* biofacies into the open-marine environment.

GNATHODID-HINDEODID BIOFACIES

LOW-ENERGY, OPEN-MARINE ENVIRONMENT

This biofacies is represented by a single sample (53 m above the base of the Wahoo Limestone) that is the youngest Mississippian collection used for analysis from the formation (table 2). It is from a poorly sorted bryozoan packstone containing common pelmatozoan, ramose bryozoan, and brachiopod fragments, minor quartz grains, and rare bioclasts of foraminifers, trilobites, and algae. Microlithofacies indicate a low-energy, open-marine environment (table 2 and fig. 9).

Conodonts are relatively common (15/kg); 50 percent are generically determinate, and many elements are complete. We believe that *Gnathodus* (63 percent) and *Hindeodus* (32 percent) were living in and probably seaward of this environment, as these forms are rare or absent in adjacent shoreward biofacies (fig. 10A). *Hindeodus minutus* (Ellison), the only hindeodid recovered from the Wahoo Limestone, is a long-ranging (latest Chesterian to at least Early Permian), cosmopolitan species that is generally a persistent component in samples from most normal-marine environments. The gnathodids are represented chiefly by *Gnathodus girtyi simplex* and *G. g. girtyi* (in a ratio of 3:2); rare, but biostratigraphically significant *G. girtyi simplex* transitional to *Declinognathodus noduliferus* as well as *G. bilineatus bilineatus* also occur. The species association and the absence of nearshore conodont species confirm the microlithofacies interpretation of a below-wave-base, open-marine depositional setting (fig. 10A). This sample represents maximum transgression during deposition of the lower member of the Wahoo Limestone.

PENNSYLVANIAN PART OF THE WAHOO LIMESTONE

The maximum transgression in the latest Mississippian, represented by open-marine deposits that formed below wave base (fig. 10A), was followed by rapid shallowing in the earliest Pennsylvanian. Locally, uppermost Mississippian deposits were subaerially and (or) subaqueously eroded as evidenced by paleotopography beneath an exposure surface (local preburial banded caliche, Watts, 1990; fig. 6). Rare, redeposited latest Mississippian conodonts occur in basal Pennsylvanian deposits above this unconformity (table 1). Depositional patterns were more complex in the Pennsylvanian than in the Mississippian. The lowest part of the Pennsylvanian, however, is generally similar to the Mississippian because it lacks the ooid grainstones that typify the upper member of the Wahoo Limestone. Additionally, the upper member contains shorter and more numerous shallowing-upward cycles, as reflected in its characteristic ledge-and-slope topography (fig. 5).

The maximum duration of regression in the Wahoo Limestone is apparently not at the Mississippian-Pennsylvanian boundary but is 14 m higher at the contact between the lower and upper members of the formation (fig. 4). Redeposited Mississippian conodonts are more prevalent immediately below the contact, the shallowest water deposits in the Wahoo Limestone occur immediately above the contact, and quartz increases from an average of 3 to at least 12 percent in the lower 20 m of the upper member. All these features indicate significant regression and some exposure and erosion of older deposits. The duration of this possible unconformity is unknown; it may be as short as a diastem or as long as most of the Morrowan.

Six depositional environments—intertidal, restricted platform, open platform, shoal, tidal channel, and open marine—are recognized in the Pennsylvanian part of the Wahoo Limestone. The general characteristics and paleogeographic setting of each are given in figure 9. Rocks representing the intertidal environment were not sampled for conodonts.

Greatly influencing conodont biofacies in the upper member of the Wahoo Limestone is the ooid facies that makes up 20 percent of the member. This high-energy regime caused many conodont elements, particularly rhachistognathids, to be transported beyond their biofacies, substantially disrupting and even obliterating original biofacies patterns. Consequently, some samples representing the same environment, as interpreted from microlithofacies and stratigraphic relationships, produce significantly different relative abundance of conodont genera. Postmortem mixing of conodonts eradicated some biofacies and artificially created others.

LOWER MEMBER OF THE WAHOO LIMESTONE

ADETOGNATHID-RELATED BIOFACIES

NEAR-RESTRICTED TO OPEN-PLATFORM ENVIRONMENT

Two samples from the Pennsylvanian part of the lower member of the Wahoo Limestone represent an adetognathid-declinognathodid biofacies (table 2). The first is from 56 m above the base of the Wahoo Limestone and is an interlaminated peloidal packstone-wackestone and moderately sorted bryozoan-pelmatozoan grainstone; this mixture of lithologies suggests hydraulic mixing of open- and restricted-platform grain types. The second is from 59 m above the base of the Wahoo Limestone and is a moderately sorted bryozoan grainstone-packstone containing common bioclasts of brachiopods and pelmatozoans and rare algae, foraminifers, trilobites, and peloids. The microlithofacies suggest a moderate-energy, open-marine setting.

Conodonts are relatively common in the adetognathid-declinognathodid biofacies (13/kg); 50 percent are generically indeterminate indicating considerable postmortem transport. Adetognathids and *Cavusgnathus? tythius*, together, account for 35 to 58 percent of the conodonts in this biofacies. Adetognathids are a long-ranging (latest Chesterian to Early Permian), relatively shallow-water, eurytopic group that is a common to abundant component of all our Pennsylvanian faunas. The group was competitively successful in partly restricted and (or) variable environments. *Cavusgnathus? tythius* is relatively abundant (22–35 percent) in the adetognathid-declinognathodid biofacies. It is a relatively rare, short-ranging, latest Mississippian and very earliest Pennsylvanian species in the northeast Brooks Range. Consequently, it is restricted to the lower 20.5 m of the Pennsylvanian part of our section. The species is known only from the northeast Brooks Range, western Utah, and its type area in the Illinois basin. It appears to extend from nearshore, possibly intermittently restricted environments that typify the inner margins of intracratonic basins to the shallower part of the open-platform environment. Its presence in open-marine environments may be chiefly a consequence of postmortem hydraulic transport (fig. 10B). In the adetognathid-declinognathodid biofacies, it occurs with *Declinognathodus noduliferus japonicus*. *Declinognathodus noduliferus* is a cosmopolitan species that has a variety of ecophenotypes. We assume that the most nodose form (*D. n. japonicus*) occupied shallower and more variable environments than the more delicately ornamented *D. n. inaequalis*. Indeed, *D. n. japonicus* makes up about 90 percent of the declinognathodids in this relatively shallow-water biofacies.

Rhachistognathids are few in the Pennsylvanian part of the lower member of the Wahoo Limestone because their principal habitat, the shoal-water environment, was rare (fig. 10B). *Rhachistognathus muricatus*, virtually the only rhachistognathid in this part of the Wahoo Limestone,

makes up 8 to 21 percent of the conodont assemblage in the two samples from the adetognathid-declinognathodid biofacies. This species is morphologically variable, a characteristic of conodonts that are successful in a variety of shallow-water environments.

LOW-ENERGY, OPEN-MARINE ENVIRONMENT

A single sample of bryozoan packstone containing common pelmatozoans, minor brachiopods and bivalves, and rare bioclasts of foraminifers, gastropods, sponge spicules, and trilobites produced conodonts of the hindeodid-adetognathid biofacies (tables 1, 2; 69 m above the base of the Wahoo Limestone). The microlithofacies indicates a low-energy open-marine environment. Although the sample qualifies for biofacies analysis, the species association suggests a mixed assemblage. It is likely that *Hindeodus minutus* occupied this environment as all elements of its apparatus are present. This species is long ranging and consistently appears in rocks representing the relatively deeper depositional settings of the Wahoo Limestone (figs. 10A, B). This biofacies may represent the outer limit of the *Cavusgnathus? tythius* and adetognathid habitats. More likely, these forms are hydraulic admixtures. In addition, rhachistognathids (18 percent) were probably carried here from their shallow-water high-energy habitat.

UPPER MEMBER OF THE WAHOO LIMESTONE

ADETOGNATHID-RHACHISTOGNATHID BIOFACIES

RESTRICTED TO NEAR OPEN-PLATFORM ENVIRONMENT

Restricted platform conditions were prominent near the base and top of the upper member of the Wahoo Limestone when shoals had migrated farther south. Six samples from the upper member were collected from restricted- to near open-platform environments as determined by field observations and microlithofacies (table 2).

Only two samples from the least restricted part of this environment qualified for biofacies analysis. These produced nearly equal numbers of adetognathids and rhachistognathids. One (246 m above the base of the Wahoo Limestone) is a peloidal grainstone containing common quartz and minor bioclasts of pelmatozoans, brachiopods, foraminifers, sponge spicules, ostracodes, and calcispheres. The other, at 261.5 m, is spiculitic mudstone containing common peloids, oncoids, and a variety of bioclasts. Conodonts in these collections represent either the edge of the rhachistognathid-adetognathid biofacies or, more likely, storm-tossed skeletons, stranded voyagers, or fecal droppings.

Four samples from the restricted platform did not qualify for biofacies analysis; their microlithofacies are listed in table 2. The conodonts that occur in these samples were

probably derived from the adjacent open-platform environment that hosted the rhachistognathid-adetognathid biofacies (fig. 10C).

OPEN-PLATFORM TO NEAR-SHOAL OPEN-PLATFORM ENVIRONMENTS

Five samples from the adetognathid-rhachistognathid biofacies occur in a variety of open-platform subenvironments (table 2; 84, 118, 157, 203, 241 m above the base of the Wahoo Limestone). These are variously sorted grainstones and one moderately sorted grainstone-packstone. These rocks contain locally abundant bryozoans or pelmatozoans, as well as a variety of bioclasts such as brachiopods, gastropods, and algae. Peloids, ooids, superficial ooids, oncoids, and intraclasts are common in several samples and grains are commonly micritized (table 2). *Donezella* algae are common to minor in two samples.

Conodonts are rare (6/kg) in these samples. About 50 percent are generically determinate, most are incomplete Pa elements, and some are abraded. Many, particularly the rhachistognathids, were probably transported from the adjacent, higher energy, shoal-water environment. *Adetognathus* forms 40 to 54 percent of the assemblage in open-platform settings and shoal aprons. It probably lived in these settings as its relative abundance generally decreases seaward (fig. 10C). Although rhachistognathids make up about half the conodonts in open-platform to near-shoal deposits, they become even more abundant shoalward. We cannot distinguish postmortem admixtures from in situ specimens but suspect that a high percentage represent the former. Collections from this biofacies are remarkably free of other genera. This may be the natural species association or an artifice of winnowing and breakage. Both the microlithofacies and the low diversity of conodonts favor an open-platform to near-shoal interpretation.

TIDAL-CHANNEL(?) ENVIRONMENT

One sample of very well sorted grainstone containing common highly abraded bioclasts of foraminifers, bryozoans, and ostracodes and minor peloids, quartz, and other bioclasts including algae suggests a high-energy, open-platform to open-marine setting, possibly a tidal channel (table 2; 113 m above the base of the Wahoo Limestone). It produced 66 and 31 percent rhachistognathids and adetognathids, respectively. The abundance of rhachistognathids suggests a high-energy regime, either a shoal or tidal-channel setting. The species association favors a tidal-channel or near-shoal open-platform environment because adetognathids are abundant and other conodonts are rare. In combination, biofacies and microlithofacies data favor a tidal-channel setting. This sample is plotted in the

rhachistognathid-dominated shoal or tidal channel environment on figure 10C.

RHACHISTOGNATHID BIOFACIES

Rhachistognathids are the most abundant conodonts in a variety of high-energy environments including shoal and shoal aprons in open-platform and open-marine settings. The association of rhachistognathids and lesser adetognathids suggests a near-shoal, open-platform setting, particularly if the adetognathids are relatively intact. In shoal to tidal-channel environments, the number of rhachistognathids is generally much greater in the adjacent shoal aprons (table 2). If typically open-marine forms, such as declinognathodids or idiognathodids, occur with abundant rhachistognathids and are nearly as common as adetognathids, we favor a near-shoal, open-marine setting.

NEAR-SHOAL, OPEN-PLATFORM ENVIRONMENT

Three samples (table 2; 95, 107, and 257.5 m above the base of the Wahoo Limestone) from the rhachistognathid biofacies referred to this environment contain adetognathids as virtually the only other conodonts. Poorly to well-sorted grainstone-packstone to grainstone contain a variety of common to minor bioclasts (bryozoans, pelmatozoans, foraminifers, oncoids, and algae) and ooids, superficial ooids, peloids, and intraclasts. Conodonts are relatively common (12/kg); 73 percent are identifiable to genus. The abundant rhachistognathids (71–80 percent) indicate a relatively high-energy shoal to near-shoal environment. The virtual absence of conodonts other than adetognathids (20–29 percent) favors a back-shoal setting. Environmental interpretations, based on microlithofacies, generally match the conodont-based interpretations. These three samples are plotted with the adetognathid-rhachistognathid open-platform to near-shoal biofacies on figure 10C.

SHOAL OR TIDAL-CHANNEL ENVIRONMENTS

High-energy shoal or tidal-channel environments include oolitic-rich and skeletal-rich grainstones. Although no tidal channels were distinguished in the field, some conodont and microlithofacies samples produce a well-sorted mixture of grains derived from open-platform, open-marine, and shoal environments that are compatible with a tidal-channel setting.

Five samples qualifying for biofacies analysis are from massive-bedded, very well to well-sorted grainstone containing mixtures of common to minor bioclasts (foraminifers, bryozoans, pelmatozoans, algae, brachiopods, and bivalves), ooids, superficial ooids, peloids, intraclasts, and

quartz (table 2). Conodonts are common (21/kg) and remarkably well preserved; 67 percent are generically determinate suggesting the conodonts lived in and (or) adjacent to shoal and tidal-channel environments.

Rhachistognathids overwhelmingly dominate the shoal and tidal-channel environments, making up 73 to 90 percent of the collections. In the upper member of the Wahoo Limestone, this group is probably as diverse as in any other succession thus far described (for example, Baesemann and Lane, 1985). Specimens are abundant and extremely robust. If *Rhachistognathus minutus* had been first described from the Wahoo, its trivial name would have been *gigantus*. The rhachistognathids include, in order of decreasing abundance, *R. muricatus*, *R. minutus* subsp., and *R. websteri*. The two lowest samples are dominated by *R. muricatus*, the next higher two by *R. websteri*, and the stratigraphically highest by *R. minutus* subsp. Species of *Rhachistognathus* probably occupied different areas of the shoal and tidal-channel environments. The replacement of *R. muricatus* by *R. websteri* and subsequent replacement of *R. websteri* by *R. minutus* subsp. generally parallel a major transgression and the concomitant expansion of shoal facies in the upper member of the Wahoo Limestone. The same species succession is found at similar stratigraphic levels in the near-shoal open-platform environment (see tables 1 and 2). Morphologically, *R. muricatus* and *R. websteri* are more variable than *R. minutus* subsp., likely reflecting their adaptation to variable environments. *Rhachistognathus minutus* subsp. first appears in the study section 14 m above the base of the upper member and eventually replaces other rhachistognathids as the dominant species in environments favorable for the genus. The more uniform and symmetrical morphology of *R. minutus* subsp. suggests its adaptation to more uniform, normal-marine environments. Indeed, *R. minutus* subsp. is the dominant rhachistognathid in seaward settings.

Adetognathids, the only other group common to the shoal and tidal-channel environments, make up 10 to 27 percent of the collections. Their relative abundance does not appear to correlate well with any particular species of *Rhachistognathus*. The adetognathids are probably migrants and (or) hydraulic admixtures from the open platform. Virtually no other conodonts occur in this biofacies in these environments (table 1).

NEAR-SHOAL, OPEN-MARINE ENVIRONMENT

Three samples from the rhachistognathid biofacies are attributed to this environment (table 2). One sample (133.5 m above the base of the Wahoo Limestone) is from moderately sorted, bryozoan grainstone containing common pelmatozoans and a variety of minor bioclasts, peloids, intraclasts, and quartz. Conodonts are abundant (34/kg); 62 percent are generically determinate. They include

rhachistognathids (77 percent), adetognathids (14 percent), and declinognathodids (9 percent). The rhachistognathids indicate proximity to a high-energy environment, and the declinognathodids suggest a position seaward of a shoal or tidal channel. Microlithofacies also suggest a near-shoal, open-marine setting, but of moderate energy (table 2). An open-marine shoal apron seems appropriate for a faunule dominated by cosmopolitan *Rhachistognathus minutus* subsp. The second sample (at 232 m) is a well-sorted bryozoan grainstone containing common pelmatozoans and minor bioclasts of gastropods, oncoids, foraminifers, algae, bivalves, and brachiopods. Conodonts are relatively common (11/kg), and 43 percent are determinable to genus. These include rhachistognathids (54 percent), idiognathodids (23 percent), adetognathids (12 percent), and declinognathodids (10 percent). For convenience, this sample is included in the rhachistognathid biofacies even though rhachistognathids make up less than 70 percent of the faunule. Rhachistognathids indicate proximity to a high-energy environment. The declinognathodids and idiognathodids suggest open-marine conditions, and the adetognathids, in particular *A. spathus*, may indicate proximity to an open-platform high-energy regime. Taken together, this mix favors a near-shoal, open-marine setting, assuming some of the adetognathids are postmortem admixtures. Alternatively, declinognathodids may have been carried over the shoals and into the open platform. Microlithofacies support either interpretation. In the overall TR sequence of the upper member of the Wahoo Limestone, both samples occur at the transition from open-platform to shoal conditions, thus possibly favoring an open-platform interpretation. The high percentage of declinognathodids and idiognathodids influenced the choice of an open-marine near-shoal depositional environment.

A third collection, (187 m above the base of the Wahoo Limestone) contains the greatest number of *Rhachistognathus minutus declinatus* in our sample set and is questionably included in this environment. It is the most productive sample (51/kg) and yields 62 percent generically determinate conodonts. No other rhachistognathids occur in this sample; other conodonts include 10 percent declinognathodids and 3 percent each of idiognathodids and adetognathids. The association suggests an open-marine shoal apron to near-shoal environment. The collection is from a moderately sorted bryozoan grainstone interbedded with fine-grained foraminiferan packstone that could have formed in open-platform and (or) open-marine environments. Perhaps *R. m. declinatus* occupied the open-marine shoal apron. The unusual species association may have resulted from sampling two lithologies with bryozoan grainstone producing rhachistognathids and adetognathids and the deeper(?) water foraminiferan packstone supplying idiognathodids and declinognathodids.

DECLINOGNATHODID-RELATED BIOFACIES

NEAR-SHOAL, OPEN-MARINE ENVIRONMENT

Two samples of moderately sorted bryozoan grainstone to packstone containing common pelmatozoans and minor brachiopod bioclasts and ooids produced a declinognathodid and declinognathodid-idiognathodid biofacies (table 2; 197.5 and 207 m above the base of the Wahoo Limestone). Conodonts are rare (6/kg); only 28 percent are generically determinate suggesting an abundant influx of fragments from high-energy environments. *Declinognathodus noduliferus*, chiefly *D. n. noduliferus*, is most abundant (62 percent), followed by idiognathodids (21 percent) and *Rhachistognathus minutus declinatus* (9 percent). The species association and microlithofacies suggest an open-marine, near-shoal depositional environment. Both samples are from strata that represent the maximum transgression during deposition of the upper part of the Wahoo Limestone.

One sample (table 2; 177 m above the base of the Wahoo Limestone) representing a declinognathodid-rhachistognathid biofacies is from a poorly sorted grainstone that contains a variety of bioclasts (for example, algae, foraminifers, bryozoans, and oncoids) and peloids, ooids, superficial ooids, and intraclasts. Conodonts are rare (7/kg); 50 percent are generically determinate. Subequal numbers of *Declinognathodus noduliferus noduliferus* and *Rhachistognathus minutus* (chiefly *R. m. declinatus*) suggest a near-shoal, open-marine setting. The bioclasts and lithoclasts are a mix of open-platform (particularly several types of algae), shoal, and open-marine forms that might represent a tidal-channel in proximity to ooid shoals. The conodonts do not argue against this interpretation. This sample has been included in the shoal to tidal-channel environment on figure 10C.

LOW-ENERGY, OPEN-PLATFORM AND (OR)
OPEN-MARINE ENVIRONMENT

Seven samples produced declinognathodids with and without other associated open-marine and shallow-water genera (table 2). Three samples (table 2; 152, 178, and 250 m above the base of the Wahoo Limestone) indicate that the low-energy, open-marine environment supported only low numbers of declinognathodids (3/kg). The samples, from lowest to highest, are lime mudstone, poorly sorted packstone containing common bioclasts of bryozoans and pelmatozoans, and a dolomitized mudstone to wackestone. Microlithofacies and conodont biofacies both indicate an open-marine depositional environment.

Only two samples from the declinognathodid-related biofacies produced *Declinognathodus noduliferus* subspp. together with *Idiognathodus sinuosus* (table 2; 217.5 and 237 m above the base of the Wahoo Limestone). Both are

poorly sorted packstone containing common bioclasts of bryozoans, pelmatozoans, and brachiopods and minor algae. Conodonts are rare to common (8–17/kg), and only 40 percent are generically determinate. The conodont species associations indicate a low-energy, open-marine environment; microlithofacies indicate the same environment for one sample (at 217.5 m) and an open-platform to open-marine environment for the other sample.

Microlithofacies and conodont biofacies of the final two samples indicate a low-energy, open-platform or open-marine depositional environment (table 2; 142 and 162 m above the base of the Wahoo Limestone). These are included in the low-energy open-marine environment on figure 10C. The lower sample is dolomitized packstone that contains common bryozoans and minor quartz and bioclasts of brachiopods and pelmatozoans. These constituents indicate a low-energy open-platform or open-marine environment. The conodont biofacies is equally ambiguous. Rhachistognathids (47 percent) suggest a relatively high-energy near-shoal or shoal setting; adetognathids (31 percent) suggest proximity to a back-shoal area, but declinognathodids (22 percent) favor a more open-marine setting. The sample could represent postmortem seaward transport of adetognathids and probably rhachistognathids into an open-marine habitat that contained low numbers of declinognathodids. Alternatively, the declinognathodids could have been transported to the open platform. The higher sample is a dolomitized packstone-wackestone containing some grains possibly derived from the open platform (minor peloids and quartz and rare ooids, spicules, and ostracodes). The conodonts are a mix of platform, shoal, and open-marine forms (29 percent adetognathids, 40 percent rhachistognathids, and 27 percent declinognathodids).

BIOFACIES SUMMARY

The Wahoo Limestone formed in chiefly open-platform, near-shoal, and open-marine environments on the shallow, inner part of a high-energy carbonate ramp. In the uppermost Mississippian and lowermost Pennsylvanian part of the Wahoo Limestone, shoal facies were uncommon so that open-platform and open-marine microlithofacies and conodont biofacies were not clearly separated. Grain types and, to a lesser extent, conodonts were hydraulically spread beyond their original settings making some environmental interpretations equivocal. The use of conodont biofacies and microfacies in concert clarifies some of these environmental ambiguities. In the upper member of the Wahoo Limestone, extensive ooid and skeletal shoal tracts separated open-marine and open-platform environments producing more distinct biofacies and diagnostic microlithofacies. Rhachistognathids thrived in and adjacent to the shoal facies. After death, many of their skeletal elements remained in place, however, a substantial number were

washed into surrounding environments, masking original species associations (see table 2). Similarly, mixing of carbonate grains obscures microlithofacies interpretations. The vertical succession of conodont biofacies substantiates our microlithofacies interpretations that indicate the upper part of the Wahoo Limestone formed in a TR sequence passing from restricted platform to shoals and, finally, back to restricted platform. Additional studies are needed to further integrate conodont biofacies and microlithofacies analyses.

CONODONT PRESERVATION AND CAI VALUES

Epstein and others (1977) and Rejebian and others (1987) demonstrated in controlled laboratory experiments that color alteration in conodonts is time and temperature dependent. These color changes were assigned color alteration indices (CAI) from 1 to 8. Conodonts visibly change from pale yellow to brown and black (CAIs 1 to 5) from 50° to 300°C as a result of carbonization of the trace amounts of organic matter sealed within a conodont element. Conodonts change from black to gray, opaque white, and finally crystal clear (CAIs 5 to 8) from 300° to >600°C as a result of loss of carbon and water of crystallization and recrystallization.

Conodonts altered during burial metamorphism have consistent CAI values, locally and regionally, that reflect depth and duration of burial; textural alteration related to burial thermal regimes does not generally begin until a CAI of 4.5 or greater. In contrast, conodonts recovered from contact-metamorphosed or hydrothermally altered rocks have a range of CAI values locally within an area and even within a single sample; these can be texturally unaltered to corroded and may be fractured or deformed. If a range of CAI values occurs in a small area, the minimum value is used to estimate the regional background (burial metamorphic) temperature (Rejebian and others, 1987). Significantly, CAI values of 6 and 7 can also be produced by relatively low-temperature saline solutions. These solutions corrode conodonts and oxidize their organic matter thereby producing CAI values of 6 and 7 that are unrelated to the thermal regimes that can also produce these values during burial and contact metamorphism (Rejebian and others, 1987; Harris and others, 1990). Characteristically, conodonts from hydrothermally altered rocks tend to have low to medium CAI values mixed with values of 6 and 7; CAI values of 5, 5.5, and 8 are generally absent.

CAI values in Ordovician through Permian rocks in the Sadlerochit Mountains range chiefly from 3 to 4 (Johnson and others, 1992) suggesting that regional burial temperatures reached at least 150° to 200°C. None of the samples reported by them have CAI values greater than 4.5. Nine samples from a 102-m-thick section in the upper part of the Wahoo Limestone at Katakaturuk River gorge (fig. 2,

loc. 2), about 40 km west of the study section, produced conodonts having consistent CAI values of 3 to 3.5 (app. 1, locs. 2a–j).

In the study section, 71 of 73 samples could be analyzed for CAI; two samples contain conodonts that were too few and (or) small for CAI analysis (table 1). CAI values of 3 to 4.5 and 6 were determined; no CAI values of 5 were observed. Most samples (96 percent) contain conodonts of CAI 4, but half of these have a mixture of CAI values (chiefly 4 and 6, rarely 3, and very rarely 3.5 and 4.5). In addition, most conodonts have a sugary and (or) corroded texture (many are coated with dolomite crystals; pl. 5, figs. 18, 19). The range of CAI values and textures suggest hydrothermal alteration of the Wahoo Limestone. A section 1 km west of the study section (fig. 2, loc. 1B1b–e), produced CAIs of 4 and 6 in four samples taken immediately above the Mississippian-Pennsylvanian boundary.

What caused the anomalously “high” CAI 6 values in the study area? Nearly 50 percent of the samples produced some conodonts having a CAI of 6. About 60 percent of the anomalous samples are from grainstone or packstone-grainstone and another 30 percent are from a variety of dolomitized carbonate rocks. These data suggest positive correlation between anomalous CAI and rock porosity and permeability. However, not all grainstones or dolomitized carbonate rocks produced conodonts having anomalous CAIs. Some of the variability in CAI values could be related to occlusion of porosity and permeability by cements that formed prior to deposition of the Permian Echooka Formation (Watts, 1991). To date, the carbonate-cement stratigraphy of the study section has not been analyzed. Carlson (1990) and Watts (1991), however, partly analyzed the carbonate-cement stratigraphy of a section 3 km to the southwest (fig. 2, loc. 1C) and found that most of the cements in the Wahoo Limestone formed prior to deposition of the Echooka Formation. But, post-Permian cements do form 20 to 80 percent of the cement in the lowermost 35 m of the Wahoo Limestone. Some of this porosity may have still been open for fluid migration during orogenesis. The anomalous CAI values, at least in the lower member at the study section, may have formed prior to or concurrently with these late-stage cements, but other intervals of anomalous CAIs may be related to still other factors. For example, fracture porosity (related to Late Cretaceous to Holocene regional orogenesis; Wallace and Hanks, 1990) undoubtedly influenced hydrothermal circulation patterns.

Two intervals in our section lack conodonts having anomalous CAIs: (1) an interval from 69 to 97 m above the base of the Wahoo Limestone that approximates the quartz-rich lower part of the upper member of the formation and (2) a 10-m-thick interval at the top of the upper member containing a higher than average percentage of undolomitized spiculitic mudstone and wackestone. These data suggest a negative correlation between anomalously high CAI values and mixed mineralogy or poorly washed

deposits; such rock types tend to have low porosity and permeability. Much of the above data suggest that the anomalous CAI values of 6 were produced by hydrothermal solutions (probably low-temperature saline solutions) moving through relatively permeable channelways and possibly elevating CAIs no more than one index value (from 3 to 3.5 or 4), as well as corroding and bleaching some specimens to produce CAIs of 6. Additional samples from the uppermost part of the Alapah Limestone at the study section are severely bleached and corroded and approximate a CAI of 7, suggesting increased alteration at this level. Watts (1990) also noted that porous dolostones and spar-filled caverns in the upper part of the Alapah Limestone probably acted as channelways for hydrothermal fluids. The hydrothermal alteration occurred after the early Atokan, most likely after the Permian. It is probably related to Brookian orogenesis and occurred after maximum burial metamorphism that elevated CAI values to 3 or 3.5 in Carboniferous and Permian rocks.

SYSTEMATIC PALEONTOLOGY

We have used the element notation summarized by Sweet (1988, fig. 2.10). Most of the generically and specifically determinate specimens in our collections are Pa elements. Wherever possible we have tried to identify other elements of apparatuses, particularly for hindeodids, idioprioniodids, and kladognathids (table 1). Genera are listed alphabetically. Many specimens are easily assignable to a genus but are not well enough preserved for specific determination. Most conodonts in the collections have undergone extensive postmortem transport and are thus incomplete and abraded; moreover, some are diagenetically and hydrothermally altered.

All specimens shown on plates 1–5 are repositied in the U.S. National Museum (USNM), Washington, D.C. All other specimens are in the collections of the conodont laboratory of the U.S. Geological Survey, Reston, Va., and are cataloged by USGS collection number. Table 1 and plate 6 show the distribution and abundance of conodont elements, and figure 10 and table 2 show their inferred paleoenvironmental distribution.

Genus *ADETOGNATHUS* Lane, 1967

Type species.—*Cavusgnathus lautus* Gunnell, 1933
p. 286, pl. 31, figs. 67, 68

Adetognathus lautus (Gunnell, 1933)

Plate 1, figures 13–15, 21–24

For synonymy to 1971, see Lane and Straka (1974, p. 64).

- 1971 *Adetognathus gigantus* (Gunnell). Lane and others, pl. 1, fig. 6.
- 1971 *Adetognathus lautus* (Gunnell). Lane and others, pl. 1, fig. 5.
- 1971 *Cavusgnathus gigantus* Gunnell. Merrill and King, p. 654–655, pl. 75, figs. 9–22 (only).
- 1971 *Cavusgnathus lautus* Gunnell. Merrill and King, p. 655, pl. 75, figs. 23, 24, 26–29 (only).
- 1972 *Cavusgnathus lautus* Gunnell. von Bitter, p. 61–63, pl. 4, figs. 3a–h; pl. 5, figs. 1a–h.
- 1973 *Adetognathus gigantus* (Gunnell). Baesemann, p. 696–697, pl. 2, figs. 23?–28?, 32?, 33?, 35, 36, 37?, 38–41.
- 1973 *Adetognathus lautus* (Gunnell). Baesemann, p. 697, pl. 2, figs. 29–31, 34.
- 1974 *Adetognathus lautus* (Gunnell). Lane and Straka, p. 64–65, figs. 36: 17, 21, 22, 25–31; figs. 38: 1–4, 6–8, 10–15, 20; figs. 39: 14, 15, 19, 20; figs. 40: 1–3, 7–14?.
- 1974 *Cavusgnathus lautus* Gunnell. Merrill, pl. 1, figs. 8, 9.
- 1974 *Adetognathus gigantus* (Gunnell). Toomey and others, pl. 3, fig. 15.
- 1974 *Adetognathus lautus* (Gunnell). Toomey and others, pl. 3, fig. 14.
- 1975 *Adetognathus gigantus* (Gunnell). Perlmutter, p. 101, pl. 3, figs. 32, 33, 40, 41, 46, 47.
- 1975 *Adetognathus lautus* (Gunnell). Perlmutter, p. 101, pl. 3, figs. 34–39, 42–45.
- 1975 *Cavusgnathus lautus* Gunnell. Merrill, p. 44–46, figs. 14: 8?, 9, (not figs. 14: 1, 2); figs. 15: 1, 2, 13–16; figs. 16: 3, 4, 36, 37; (not figs. 17: 1, 2).
- 1979 *Cavusgnathus lautus* Gunnell. Einor and others, pl. 14, figs. 13a–c.
- 1979 *Adetognathus gigantus* (Gunnell). Semichatova and others, pl. 22, fig. 16.
- 1980 *Adetognathus lautus* (Gunnell). Bender, p. 8, 9, pl. 4, figs. 26–33.
- 1980 *Cavusgnathus lautus* Gunnell. Merrill and Powell, pl. 1, figs. 30–33.
- 1980 *Adetognathus lautus* (Gunnell). Tynan, p. 1298, 1299, pl. 2, figs. 12, 13, 20, 21 (not fig. 22).
- 1984 *Adetognathus* spp. Driese and others, pl. 1, figs. 1–3.
- 1984 *Adetognathus lautus* (Gunnell). Grayson, pl. 3, figs. 8, 9, 26, 27.
- 1985b *Adetognathus lautus* (Gunnell). Grayson and others, p. 124, pl. 1, figs. 22, 29.
- 1985a *Adetognathus lautus* (Gunnell). Lane and others, figs. 6D, E.
- 1985 *Adetognathus lautus* (Gunnell). Rexroad and Merrill, p. 45, 46, pl. 2, figs. 5, 6?, 28–39; pl. 3, figs. 26–28; pl. 4, figs. 22–25.
- 1985 *Adetognathus gigantus* (Gunnell). Skipp and others, pl. 8, fig. 7.
- 1985 *Adetognathus lautus* (Gunnell). Skipp and others, pl. 8, fig. 6.

- 1985 *Adetognathus lautus* (Gunnell). Wardlaw, p. 400, pl. 3, fig. 7.
- 1985 *Adetognathus spathus* (Dunn). Wardlaw, p. 400, pl. 2, figs. 7, 8.
- 1989 *Cavusgnathus lautus* Gunnell. Merrill and Grayson, pl. 1, figs. 31, 32, 33?, 34?; pl. 2, figs. 20–23, 24?, 25?–29?.
- 1991 *Adetognathus lautus* (Gunnell). Brown and others, figs. 7: 8–11.
- 1991 *Adetognathus lautus* (Gunnell). Morrow and Webster, pl. 1, figs. 4–11.
- 1991 *Adetognathus lautus* (Gunnell). Nemirovskaya and others, pl. 3, figs. 20–24.
- 1992 *Adetognathus lautus* (Gunnell). Morrow and Webster, pl. 1, fig. 12.
- 1992 *Adetognathus lautus* (Gunnell) morphotype A. Weibel and Norby, p. 44, 45, text-fig. 5, pl. 2, figs. 1–35.
- 1992 *Cavusgnathus lautus* Gunnell. Sutherland and Grayson, pl. 2, fig. 2.
- 1969 *Cavusgnathus spathus* Dunn. Webster, p. 28, 29, pl. 4, figs. 1, 4, 5.
- 1970b *Adetognathus spathus* (Dunn). Dunn, p. 327, text-fig. 10B, pl. 61, figs. 11–13.
- 1970 *Adetognathus gigantus* (Gunnell). Thompson, pl. 139, fig. 26.
- 1971 *Adetognathus spathus* (Dunn). Lane and others, pl. 1, fig. 25.
- 1971 *Cavusgnathus gigantus* Gunnell. Merrill and King, p. 654, 655, pl. 75, figs. 30–32 (only).
- 1971 *Cavusgnathus lautus* Gunnell. Merrill and King, p. 655, pl. 75, fig. 25 (only).
- ?1973 *Adetognathus gigantus* (Gunnell). Baesemann, p. 696, 697, pl. 2, figs. 36, 38–41.
- 1974 *Adetognathus spathus* (Dunn). Lane and Straka, p. 65, 66, figs. 38: 5, 9, 16–19; figs. 40: 4–6.
- 1975 *Cavusgnathus lautus* Gunnell. Merrill, figs. 14: 1, 2 (only); figs. 17: 1?, 2?.
- 1985 *Adetognathus spathus* (Dunn). Skipp and others, pl. 8, figs. 1, 4.
- 1985 *Adetognathus spathus* (Dunn). Wardlaw, pl. 3, figs. 8, 9? (only).
- 1991 *Adetognathus spathus* (Dunn). Morrow and Webster, pl. 1, figs. 12–16; pl. 2, figs. 1–4.
- 1992 *Adetognathus spathus* (Dunn). Morrow and Webster, pl. 1, fig. 13.

Remarks.—Rexroad and Merrill (1985) suggest that *A. spathus* may be a recurrent ecophenotype of *A. lautus*. We retain *A. spathus*, however, as a separate taxon to test this concept; see remarks under *A. spathus*.

A few sinistral specimens (pl. 1, figs. 13–15) have a short right-trending carinal extension of the blade.

The first appearance of *Adetognathus lautus* below *Declinognathodus noduliferus* defines the Upper *muricatus* Subzone of the latest Chesterian. *Adetognathus lautus* occurs in two collections from 72 and 65 m below the top of the Alapah Limestone (app. 1, locs. 1A1a, b) but is represented by only one specimen in the Mississippian part of the overlying Wahoo Limestone. This specimen is from a sample taken 53.4 m above the base of the Wahoo Limestone (app. 1, loc. 1A1c), about 50 m along strike from USGS colln. 30757-PC in the study section (table 1). *Adetognathus lautus* does not reappear in our collections from the study section until 84 m above the base of the Wahoo Limestone.

Distribution in the study section.—84 to 260.5 m above the base of the Wahoo Limestone (Morrowan to lower Atokan; lower *minutus* Fauna to *Idiognathodus* Fauna).

Known stratigraphic range.—uppermost Chesterian (base of Upper *muricatus* Subzone) to Lower Permian.

Material.—306 Pa elements.

Adetognathus spathus (Dunn, 1966)

Plate 1, figures 16–20, 25, 26

- 1966 *Cavusgnathus spatha* Dunn, p. 1297, 1299, pl. 157, figs. 3, 7, 8.
- 1967 *Adetognathus lauta* (Gunnell). Lane, pl. 121, figs. 4, 5, 18.

Remarks.—Specimens of *Adetognathus spathus* from the Wahoo Limestone may have large, exaggerated antler-like denticles on the posterior process (pl. 1, figs. 25, 26). Biofacies analysis does not show significant environmental separation in the distribution of *A. spathus* and *A. lautus*. This may be a consequence of postmortem hydraulic mixing. The Pa-element morphology suggests a very shallow water, possibly high-energy environment (G.D. Webster, written commun., 1994, and unpub. U.S. Geological Survey collections). We agree with Rexroad and Merrill (1985) who believe that *A. spathus* may be a recurrent ecophenotype of *A. lautus*.

Distribution in the study section.—113 to 257.5 m above the base of the Wahoo Limestone (Morrowan to lower Atokan; lower *minutus* Fauna to *Idiognathodus* Fauna).

Known stratigraphic range.—uppermost Chesterian (base of Upper *muricatus* Subzone) to at least Upper Pennsylvanian. Webster (1969) reported *Adetognathus spathus* from the uppermost *Rhipidomella nevadensis* Zone suggesting a latest Chesterian age for the lowest part of its range.

Material.—54 Pa elements.

Adetognathus spp. indet.

Remarks.—Included are chiefly broken, abraded, or juvenile Pa elements.

Distribution in the study section.—56 to 261.5 m above the base of the Wahoo Limestone (Morrowan to

lower Atokan; *noduliferus-primus* Zone to *Idiognathodus* Fauna).

Known stratigraphic range.—uppermost Chesterian (base of Upper *muricatus* Subzone) to Lower Permian.

Material.—277 Pa and 3 Pb elements.

Genus *CAVUSGNATHUS* Harris and Hollingsworth, 1933

Type species.—*Cavusgnathus alta* Harris and Hollingsworth, 1933
p. 201, 10a, b

Cavusgnathus altus Harris and Hollingsworth, 1933

Plate 1, figure 27

For synonymy to 1968, see Thompson and Goebel (1969).

1969 *Cavusgnathus alta* Harris and Hollingsworth. Thompson and Goebel, p. 21, 22, pl. 1, figs. 19, 22.

1979 *Cavusgnathus altus* Harris and Hollingsworth. Chaplin, p. 276, pl. 3, figs. 1–3.

1981 *Cavusgnathus altus* Harris and Hollingsworth. Rexroad, p. 7, 8, pl. 1, figs. 28–34.

1985 *Cavusgnathus altus* Harris and Hollingsworth. Wardlaw, p. 400, pl. 3, fig. 13.

1991 *Cavusgnathus altus* Harris and Hollingsworth. Stone, p. 17, pl. 4, figs. 1?, 2?, 4, 5?.

Remarks.—Three specimens of *Cavusgnathus altus* have a posterior process with 1 or 2 low denticles, a common characteristic of the species (see photograph of holotype in Rexroad and Lane, 1966).

Distribution in the study section.—7 to 22 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—upper Meramecian to uppermost Chesterian (Upper *muricatus* Subzone).

Material.—3 Pa elements.

Cavusgnathus? tyththus Brown and Rexroad, 1990

Plate 1, figures 7–12; plate 5, figure 20

1980 *Adetognathus lautus* (Gunnell). Tynan, p. 1298, 1299, pl. 2, fig. 22 (only).

1980 *Adetognathus* n. sp. Tynan, p. 1299, pl. 2, figs. 15–17.

1990 *Cavusgnathus tyththus* Brown and Rexroad. Brown and others, p. 81, 82, text-fig. 5 [part], pl. 1, figs. 1, 4–6, 10–12, 14, 18.

?1991 *Adetognathus* sp. cf. *Adetognathus* n. sp. Tynan. Morrow and Webster, pl. 2, figs. 5, 6.

Description.—Three Pa-element morphotypes occur in the Wahoo Limestone. The two most abundant morphotypes are right sided. The first (pl. 1, figs. 7, 8; = α morphotype of Brown and Rexroad, in Brown and others, 1990) has a free blade with three to four denticles that joins the right parapet (outer) and continues as a fixed blade bearing two

to three denticles; the posteriormost denticle is the largest; therefore, the upper blade profile increases in height posteriorly. The left parapet intercepts the blade two to four denticles behind its anterior margin. In lateral view, the outer margin is slightly to considerably higher than the inner margin. The free blade of the second morphotype (pl. 1, figs. 9, 10; = β morphotype of Brown and Rexroad, in Brown and others, 1990) joins the platform on or slightly left of the right parapet; the very low posteriormost denticle may be slightly to moderately offset to the left; a notch separates the blade from the platform. The upper margin profile of the blade forms a moderate asymmetric arch that is highest in the middle, descends only slightly anteriorly, but steeply posteriorly. In lateral view, the right parapet margin is slightly to considerably higher than the left. The third and rarest Pa morphotype (pl. 1, figs. 11, 12; = γ morphotype of Brown and Rexroad, in Brown and others, 1990) has a free blade that joins the platform centrally or subcentrally toward the right. The blade has the same upper margin profile as the β morphotype; the two very low, posteriormost denticles of the blade continue onto the platform as a short carina. In lateral view, right and left parapet margins are approximately equal in height.

Remarks.—Characteristics of the α morphotype do not appear to change ontogenetically; the β morphotype develops a carinal extension of the blade ontogenetically; no juveniles of the γ morphotype were found. The collections contain chiefly adult specimens. Specimens of *Cavusgnathus? tyththus* in the Wahoo Limestone differ slightly from topotype material from the Kinkaid Limestone of the Illinois basin. Carinal extensions of the blade in the β and γ morphotypes that are obvious in the material from the Wahoo Limestone were not noted by Brown and Rexroad (in Brown and others, 1990). This is probably because their specimens are small; the name they chose for the species reflects that condition. The trivial name is somewhat unsuitable for the material from the Wahoo Limestone in which most representatives of the species are rather large.

Because no left-bladed specimens appear to occur in *Cavusgnathus? tyththus*, it seems inappropriate to place the species in *Adetognathus*, even though its fixed blade is short and, in some morphotypes, may be absent. Presently, it seems best to questionably retain it in *Cavusgnathus*. The array of morphotypes that occur in *C.? tyththus* is reminiscent of morphotypes assigned to older Mississippian species of *Taphrognathus* and *Cloghergnathus* that are found in shallow-water, somewhat restricted depositional environments.

Brown and Rexroad (in Brown and others, 1990) theorized that *Cavusgnathus? tyththus* is the phylogenetic link between *C. unicornis* and *C. monocerus* (= *Adetognathus unicornis* (Rexroad and Burton) of Lane, 1967). *Cavusgnathus? tyththus* occurs with abundant representatives of *C. unicornis* in the lower part of its range in our section; *C. unicornis* does not occur above the lower 51 m of the

Wahoo Limestone, and *C. monocerus* is absent at the study section. Thus, our data neither confirm nor contradict Brown and Rexroad's phylogenetic hypothesis.

Distribution in the study section.—22 to 76.5 m above the base of the Wahoo Limestone (uppermost Chesterian to lowermost Morrowan; Upper *muricatus* Subzone to within *noduliferus-primus* Zone). *Cavusgnathus?* *tythtus* occurs in the upper part of the Alapah Limestone and in many collections from the Wahoo Limestone in the northeast Brooks Range including the type section at Wahoo Lake (app. 1, loc. 4A1c), at Plunge Creek (app. 1, loc. 6), and as far east as the Clarence River at the Canadian border (app. 1, locs. 10A1b, c).

Known stratigraphic range.—upper Chesterian and lower Morrowan (upper part of *naviculus* Zone (Brown and others, 1990) into *noduliferus-primus* Zone).

Material.—99 Pa and 3 Pb (pl. 5, fig. 20) elements.

Cavusgnathus unicornis Youngquist and Miller, 1949

Plate 1, figures 28–31; plate 2, figures 1–17

For synonymy to 1987, see Rexroad and Horowitz (1990). Additions and exceptions are noted below.

1979 *Cavusgnathus unicornis* Youngquist and Miller. Aisenverg and others, pl. 6, fig. 8.

1985 *Cavusgnathus unicornis* Youngquist and Miller. Skipp and others, pl. 8, fig. 10.

1987 *Cavusgnathus unicornis* Youngquist and Miller. Armstrong and Purnell, pl. 1, figs. 11–13 (only).

1989 *Cavusgnathus unicornis* Youngquist and Miller. Wang and Higgins, p. 275, 276, pl. 13, figs. 2–4.

1990 *Cavusgnathus unicornis* Youngquist and Miller. Rexroad and Horowitz, p. 499, 500, pl. 1, figs. 5–20.

1991 *Cavusgnathus unicornis* Youngquist and Miller. Morrow and Webster, pl. 3, figs. 1–3.

1992 *Cavusgnathus unicornis* Youngquist and Miller. Morrow and Webster, pl. 1, fig. 1.

1992 *Cavusgnathus unicornis* Youngquist and Miller. Purnell, p. 10, 11, pl. 2, figs. 1–5, 7.

1992 *Cavusgnathus* cf. *unicornis* Youngquist and Miller. Purnell, pl. 2, fig. 6.

1992 *Cavusgnathus unicornis* Youngquist and Miller. Weibel and Norby, pl. 1, fig. 18.

Remarks.—Rexroad (1981) synonymized *Cavusgnathus regularis* (β morphotype) and *C. convexus* (γ morphotype) under *C. unicornis* (α morphotype). All specimens have a right-sided free blade that is shorter than the fixed blade. In the α morphotype, denticles decrease in size anteriorly; the largest denticle is posteriormost. The blade profile of the β morphotype is uniform in height or may decrease slightly anteriorly. The blade profile of the γ morphotype is arched. In collections from the study section, many of the blade denticles are broken so that morphotypes are indeterminate. Of the complete specimens, α and β morphotypes are more common than γ morphotypes.

Wardlaw (1985, pl. 2, figs. 9–11, 13) included robust, digyrate elements in the apparatus of *Cavusgnathus naviculus* that he claimed were vicariously shared by most species of *Cavusgnathus*, including *C. unicornis*. We strongly disagree with this reconstruction and concur with the element morphotypes determined by Norby (1976) from natural assemblages. The digyrate elements Wardlaw attributed to *Cavusgnathus* belong instead to *Kladognathus* (see Merrill and others, 1990). Armstrong and Purnell (1987) also included an Sc element of *Kladognathus* as well as two morphologically dissimilar M elements in the apparatus of *C. unicornis*.

Distribution in the study section.—0.4 to 50.5 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—upper Meramecian to uppermost Chesterian (Upper *muricatus* Subzone).

Material.—415 Pa, 11 Pb, 26 M, and 6 Sc elements.

Cavusgnathus spp. indet.

Remarks.—Chiefly broken, abraded, or juvenile Pa elements are included in this category.

Distribution in the study section.—13.2 to 53 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—upper Meramecian to uppermost Chesterian (Upper *muricatus* Subzone).

Material.—122 Pa elements.

Cavusgnathoids

Remarks.—Included are posterior Pa-element fragments of *Cavusgnathus*, *Cavusgnathus?*, or *Adetognathus*.

Distribution in the study section.—0.4 to 137 m above the base of the Wahoo Limestone (uppermost Chesterian to Morrowan; Upper *muricatus* Subzone to lower *minutus* Fauna).

Known stratigraphic range.—upper Meramecian to Lower Permian.

Material.—419 Pa element fragments.

Genus *DECLINOGNATHODUS* Dunn, 1966

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

p. 4, 5, pl. 3, figs. 4, 6

Remarks.—Dunn (1970b) expanded the concept of the genus to include forms with a median longitudinal trough and a long, slightly declined, medial carina (= *Declinognathodus lateralis* (Higgins and Bouckaert)). Grayson and others (1990) concurred with Dunn's emendation but considered *D. lateralis* morphotypes as vertically persistent species of *Declinognathodus* that are convergent with *Neognathodus*.

***Declinognathodus noduliferus* (Ellison and Graves, 1941)**

Grayson and others (1990) provide an extensive synonymy for the species.

Remarks.—Declinognathodids in our collections are assigned to *Declinognathodus noduliferus noduliferus*, *D. n. japonicus*, or *D. n.* subsp. indeterminate. A few specimens in a single collection (USGS colln. 30786-PC; pl. 3, fig. 32), 187 m above the base of the Wahoo Limestone, resemble forms assigned to *D. lateralis* (Higgins and Bouckaert) by other workers. These specimens are the largest declinognathodids in a sample that also contains the most abundant and largest rhachistognathids in our collections. We suspect that these *D. lateralis* morphotypes are ecophenotypic and (or) gerontic specimens. Consequently, they are included in *D. noduliferus*.

Specimens identified as *Declinognathodus noduliferus japonicus*, however, exhibit variation in ornamentation, deflection of the carina, and spacing of posterior nodes within each sample throughout the Wahoo Limestone. Some specimens have transverse ridges on the anterior inner margin (pl. 3, figs. 6, 7). All specimens of *D. n. japonicus* have one or two accessory nodes that are in contact with or cleanly separated from the carina near the anterior platform margin. Juvenile specimens tend to have more widely spaced posterior nodes and a straighter carina. Specimens with very nodose ornamentation (pl. 3, fig. 22) are rare and considered ecophenotypes; Grayson (1984, p. 50) erected a separate species (*Idiognathoides marginodosus*; = *Declinognathodus marginodosus* of Grayson, 1990) for such forms. We see no stratigraphic succession of *D. noduliferus* morphotypes in our section and, therefore, retain these forms in *D. n. japonicus*.

***Declinognathodus noduliferus japonicus* (Igo and Koike, 1964)**

Plate 3, figures 1–8, 19–22

- 1964 *Streptognathodus japonicus* Igo and Koike, p. 188, 189, pl. 28, figs. 5–10, ?11–13.
- 1966 *Declinognathodus nevadensis* Dunn, p. 1300, pl. 158, figs. 4, 8.
- 1967 *Gnathodus nodulifera* (Ellison and Graves). Koike, p. 297, 298, pl. 3, figs. 9, 11 (only).
- 1967 *Idiognathoides* aff. *I. nodulifera* (Ellison and Graves). Lane, p. 938, pl. 123, figs. 10, 13 (only).
- 1968 *Gnathodus japonicus* (Igo and Koike). Higgins and Bouckaert, p. 35, 36, pl. 4, figs. 1, 2, 4.
- 1970b *Declinognathodus noduliferus* (Ellison and Graves). Dunn, p. 330, pl. 62, fig. 1 only, text-fig. 9D.
- 1970 *Idiognathoides noduliferus* (Ellison and Graves). Thompson, p. 1046, 1047, pl. 139, figs. 2?, 3?, 5, 6, 8, 16, 20.

- 1971 *Gnathodus noduliferus* (Ellison and Graves). Lane and others, pl. 1, fig. 32.
- 1971 *Idiognathoides noduliferus* (Ellison and Graves). Lane and others, pl. 1, fig. 11.
- 1972 *Idiognathoides noduliferus* (Ellison and Graves) transitional to *Streptognathodus lateralis* Higgins and Bouckaert. Austin, pl. 1, figs. 33, 40.
- 1972 Unnamed figured specimens. Austin, pl. 2, figs. 27, 28.
- 1974 *Idiognathoides noduliferus* (Ellison and Graves). Lane and Straka, p. 85–87, figs. 35: 1–3, 5?, 6?, 10–12, 13–15?.
- 1975 *Idiognathoides noduliferus japonicus* (Igo and Koike). Higgins, p. 54, pl. 14, figs. 7–10.
- 1979 *Declinognathodus noduliferus* (Ellison and Graves). Semichatova and others, pl. 22, figs. 12, 13.
- 1980 *Idiognathoides noduliferus japonicus* (Igo and Koike). Metcalfe, p. 306, pl. 38, figs. 14?, 17?.
- ?1984 *Declinognathodus noduliferus japonicus* (Igo and Koike). Orchard and Struik, pl. 2, fig. 9.
- 1984 *Idiognathoides marginodosus* Morphotype B, Grayson, p. 50, pl. 1, figs. 3, 4, 9–11 (pl. 2, fig. 17= pl. 1, fig. 10), 13, 14; pl. 3, fig. 19?; pl. 4, figs. 11, 12, 22.
- 1985 *Declinognathodus noduliferus japonicus* (Igo and Koike). van den Boogaard and Bless, p. 140, 141, fig. 9: 5.
- 1985a *Declinognathodus noduliferus japonicus* (Igo and Koike). Grayson and others, p. 163–165, pl. 1, figs. 13, 18.
- 1985b *Idiognathoides marginodosus* Grayson. Grayson and others, pl. 1, fig. 21.
- ?1985a *Declinognathodus noduliferus* (Ellison and Graves). Lane and others, figs. 7D–G [figs. 7D, E, ?*Declinognathodus noduliferus*; figs. 7F, G, *D. noduliferus japonicus*?].
- 1985 *Declinognathodus noduliferus* (Ellison and Graves). Sada and others, pl. 1, fig. 3.
- 1987 *Declinognathodus marginodosus* (Grayson). Grayson and others, pl. 8, figs. 8, 11.
- 1987 *Declinognathodus noduliferus japonicus* (Igo and Koike). Nemirovskaya, pl. 1, figs. 12, 15, 19.
- 1988 *Declinognathodus noduliferus japonicus* (Igo and Koike). Dong and Ji, pl. 6, figs. 7, 8.
- 1989 *Declinognathodus noduliferus japonicus* (Igo and Koike). Wang and Higgins, p. 276, pl. 1, figs. 6–9.
- 1990 *Declinognathodus marginodosus* (Grayson). Grayson, p. 90, 91, pl. 4, figs. 9, 10?, 11–13.
- 1990 “*Declinognathodus*” *marginodosus* (Grayson). Grayson and others, p. 365, pl. 1, fig. 28.
- 1990 “*Declinognathodus*” *noduliferus* (Ellison and Graves). Grayson and others, p. 365, pl. 1, fig. 21.
- 1992a *Declinognathodus noduliferus* s.l. (Ellison and Graves). Nigmatdaganov and Nemirovskaya, pl. 3, figs. 6?, 7, 10.

- 1992 *Declinognathodus marginodosus* (Grayson). Sutherland and Grayson, pl. 2, fig. 11.

Remarks.—Most specimens are identical to the types of *Declinognathodus noduliferus japonicus*. Several specimens (pl. 3, fig. 22), however, have an undeflected carina, relatively even-noded margin and carina, and a single, prominent, round node that is cleanly separated from the carina near the anterior margin of the outer lobe. Such forms were included in *D. marginodosus* by Grayson (1990) and Sutherland and Grayson (1992). We include these in *D. n. japonicus* because some populations are intergradational between *D. n. japonicus* and *D. marginodosus* (Grayson). We regard *D. marginodosus* to be a possible shallower water ecophenotype of *D. n. japonicus*. Partial division of the anteriormost node produces an incipient third node in a few specimens (pl. 3, fig. 9).

Distribution in the study section.—56 to 250 m above the base of the Wahoo Limestone (lowest Morrowan to lower Atokan; *noduliferus-primus* Zone to *Idiognathodus* Fauna).

Known stratigraphic range.—lowest Morrowan (base of *noduliferus-primus* Zone) to at least lower Desmoinesian(?).

Material.—144 Pa elements.

***Declinognathodus noduliferus noduliferus* (Ellison and Graves, 1941)**

Plate 3, figures 10–14, 32

- 1941 *Cavusgnathus nodulifera* Ellison and Graves, p. 4, 5, pl. 3, fig. 4 (only).
- 1960 *Streptognathodus parallelus* Clarke, p. 29, pl. 5, figs. 6–8, 14, 15.
- 1967 *Gnathodus nodulifera* (Ellison and Graves). Koike, p. 297, 298, pl. 3, figs. 10, 12? (only).
- ?1967 *Idiognathoides* aff. *I. nodulifera* (Ellison and Graves). Lane, p. 938, pl. 123, figs. 9, 11, 17 (only).
- 1968 *Gnathodus noduliferus* (Ellison and Graves). Higgins and Bouckaert, p. 33–35, pl. 2, figs. 6, 12.
- 1968 *Idiognathoides nodulifera* (Ellison and Graves). Igo and Koike, p. 28, 29, pl. 3, figs. 7, 8, 9?, 10 (only).
- 1969 *Streptognathodus noduliferus* (Ellison and Graves). Webster, p. 48, 49, pl. 4, figs. 7, 8.
- 1970b *Declinognathodus noduliferus* (Ellison and Graves). Dunn, p. 330, pl. 62, fig. 2 (only).
- 1971 *Gnathodus noduliferus* (Ellison and Graves). Lane and others, pl. 1, fig. 32.
- ?1971 *Idiognathoides noduliferus* (Ellison and Graves). Lane and others, pl. 1, fig. 11.
- 1972 *Idiognathoides noduliferus* (Ellison and Graves) transitional to *Streptognathodus lateralis* Higgins and Bouckaert. Austin, pl. 1, figs. 2, 4, 5, 7, 11, 12, 14, 15, 16?, 17?, 18, 19, 27, 29–32, 34–36?, 38, 39, 41, 44, 45, 49, 50, 53?, 54.
- 1972 *Streptognathodus lateralis* Higgins and Bouckaert. Austin, pl. 2, fig. 31.
- 1972 Unnamed figured specimen. Austin, pl. 2, fig. 33.
- 1974 *Idiognathoides noduliferus* (Ellison and Graves). Lane and Straka, p. 85–87, pl. 35, figs. 11–13; pl. 41, figs. 15–17.
- ?1974 *Gnathodus noduliferus* (Ellison and Graves). Merrill, pl. 1, figs. 28, 29.
- 1975 *Idiognathoides noduliferus noduliferus* (Ellison and Graves). Higgins, p. 54, pl. 14, figs. 15, 16.
- 1975 *Idiognathoides noduliferus inaequalis* Higgins. Higgins, pl. 12, figs. 3, 4.
- 1979 *Declinognathodus noduliferus* (Ellison and Graves). Aisenverg and others, pl. 6, figs. 17, 18.
- 1979 *Streptognathodus noduliferus* (Ellison and Graves). Einor and others, pl. 14, figs. 6, 7.
- 1980 *Idiognathoides noduliferus* (Ellison and Graves). Bender, p. 12, pl. 1, figs. 3?, 8–15, 16?.
- 1980 *Idiognathoides noduliferus inaequalis* Higgins. Metcalfe, p. 306 (part), pl. 38, fig. 15.
- 1980 *Idiognathoides noduliferus noduliferus* (Ellison and Graves). Metcalfe, p. 306, pl. 38, figs. 16, 18.
- 1984 *Idiognathoides marginodosus* Morphotype A, Grayson, p. 50, pl. 1, fig. 7.
- 1985a *Declinognathodus noduliferus japonicus* (Igo and Koike). Grayson and others, p. 163–165, pl. 1, figs. 9, 15, 25.
- 1985 *Declinognathodus noduliferus inaequalis* (Higgins). Higgins, pl. 6.2, figs. 11, 14; pl. 6.3, figs. 1, 4.
- 1985 *Declinognathodus noduliferus noduliferus* (Ellison and Graves). Higgins, p. 220, pl. 6.2, figs. 13, 15; pl. 6.3, fig. 7.
- 1985 *Idiognathoides noduliferus* (Ellison and Graves). Plafker and others, figs. 48A, B.
- 1985 *Idiognathoides noduliferus* (Ellison and Graves). Savage and Barkeley, p. 1466, 1467, figs. 9: 1–8.
- ?1985 *Declinognathodus noduliferus* (Ellison and Graves). Skipp and others, pl. 8, fig. 8 [form transitional from *Gnathodus girtyi* to *D. noduliferus*].
- 1985 *Declinognathodus noduliferus* (Ellison and Graves). Wardlaw, p. 397, pl. 1, fig. 1.
- 1987 *Declinognathodus marginodosus* (Grayson). Grayson and others, pl. 8, figs. 16?, 23, 28?.
- 1987 *Declinognathodus noduliferus* (Ellison and Graves). Nemirovskaya, pl. 1, figs. 7, 9, 11, 20, 21.
- 1987 *Declinognathodus inaequalis* (Higgins). Riley and others, pl. 3, fig. 30?.
- 1987 *Declinognathodus noduliferus* (Ellison and Graves). Riley and others, pl. 3, figs. 41?, 42, 43, 44?, 46, 47.
- 1987 *Declinognathodus noduliferus noduliferus* (Ellison and Graves). Wang and others, p. 127, pl. 3, figs. 3–5; pl. 7, fig. 1.
- 1988 *Declinognathodus noduliferus inaequalis* (Higgins). Dong and Ji, pl. 6, fig. 9.

- 1988 *Declinognathodus noduliferus noduliferus* (Ellison and Graves). Dong and Ji, pl. 6, figs. 5, 6.
- 1989 *Declinognathodus noduliferus noduliferus* (Ellison and Graves). Wang and Higgins, p. 276, 277, pl. 2, figs. 5–9.
- 1990 *Declinognathodus noduliferus* (Ellison and Graves). Grayson, pl. 1, figs. 10, 13; pl. 3, fig. 29.
- 1990 *Declinognathodus noduliferus* (Ellison and Graves). Grayson and others, p. 362, 363, pl. 1, fig. 21.
- 1991 *Declinognathodus noduliferus noduliferus* (Ellison and Graves). Gibshman and Akhmetshina, pl. 5, figs. 7, 8.
- 1991 *Declinognathodus noduliferus inaequalis* Higgins. Nemirovskaya and others, pl. 4, figs. 3, 5?, 15.
- 1992 *Declinognathodus noduliferus* (Ellison and Graves). Morrow and Webster, pl. 1, fig. 5.
- 1993 *Declinognathodus noduliferus inaequalis* (Higgins). Duan, p. 206, pl. 3, figs. 7, 8?, 9.

Remarks.—Almost all specimens from the Wahoo Limestone assigned to *Declinognathodus noduliferus noduliferus* have nodose and (or) transversely ridged parapets, an outwardly deflected carina, and three or more accessory nodes on the anterior outer margin (pl. 3, fig. 12). The carina merges with the outer parapet within or slightly posterior to the anterior half of the platform (pl. 3, figs. 11, 12). According to Higgins (1975, 1985), specimens of *D. noduliferus* in which the carina merges with the outer parapet within the posterior half of the platform should be referred to *D. n. inaequalis*. None of our specimens are comparable to the holotype of *D. n. inaequalis*, which has a carina that extends well beyond the anterior half of the platform.

Distribution in the study section.—59 to 250 m above the base of the Wahoo Limestone (lowest Morrowan to lower Atokan; base of *noduliferus-primus* Zone to *Idiognathodus* Fauna).

Known stratigraphic range.—lowest Morrowan (base of *noduliferus-primus* Zone) to lower Desmoinesian(?).

Material.—285 Pa elements.

***Declinognathodus noduliferus* subsp. indet.**

Remarks.—Included are chiefly broken, abraded, and juvenile Pa elements.

Distribution in the study section.—65 to 243 m above the base of the Wahoo Limestone (lower Morrowan to lower Atokan; *noduliferus-primus* Zone to *Idiognathodus* Fauna).

Known stratigraphic range.—lowest Morrowan (base of *noduliferus-primus* Zone) to lower Desmoinesian(?).

Material.—18 Pa elements.

Genus *DIPLOGNATHODUS* Kozur and Merrill, 1975

Type species.—*Spathognathodus coloradoensis* Murray and Chronic, 1965
p. 606, 607, pl. 72, figs. 11–13

Remarks.—von Bitter and Merrill (1990) recommend that only forms having a spatulate carina be included within the genus. They admit that species presently assigned to the genus are morphologically variable and probably polyphyletic. A single specimen is tentatively assigned to *Diplognathodus? ellesmerensis*, a species questionably included in *Diplognathodus* because its Pa element has a denticulate carina.

***Diplognathodus? ellesmerensis* Bender, 1980?**

Plate 5, figures 18, 19

- 1980 *Diplognathodus ellesmerensis* Bender, p. 9, 10, pl. 4, figs. 5–7, 11, 15–21, 23–25.
- 1981 *Diplognathodus coloradoensis* (Murray and Chronic). Landing and Wardlaw, p. 1257–1259, pl. 1, figs. 1, 6, 7, 9, 10.
- 1983 *Diplognathodus ellesmerensis* Bender. van den Boogaard, p. 23, 24, pl. 1, fig. a.
- 1985 *Diplognathodus coloradoensis* (Murray and Chronic). Savage and Barkeley, p. 1473, figs. 12: 9–16.
- 1990 *Diplognathodus? ellesmerensis* Bender. von Bitter and Merrill, fig. 4: 16a–c.
- 1992 *Diplognathodus* sp. A. Sutherland and Grayson, pl. 2, fig. 9.
- ?1993 *Diplognathodus? orphanus* Merrill. Lemos, pl. 4, fig. 6.

Description.—One poorly preserved juvenile(?) Pa element has a free blade bearing eight partly fused denticles. The upper margin profile of the blade gradually increases in height from the anterior margin to midlength and then descends abruptly at the intersection of the blade and platform. A carina of eight mostly fused but distinct denticles gradually decreases in height toward the posterior tip of the platform. The platform margin is incomplete; the lobes appear to be unornamented, oval, and possibly symmetrical. The basal cavity is gnathodontid.

Remarks.—The single specimen resembles *Diplognathodus? ellesmerensis* but has a few more denticles on the carina than specimens illustrated by Bender (1980). Moreover, the upper margin profile of the posterior end of the carina decreases abruptly in height and is adenticulate in most of Bender's specimens.

We agree with Bender (1980) and von Bitter and Merrill (1990) that this species is closer to *Diplognathodus? orphanus* (Merrill) than to other diplognathodontids.

Distribution in the study section.—203 m above the base of the Wahoo Limestone (upper Morrowan or lower Atokan; *Idiognathodus* Fauna).

Known stratigraphic range.—*Diplognathodus? ellesmerensis* is known from the Canadian Arctic islands, Yukon, southeast Alaska, Oklahoma, Michigan, and Spain and apparently ranges from upper Morrowan to Desmoinesian (von Bitter and Merrill, 1990, fig. 4). Sutherland and Manger (1984a) recommended that the first appearance of *Diplognathodus* or the foraminifer *Eoschubertella* be used as a guide to the base of the Atokan. This recommendation preceded the recognition of diplognathodids in the Morrowan (von Bitter and Merrill, 1990). *Diplognathodus? orphanus* appears to be the only known species restricted to the Atokan.

Material.—1 Pa element.

Genus *GNATHODUS* Pander, 1856

Type species.—*Polygnathus bilineatus* Roundy, 1926 p. 13, pl. 3, figs. 10a–c

Remarks.—*Gnathodus bilineatus* (Roundy) was designated the type species of *Gnathodus* by Tubbs (1986) because the types of *G. mosquensis*, the oldest described species of the genus, were lost and its type locality was uncertain.

Gnathodus bilineatus bilineatus (Roundy, 1926)

Plate 2, figures 18, 19; plate 5, figure 23

Only a selected synonymy is given because this subspecies is widespread, commonly figured and cited in the literature, and relatively easily diagnosed. See Wang and others (1987) for additional selected synonymy through 1983.

- 1926 *Polygnathus bilineatus* Roundy, p. 13, pl. 3, figs. 10a–c.
- 1926 *Polygnathus texanus* Roundy, p. 14, pl. 3, figs. 13a, b.
- 1953 *Gnathodus bilineatus* (Roundy). Hass, p. 78–80, pl. 14, figs. 25–29.
- 1958 *Gnathodus bilineatus* (Roundy). Stanley, p. 464, 465, pl. 68, fig. 7.
- 1961 *Gnathodus bilineatus* (Roundy). Higgins, pl. 10, fig. 5.
- ?1965 *Gnathodus bilineatus* (Roundy). Dunn, p. 1148, pl. 140, figs. 7–9.
- 1967 *Gnathodus bilineatus* (Roundy). Globensky, p. 440, pl. 58, figs. 9?, 13.
- 1967 *Gnathodus bilineatus* (Roundy). Koike, p. 296, pl. 1, figs. 9–11.
- 1968 *Gnathodus bilineatus bilineatus* (Roundy). Higgins and Bouckaert, p. 29, pl. 3, fig. 9.
- 1971 *Gnathodus bilineatus* (Roundy). Rhodes and Austin, pl. 2, fig. 1.
- 1974 *Gnathodus bilineatus bilineatus* (Roundy). Austin and others, pl. 1, figs. 4, 5, 15, 19, 23.
- 1974 *Gnathodus bilineatus* (Roundy). Gromczakiewicz-Lomnicka, pl. I, fig. 1.

- 1974 *Gnathodus bilineatus* (Roundy). Matthews and Thomas, pl. 50, fig. 19; pl. 51, figs. 12–15, 21–24.
- 1974 *Gnathodus* sp. Matthews and Thomas, pl. 50, fig. 22.
- 1974 *Gnathodus bilineatus* (Roundy). Rice and Langenheim, p. 27, pl. 1, fig. 11.
- 1975 *Gnathodus bilineatus bilineatus* (Roundy). Higgins, p. 28, 29, pl. 11, figs. 1–4, 6, 7.
- 1979 *Gnathodus bilineatus bilineatus* (Roundy). Aisenverg and others, pl. 6, fig. 12.
- 1979 *Gnathodus bilineatus* Morphotype B. Chaplin, p. 276, 279, pl. 3, figs. 8–11; pl. 4, figs. 1, 2; pl. 5, fig. 2.
- 1985 *Gnathodus bilineatus bilineatus* (Roundy). Higgins, p. 218, pl. 6.1, figs. 1, 2.
- 1985 *Gnathodus bilineatus* (Roundy). Varker and Sevastopulo, p. 199, pl. 5.4, figs. 19, 20.
- 1985 *Gnathodus bilineatus* (Roundy). Wardlaw, pl. 1, fig. 10.
- 1986 *Gnathodus bilineatus bilineatus* (Roundy). Ji, pl. 1, figs. 1–4, 6, 8–10.
- 1986 *Gnathodus bilineatus* (Roundy). Li, pl. 1, figs. 1, 8.
- 1986 *Gnathodus bilineatus* (Roundy). Mapes and Rexroad, p. 117, pl. 2, figs. 22–31.
- 1986 *Gnathodus bilineatus* (Roundy). Ruppel and Lemmer, p. 28, pl. 2, figs. 14, 15.
- 1987 *Gnathodus bilineatus* (Roundy). Grayson and others, pl. 3, figs. 11, 36; pl. 4, figs. 20–23.
- 1987 *Gnathodus bilineatus* (Roundy). Merrill, p. 147–151, pl. 11, figs. 1–6, 9–18.
- 1987 *Gnathodus bilineatus bilineatus* (Roundy). Riley and others, pl. 2, figs. 2, 4.
- 1987 *Gnathodus bilineatus bilineatus* (Roundy). Wang and others, p. 128, pl. 1, fig. 6.
- 1988 *Gnathodus bilineatus bilineatus* (Roundy). Dong and Ji, pl. 4, figs. 6–8, 10.
- 1989 *Gnathodus bilineatus* (Roundy). Ellison and Powell, pl. 2, figs. 1–6, 13–16.
- 1989 *Gnathodus bilineatus bilineatus* (Roundy). Wang and Higgins, p. 277, 278, pl. 6, figs. 7–11.
- 1990 *Gnathodus bilineatus* (Roundy). Grayson, pl. 1, figs. 25, 26?–31.
- 1990 *Gnathodus bilineatus* (Roundy). Grayson and others, p. 361, 362, pl. 1, figs. 1, 3–6, 10–14, 18–20 [figs. 2, 7–9 appear to include two different Pb morphotypes and have thus been excluded].
- 1990a *Gnathodus bilineatus* (Roundy). Ramovs, p. 91, 92, pl. 4, figs. 2, 4, 5, 9, 12.
- 1990b *Gnathodus bilineatus* (Roundy). Ramovs, p. 109, pl. I, figs. 1–3, 11.
- 1991 *Gnathodus bilineatus bilineatus* (Roundy). Higgins and others, pl. 3, fig. 19.
- 1992a *Gnathodus bilineatus bilineatus* (Roundy). Nigmatganov and Nemirovskaya, pl. 1, fig. 3.

- 1992a *Gnathodus bilineatus bollandensis* Higgins and Bouckaert. Nigmadganov and Nemirovskaya, pl. 1, figs. 1, 2.
- 1993 *Gnathodus bilineatus* (Roundy). Alekseev and Kononova, pl. 29, figs. 8, 10.
- 1994 *Gnathodus bilineatus* (Roundy). Kolar-Jurkovsek and Jurkovsek, p. 432, pl. 2, figs. 6–8.

Distribution in the study section.—0.4 to 53 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone) and 69 m above the base of the Wahoo (lower Morrowan—redeposited?).

Known stratigraphic range.—upper Meramecian into lowermost Morrowan. Wang and Higgins (1989) report *Gnathodus bilineatus bilineatus* from the lowermost upper Carboniferous in China, but all their figured specimens are from uppermost lower Carboniferous strata. *Gnathodus bilineatus bilineatus* and (or) *G. b. bollandensis* have been reported from lowermost upper Carboniferous strata (in samples containing *Declinognathodus noduliferus* or other late Carboniferous species) in many parts of the world (for example, Malaysia, Metcalfe, 1980; South China, Wang and Higgins, 1989; Texas, Grayson and others, 1990; Ukraine, Nemirovskaya and others, 1991; south Tianshan, Uzbekistan, Nigmadganov and Nemirovskaya, 1992a). We regard the specimen of *G. b. bilineatus* (pl. 5, fig. 23) that occurs 13 m above the lowest *D. n. japonicus* in the Wahoo Limestone to be redeposited.

Material.—8 Pa elements.

Gnathodus bilineatus subsp. indet.

Remarks.—A few small specimens can be identified only as *G. bilineatus*.

Distribution in the study section.—37 to 53 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—upper Meramecian into lowermost Morrowan.

Material.—3 Pa elements.

Gnathodus defectus Dunn, 1966

Plate 2, figures 23, 24, 31–33; plate 4, figure 26

- 1966 *Gnathodus defectus* Dunn, p. 1300, pl. 158, figs. 1, 5.
- 1969 *Gnathodus defectus* Dunn. Webster, p. 32, pl. 5, fig. 16.
- 1970a *Gnathodus defectus* Dunn. Dunn, text-fig. 4.
- 1970b *Gnathodus defectus* Dunn. Dunn, p. 331, pl. 62, figs. 15, 16; text-fig. 9C.
- 1980 *Gnathodus defectus* Dunn. Tynan, pl. 1, fig. 20.
- ?1985a *Gnathodus defectus* Dunn. Grayson and others, p. 166, pl. 1, fig. 21.
- ?1991 *Gnathodus* sp. cf. *G. defectus* Dunn. Higgins and others, pl. 3, fig. 9.

- 1991 *Gnathodus defectus* Dunn. Morrow and Webster, pl. 3, figs. 6, 7.
- 1992 *Gnathodus defectus* Dunn. Morrow and Webster, pl. 1, fig. 2.
- 1993 *Gnathodus defectus* Dunn. Dumoulin and Harris, fig. 8B.

Remarks.—Most specimens assigned to this species are considerably smaller than those illustrated from Nevada by Dunn (1966). Most, however, are like the specimen illustrated by Dunn (1970b) on plate 62, figure 16 and text-figure 9C.

Distribution in the study section.—54.9? to 157 m above the base of the Wahoo Limestone.

Known stratigraphic range.—From within the Chesterian (from at least below the *muricatus* Zone) to at least the lower Morrowan (lower *minutus* Fauna). Dunn (1966) indicated that *Gnathodus defectus* extended into the lowest Morrowan because it occurred in samples with *Rhachistognathus primus*. Wardlaw (1984) and Morrow and Webster (1992) considered *G. defectus* in Pennsylvanian samples indigenous; however, it is possible that the sporadic occurrence of *G. defectus* from 30 to 102 m above the Mississippian-Pennsylvanian boundary in the study section indicates redeposition. Some redeposited Mississippian conodonts occur in the Pennsylvanian part of the section (table 1). *Gnathodus defectus* occurs in four samples from the lower member of the Wahoo Limestone between 157.5 and 100.5 m below the Wahoo Limestone and Echooka Formation contact at Pogopuk Creek (samples collected by S.K. Morgan, University of Alaska Fairbanks). The conodont species association in the lowest collection indicates the *noduliferus-primus* Zone, and the remaining collections are indicative of the lower *minutus* Fauna (app. 1, loc. 5d). The data from Pogopuk Creek and the study section indicate that *G. defectus* extends well into the Morrowan (into the lower *minutus* Fauna) in the northeast Brooks Range.

Material.—9 Pa elements.

Gnathodus girtyi Hass, 1953

Remarks.—We recognize two subspecies of *Gnathodus girtyi* in our collections, *G. g. girtyi* and *G. g. simplex*.

Gnathodus girtyi girtyi Hass, 1953

Plate 2, figures 20–22

- 1953 *Gnathodus girtyi* Hass, p. 80, pl. 14, figs. 22–24.
- 1956 *Gnathodus girtyi* Hass. Elias, p. 118, pl. III, figs. 30, 31.
- 1957 *Gnathodus girtyi* Hass. Bischoff, p. 24, 25 (part), pl. 4, figs. 17, 22, 23.
- 1960 *Gnathodus clavatus* Clarke, p. 25, pl. 4, figs. 4–8.
- 1968 *Idiognathoides nodulifera* (Ellison and Graves). Igo and Koike, pl. 3, fig. 11 (only).

- 1969 *Gnathodus girtyi girtyi* Hass. Rhodes and others, p. 98, 99, pl. 17, figs. 9, 10.
- 1969 *Gnathodus girtyi simplex* Dunn. Rhodes and others, p. 100, 101, pl. 16, figs. 1–4.
- 1969 *Gnathodus girtyi* subsp. nov. A. Rhodes and others, p. 102, 103, pl. 17, figs. 1–3.
- 1969 *Gnathodus girtyi simplex* Dunn. Webster, p. 32, pl. 5, fig. 10.
- 1970a *Gnathodus girtyi girtyi* Hass. Dunn, text-fig. 4.
- 1970b *Gnathodus girtyi girtyi* Hass. Dunn, p. 331, text-fig. 9A.
- 1970 *Gnathodus girtyi* Hass. Reynolds, p. 10, pl. I, figs. 10–12.
- 1972 *Gnathodus girtyi* Hass. Austin, pl. 2, figs. 11, 15.
- 1973 *Gnathodus girtyi* Hass. Austin and Aldridge, pl. 1, figs. 4–6; pl. 2, figs. 2, 13?, 14, 15.
- ?1974 *Gnathodus girtyi girtyi* Hass. Gromczakiewicz-Lomnicka, pl. II, fig. 1.
- 1974 *Gnathodus girtyi simplex* Dunn. Gromczakiewicz-Lomnicka, pl. I, fig. 4.
- 1974 *Gnathodus girtyi* Hass. Matthews and Thomas, pl. 51, figs. 16, 17, 28–31.
- 1974 *Gnathodus* sp. Matthews and Thomas, pl. 51, figs. 8, 9.
- 1974 *Gnathodus girtyi girtyi* Hass. Rice and Langenheim, pl. 1, figs. 15, 16.
- 1975 *Gnathodus girtyi girtyi* Hass. Higgins, p. 31, pl. 10, figs. 5, 6.
- 1979 *Gnathodus girtyi collinsoni* Rhodes and others. Aisenverg and others, pl. 6, figs. 1, 2.
- 1980 *Gnathodus girtyi simplex* Dunn. Metcalfe, p. 304, pl. 38, fig. 1.
- 1980 *Gnathodus girtyi rhodesi* Higgins. Metcalfe, p. 304, pl. 38, fig. 6.
- 1980 *Gnathodus girtyi girtyi* Hass. Tynan, p. 1302, pl. 1, figs. 16–18.
- 1981 *Gnathodus girtyi* Hass. Metcalfe, p. 23, 25, pl. 4, figs. 2, 4, 5, 7.
- 1985 *Gnathodus girtyi girtyi* Hass. Higgins, p. 220, pl. 6.2, fig. 2.
- 1985 *Gnathodus girtyi rhodesi* Higgins. Higgins, p. 220, pl. 6.2, fig. 1.
- 1985 *Gnathodus girtyi girtyi* Hass. Wardlaw, pl. 1, fig. 12.
- ?1987 *Gnathodus girtyi* Hass. Armstrong and Purnell, pl. 2, figs. 12, 13.
- 1987 *Gnathodus girtyi* Hass. Grayson and others, pl. 7, fig. 29.
- ?1987 *Gnathodus girtyi girtyi* Hass. Wang and others, p. 128, pl. 7, figs. 9, 10.
- 1988 *Gnathodus girtyi girtyi* Hass. Dong and Ji, pl. 5, fig. 14.
- 1988 *Gnathodus girtyi simplex* Dunn. Dong and Ji, pl. 6, fig. 4.
- 1990 (*Neo*)*Gnathodus* sp. aff. *G. girtyi* Hass. Grayson and others, p. 376, 377, pl. 3, figs. 2–13.
- 1991 *Gnathodus girtyi collinsoni* Rhodes and others. Higgins and others, pl. 3, fig. 2.
- 1991 *Gnathodus girtyi girtyi* Hass. Higgins and others, pl. 3, figs. 3–5.
- 1991 *Gnathodus girtyi girtyi* Hass. Morrow and Webster, pl. 3, fig. 9.
- 1992 *Gnathodus girtyi girtyi* Hass. Morrow and Webster, pl. 1, fig. 3.

Remarks.—*Gnathodus girtyi girtyi* has a well-developed transversely ridged anterior inner parapet that continues to or close to the posterior end of the platform where it is noded and merges with the carina. The anterior part of the inner parapet is as high as or higher than the carina. The outer parapet begins posterior to and terminates slightly to considerably anterior of the inner parapet and is lower than the carina. The carina is central, straight or slightly deflected, and continues to the posterior tip of the platform where it expands to form split nodes or transverse ridges in adult or gerontic specimens (pl. 2, fig. 20).

We are unable to evaluate the taxonomic position of the specimens assigned to *Gnathodus* sp. cf. *G. girtyi* subsp. by Grayson and others (1985a) as well as many specimens assigned to *G. girtyi* by other workers without examining the actual specimens and the conodont faunule in which they occur.

Distribution in the study section.—0.4 to 54.9 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone) and 69 to 74 m (lower Morrowan—redeposited?).

Known stratigraphic range.—upper Meramecian to uppermost Chesterian (Upper *muricatus* Subzone).

Material.—56 Pa elements.

***Gnathodus girtyi simplex* Dunn, 1965**

Plate 2, figures 25–27

- 1965 *Gnathodus girtyi simplex* Dunn, p. 1148, pl. 140, figs. 2, 3, 12.
- 1970a *Gnathodus girtyi simplex* Dunn, text-fig. 4.
- 1970b *Gnathodus girtyi simplex* Dunn, p. 331, 332, pl. 62, fig. 17; text-fig. 9B.
- 1971 *Gnathodus girtyi collinsoni* Rhodes and others. Rhodes and Austin, pl. 2, fig. 3.
- ?1974 *Gnathodus girtyi simplex* Hass. Gromczakiewicz-Lomnicka, pl. II, fig. 3.
- 1974 *Gnathodus girtyi simplex* Dunn. Rice and Langenheim, pl. 1, figs. 17, 18.
- 1975 *Gnathodus girtyi collinsoni* Rhodes and others. Higgins, p. 30, 31, pl. 10, figs. 1, 2.
- 1975 *Gnathodus girtyi simplex* Dunn. Higgins, p. 33, pl. 9, figs. 6, 7, 11.
- 1980 *Gnathodus girtyi collinsoni* Rhodes and others. Tynan, p. 1301, pl. 1, figs. 10, 11.
- 1980 *Gnathodus girtyi simplex* Dunn. Tynan, p. 1303, pl. 1, figs. 5–7.

- 1982 *Gnathodus girtyi girtyi* Hass. Higgins and Wagner-Gentis, p. 334, pl. 34, fig. 9.
- 1984 *Gnathodus girtyi collinsoni* Rhodes and others. Qiu, pl. 2, figs. 17–19.
- 1984 *Gnathodus girtyi simplex* Dunn. Qiu, pl. 2, figs. 15, 16.
- 1985a *Gnathodus girtyi simplex*. Lane and others, figs. 7A, B.
- 1985 *Gnathodus girtyi rhodesi* Higgins. Wardlaw, pl. 1, fig. 11.
- 1986 *Gnathodus girtyi simplex* Dunn. Ji, pl. 1, figs. 15–17.
- 1988 *Gnathodus girtyi simplex* Dunn. Dong and Ji, pl. 5, figs. 1–3.
- 1991 *Gnathodus girtyi simplex* Dunn. Higgins and others, pl. 3, figs. 6, 12.
- 1991 *Gnathodus girtyi simplex* Dunn. Morrow and Webster, pl. 3, fig. 8.
- 1992 *Gnathodus girtyi simplex* Dunn. Morrow and Webster, pl. 1, fig. 4.
- 1993 *Gnathodus girtyi simplex* Dunn. Dumoulin and Harris, fig. 8C.

Remarks.—*Gnathodus girtyi simplex* differs from *G. g. girtyi* by having an outer parapet consisting of one or two nodes that are restricted to the anterior half of the platform.

Specimens from the Wahoo Limestone below the Mississippian-Pennsylvanian boundary are transitional to *Declinognathodus noduliferus japonicus* (pl. 2, fig. 30) confirming Dunn's (1970b) concept of the phylogeny of *D. noduliferus*.

Distribution in the study section.—6 to 54.9 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—Chesterian into *noduliferus-primus* Zone. Lane and others (1985a) and Baesemann and Lane (1985) reported *Gnathodus girtyi simplex* from about the basal 5 m of the Pennsylvanian in their Arrow Canyon section, Nevada. In the northeast Brooks Range, *G. g. simplex* occurs in two sections with or above *Declinognathodus noduliferus*, 1 km west of the study section (app. 1, locs. 1B1e, g) and at Pogopuk Creek, about 220 m below the base of the Echooka Formation (app. 1, loc. 5b).

Material.—72 Pa elements.

***Gnathodus girtyi* subspp. indet.**

Remarks.—Included are chiefly broken, abraded, or juvenile Pa elements.

Distribution in the study section.—0.4 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—upper Meramecian into lowermost Morrowan (into *noduliferus-primus* Zone).

Material.—54 Pa elements.

***Gnathodus girtyi* subspp. Hass transitional to *Declinognathodus* spp.**

Plate 2, figures 29, 30

- 1985a *Gnathodus girtyi simplex* transitional to *Declinognathodus noduliferus*. Lane and others, fig. 7C.

Remarks.—An array of gnathodontid Pa element morphotypes that range from *Gnathodus girtyi* subspp. to *Declinognathodus* spp. appear close to the Mississippian-Pennsylvanian boundary. These morphologic variations make taxonomic assignment uncertain. Pa elements transitional between *G. g. simplex* and *D. n. japonicus* (pl. 2, fig. 30) in the highest Mississippian samples (53 and 54.9 m above the base of the Wahoo Limestone and 2 and 0.1 m below the base of the Pennsylvanian) support the suggestion of Dunn (1970b) and Lane and Manger (1985) that *G. g. simplex* is the ancestor to *D. noduliferus*. These specimens are closer to *G. g. simplex* because the trough separating the inner parapet from the carina does not extend to the posterior tip of the platform, and the node(s) forming the outer parapet are not cleanly separated from the carina. These specimens do show, however, a slight depression between the inner parapet and carina near the posterior tip of the platform. A few specimens from 13 m above the Mississippian-Pennsylvanian boundary are transitional between *G. g. girtyi* and *D. inaequalis* (Higgins) (pl. 2, fig. 29).

Distribution in the study section.—53 to 69 m above the base of the Wahoo Limestone (uppermost Chesterian to lowermost Morrowan; Upper *muricatus* Subzone into *noduliferus-primus* Zone).

Material.—9 Pa elements.

***Gnathodus* spp. indet.**

Plate 2, figure 28

Remarks.—Included are broken, abraded, or juvenile Pa elements and one vicarious M element.

Distribution in the study section.—0.4 to 53 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—Mississippian to lowermost Pennsylvanian (upper Kinderhookian into lowermost Morrowan).

Material.—5 Pa and 1 M (pl. 2, fig. 28) elements.

Genus *HINDEODUS* Rexroad and Furnish, 1964

Type species.—*Spathognathodus cristula* Youngquist and Miller, 1949

p. 621, pl. 101, figs. 1–3

Remarks.—See discussion of genus in Sweet (1977).

***Hindeodus minutus* (Ellison, 1941)**

Plate 1, figures 1–6

Only a selected synonymy, chiefly for Chesterian and Lower Pennsylvanian occurrences, is given for this long-ranging, widespread species. For occurrences to 1971, see Sweet (1973).

- 1941 *Spathodus minutus* Ellison, p. 120, pl. 20, figs. 50–52.
- 1964 *Spathognathodus echigoensis* Igo and Koike, p. 187, pl. 28, figs. 24?, 25?.
- 1965 *Spathognathodus minutus* (Ellison). Dunn, p. 1149, pl. 140, figs. 15, 21, 24.
- 1967 *Spathognathodus minutus* (Ellison). Koike, p. 311, pl. 3, figs. 39–42.
- 1969 *Spathognathodus minutus* (Ellison). Palmieri, p. 9, 10, pl. 5, figs. 17, 18.
- 1973b *Spathognathodus minutus* (Ellison). Merrill, p. 305–308, pl. 1, figs. 1–14; pl. 2, figs. 1–28.
- 1973 *Anchignathodus minutus* (Ellison). Sweet, p. 15–17, pl. 1, fig. 2.
- 1974 *Spathognathodus minutus* (Ellison). Lane and Straka, p. 101, figs. 44: 7, 12.
- 1974 *Anchignathodus minutus* (Ellison). Merrill, pl. 2, fig. 8.
- 1980 *Hindeodus* ex. pr. *H. minutus* (Ellison). Bender, p. 10, pl. 4, fig. 22.
- 1980 *Anchignathodus minutus* (Ellison). Tynan, p. 1300, pl. 2, figs. 8, 9.
- 1981 *Hindeodus minutus* (Ellison). Landing and Wardlaw, p. 1259, 1260, pl. 1, figs. 11, 12, 18, 23?.
- 1984 *Hindeodus* sp. Driese and others, pl. 1, fig. 4.
- 1984 *Anchignathodus minutus* (Ellison). Grayson, pl. 2, figs. 3, 26.
- 1985b *Hindeodus minutus* (Ellison). Grayson and others, pl. 1, figs. 47, 48.
- 1985 *Hindeodus minutus* (Ellison). Rexroad and Merrill, pl. 3, figs. 21, 22.
- 1985 *Hindeodus* sp. Sada and others, pl. 1, figs. 7–10.
- 1985 *Hindeodus minutus* (Ellison). Savage and Barkeley, p. 1472, figs. 12: 1–8.
- 1985 *Hindeodus minutus* (Ellison). Wardlaw, p. 400, pl. 3, fig. 1.
- 1986 *Hindeodus minutus* (Ellison). Mapes and Rexroad, pl. 1, figs. 7–15.
- 1987 *Hindeodus minutus* (Ellison). Grayson and others, pl. 9, fig. 1.
- 1989 *Hindeodus minutus* (Ellison). Wang and Higgins, p. 279, pl. 13, figs. 6, 7.
- 1990 *Hindeodus minutus* (Ellison). Grayson, pl. 2, figs. 6, 7, 8?.
- 1991 *Hindeodus minutus* (Ellison). Brown and others, figs. 7: 12–19.
- 1992 *Hindeodus minutus* (Ellison). Sutherland and Grayson, pl. 2, fig. 1.

- 1992 *Hindeodus minutus* (Ellison). Weibel and Norby, pl. 1, fig. 21.
- 1993 *Hindeodus minutus* (Ellison). Lemos, p. 87, 88, pl. 4, figs. 1, 2; pl. 5, figs. 1, 2?, 3, 4 (fig. 3, Sb element; fig. 4, Sc element).
- 1993 *Hindeodus minutus* (Ellison). Rexroad, figs. 3: 14–17, 19.

Remarks.—All specimens of the apparatus of *Hindeodus minutus* in the collections from the Wahoo Limestone conform to the multielement reconstruction shown in Mapes and Rexroad (1986) and Brown and others (1991).

A Pa element figured by Rexroad and Horowitz (1990, pl. 1, fig. 42) as *Hindeodus cristula* (Youngquist and Miller) has the same anterior denticulation as *H. minutus*. We assume this morphotype is a rare component of the *H. cristula* population in the lower Chesterian and is appropriately assigned to *H. cristula*.

Distribution in the study section.—27 to 237 m above the base of the Wahoo Limestone (uppermost Chesterian to lower Atokan?; Upper *muricatus* Subzone to *Idiognathodus* Fauna).

Known stratigraphic range.—upper Chesterian (from within the *Cavusgnathus monocerus* Zone (= *Adetognathus unicornis* Zone)) through at least the Lower Permian.

Material.—41 Pa, 10 Pb, 14 M, 3 Sa, 2 Sb, and 3 Sc elements.

***Hindeodus* spp. indet.**

Remarks.—Included are broken or abraded Pa elements.

Distribution in the study section.—37? to 253 m above the base of the Wahoo Limestone (uppermost Chesterian to lower Atokan; Upper *muricatus* Subzone to *Idiognathodus* Fauna).

Known stratigraphic range.—Mississippian to lowermost Triassic (middle Kinderhookian to Dienerian).

Material.—14 Pa elements.

Genus *IDIOGNATHODUS* Gunnell, 1931

Type species.—*Idiognathodus claviformis* Gunnell, 1931
p. 249–250, pl. 29, figs. 21, 22
Idiognathodus incurvus Dunn, 1966?

Plate 5, figure 21

For synonymy of the species through 1987, see Grayson and others (1990).

- 1989 *Idiognathodus incurvus* Dunn Complex. Grayson and others, p. 87, 88, pl. 1, figs. 21–25.
- 1990 *Idiognathodus incurvus* Dunn. Grayson, pl. 4, figs. 4–7, 8?.
- 1990 *Idiognathodus incurvus* Dunn. Whiteside and Grayson, p. 159, pl. 1, figs. 15, 20–23, 34.
- 1992 *Idiognathodus incurvus* Dunn. Sutherland and Grayson, pl. 2, figs. 4, 12.

Remarks.—Grayson and others (1989) revised the diagnosis for *Idiognathodus sinuosus*, *I. klapperi*, and *I. incurvus* on the basis of the position of the adcarinal ridges and used this characteristic to establish a phylogeny. *Idiognathodus sinuosus* (originating in the middle Morrowan) has two adcarinal ridges, the inner of which extends slightly anterior of the platform and parallel to the free blade; *I. klapperi* (late Morrowan) has ridges that are restricted to the platform; and *I. incurvus* (Atokan) has ridges that extend anteriorly beyond the platform and intersect the free blade. The poor preservation and apparent low diversity of idiognathodids in the Wahoo Limestone do not allow us to test the evolutionary model proposed for the genus by Grayson and others (1989). Some specimens that Grayson and others (1990) and Sutherland and Grayson (1992, for example, pl. 2, fig. 21) include in *I. klapperi* appear to be representatives of the *I. sinuosus* complex (*I. delicatus* morphotype). We did not recognize any specimens that we could confidently assign to *I. klapperi*.

Two specimens, 16 and 12 m below the top of the Wahoo Limestone, are questionably assigned to *Idiognathodus incurvus*. One is a juvenile and the other is a large adult. Although the latter is abraded, the adcarinal ridges extend beyond the anterior platform margin to intersect the remnant of the free blade (pl. 5, fig. 21).

Distribution in the study section.—246 to 250 m above the base of the Wahoo Limestone (lower Atokan; *Idiognathodus* Fauna). *Idiognathodus incurvus*? is used to indicate a level no older than Atokan at the study section on the basis of its distribution in the Atoka Formation in Oklahoma.

Known stratigraphic range.—From within the Atokan (probably lower Atokan) to lower Desmoinesian.

Material.—2 Pa elements.

***Idiognathodus sinuosus* Ellison and Graves, 1941**

Plate 3, figures 15–18, 23–25

For synonymy through 1987, see Grayson and others (1990).

1990 *Idiognathodus sinuosus* Ellison and Graves. Grayson, pl. 4, figs. 36–39.

1992 *Idiognathodus sinuosus* Ellison and Graves. Sutherland and Grayson, pl. 2, figs. 28, 29.

Remarks.—See remarks under *Idiognathodus incurvus*? for Grayson and others' (1989) concept of *I. sinuosus*. In addition, Grayson and others (1990) synonymize *I. delicatus* Gunnell and *I. sinuosus*; we follow their concept here. Many subadult and adult specimens included in *Idiognathodus sinuosus* have nodes on only one side of the platform but, uncharacteristic of *I. sinuosus*, have a relatively straight platform. One subadult specimen (pl. 3, fig. 23) has rostral ridges of equal length that extend slightly beyond the anterior end of the platform. This specimen is included in *I. sinuosus* and not in *I. incurvus* because similar size speci-

mens of the latter exhibit rostral ridges characteristic of that species. Grayson (1990, pl. 4, figs. 37–39) includes similar forms in *I. sinuosus*.

Distribution in the study section.—187 to 243 m above the base of the Wahoo Limestone (upper Morrowan and (or) lower Atokan; *Idiognathodus* Fauna).

Known stratigraphic range.—upper Morrowan (*sinuosus* Zone) to at least Upper Pennsylvanian.

Material.—100 Pa elements.

***Idiognathodus* spp. indet.**

Remarks.—Included are broken, abraded, or juvenile Pa elements.

Distribution in the study section.—177 to 257.5 m above the base of the Wahoo Limestone (upper Morrowan to lower Atokan; *Idiognathodus* Fauna).

Known stratigraphic range.—upper Morrowan (*I. sinuosus* Zone) to Lower Permian.

Material.—52 Pa elements.

Genus *IDIOGNATHOIDES* Harris and Hollingsworth, 1933

Type species.—*Idiognathoides sinuata* Harris and Hollingsworth, 1933
p. 201–202, pl. 1, fig. 14

Idiognathoides sinuatus Harris and Hollingsworth, “*I. ouachitensis*” morphotype

Plate 5, figure 22

For synonymy of *Idiognathoides sinuatus* to 1987, see Grayson and others (1990).

1992 *Idiognathoides sinuatus* Harris and Hollingsworth. Lemos, pl. 3, figs. 3, 8.

1992a *Idiognathoides corrugatus* (Harris and Hollingsworth). Nigmatdaganov and Nemirovskaya, pl. 5, figs. 6–11.

1992a *Idiognathoides sinuatus* Harris and Hollingsworth. Nigmatdaganov and Nemirovskaya, pl. 5, figs. 4, 5.

Remarks.—Grayson (1984) indicated that the length of the trough of the dextral Pa element of *Idiognathoides ouachitensis* was diagnostic of this late Morrowan species. Moreover, he inferred a phylogenetic succession, on the basis of increasing trough length, from *I. corrugatus* to *I. ouachitensis*. Subsequently, Grayson (1990) and Grayson and others (1990) synonymized these species with the long-ranging *I. sinuatus* and speculated that the character of the trough was environmentally controlled. Wang and others (1987) synonymized *I. ouachitensis* in *I. corrugatus* but continued to recognize *I. sinuatus* as a separate species. We follow the multielement concept implemented by Grayson and others (1990) by including all three within *I. sinuatus*.

Only three specimens of the genus were recovered from the study section. All are from one sample and appear to have troughs characteristic of the “*I. ouachitensis*” mor-

phototype. Because of their rarity, we cannot evaluate the environmental preference of these forms. Likewise, we cannot evaluate their biostratigraphic utility.

Distribution in the study section.—217.5 m above the base of the Wahoo Limestone (upper Morrowan or lower Atokan; *Idiognathodus* Fauna).

Known stratigraphic distribution.—lower Morrowan (*sinuatus-minutus* Zone) through at least Atokan.

Material.—3 Pa elements.

Genus *IDIOPRIONIODUS* Gunnell, 1933

Type species.—*Idioproniodus typus* Gunnell, 1933
p. 265, pl. 31, fig. 47

Remarks.—For discussion of the genus see Stone (1991).

Idioproniodus conjunctus (Gunnell, 1931)?

Plate 5, figures 11, 14–17

For synonymy to 1975, see Higgins (1975) and Higgins and Wagner-Gentis (1982).

1982 *Idioproniodus conjunctus* (Gunnell). Higgins and Wagner-Gentis, p. 332, 333, pl. 34, figs. 18, 21, 23, 27–29.

?1985 *Idioproniodus* cf. *I. conjunctus* (Gunnell). Rexroad and Merrill, pl. 3, figs. 15?, 16–20; pl. 4, figs. 17–19.

1985 *Idioproniodus conjunctus* (Gunnell). Savage and Barkeley, p. 1459, figs. 5: 1–14.

1987 *Idioproniodus conjunctus* (Gunnell). Grayson and others, pl. 2, figs. 1–6.

1987 *Idioproniodus* cf. *conjunctus*. Grayson and others, pl. 5, 7–9; pl. 6, figs. 13–20.

1990 *Idioproniodus conjunctus* (Gunnell). Grayson, pl. 2, figs. 15–24.

1991 *Idioproniodus conjunctus* (Gunnell). Brown and others, pl. 7, figs. 23–25, 26?, 27–29.

1993 *Idioproniodus conjunctus* (Gunnell). Rexroad, figs. 4: 1?, 2–12, 13?, 14?.

Remarks.—*Idioproniodus* elements are relatively rare in the Wahoo Limestone; all are incomplete. Elements approximate the better preserved material illustrated by Savage and Barkeley (1985, fig. 5). We have referred virtually all representatives of *Idioproniodus* in the collections from the Wahoo Limestone to *I. conjunctus*?

Distribution in the study section.—53 to 257.5 m above the base of the Wahoo Limestone (uppermost Chesterian to lower Atokan; Upper *muricatus* Subzone to *Idiognathodus* Fauna).

Known stratigraphic range.—Within the Upper Mississippian to at least Desmoinesian.

Material.—6 Pb, 7 M, 5 Sa, 10 Sb, and 7 Sc elements.

Idioproniodus cf. *I. healdi* (Roundy, 1926)?

Plate 5, figure 13

For synonymy to 1987, see Stone (1991).

Remarks.—Stone (1991) assigned many Mississippian representatives of *Idioproniodus* to *I. cf. I. healdi*, including *I. paraclaviger* (Rexroad). One Pb? element from the Wahoo Limestone conforms to the Sb₁ element illustrated by Stone for *I. cf. I. healdi* (1991, pl. 5, fig. 5). This element, unlike similar elements of *I. conjunctus*, has a denticle immediately anterior to the cusp that is fused to it, at least near its base. Pb or Sb elements of forms we assign to *I. conjunctus*? do not have an anterior denticle fused to or impinging on the cusp.

Distribution in the study section.—207 m above the base of the Wahoo Limestone (Morrowan or lower Atokan; *Idiognathodus* Fauna).

Known stratigraphic range.—upper Osagean to at least Chesterian. The specimen from the Wahoo Limestone is from Pennsylvanian strata.

Material.—1 Pb? element.

Idioproniodus spp. indet.

Plate 5, figure 12

Remarks.—Broken and abraded robust digryate elements, some of which are indeterminate to morphotype.

Distribution in the study section.—0.4 to 241 m above the base of the Wahoo Limestone (uppermost Chesterian to lower Atokan?; Upper *muricatus* Subzone to *Idiognathodus* Fauna).

Known stratigraphic range.—Lower Mississippian (upper Osagean) to at least Desmoinesian.

Material.—1 Pa, 3 Pb, 8 M, 6 Sa, and 7 Sb elements and 9 elements indeterminate to morphotype.

Genus *KLADOGNATHUS* Rexroad, 1958

Type species.—*Cladognathus prima* Rexroad, 1957
p. 28, 29, pl. 1, figs. 8–10

Kladognathus spp.

Plate 5, figures 1–10

For synonymies of several species of *Kladognathus*, see Rexroad (1981) and Rexroad and Horowitz (1990).

Remarks.—Element notation for *Kladognathus* spp. follows that of Purnell (1993). Purnell's reconstruction is based on a well-preserved bedding-plane assemblage in the gut of a conodont predator. Except for some M elements, all kladognathid specimens from the Wahoo Limestone are incomplete. Thus, we could not distinguish Pa from Pb elements, and we have not attempted to identify the four morphotypes of the Sb-Sc transition series documented by Purnell (1993). The end members of the Sb-Sc transition series are illustrated (pl. 5, figs. 9, 10).

The lowest collection from the Wahoo Limestone contains the greatest number of kladognathids (table 1, USGS colln. 30745-PC). Most elements appear to be *Kladognathus tenuis* (Branson and Mehl) as reconstructed by Rexroad and Horowitz (1990).

Distribution in the study section.—0.4 to 54.9 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone). Specimens from 59 to 107 m above the base of the formation are considered redeposited.

Known stratigraphic range.—upper Osagean to uppermost Chesterian.

Material.—68 P, 52 M, 6 Sa, and 115 Sb-Sc elements.

Genus *LOCHRIEA* Scott, 1942

Type species.—*Spathognathodus commutatus* Branson and Mehl, 1941b
p. 98, pl. 19, figs. 1–4

Lochriea commutata (Branson and Mehl, 1941b)

Plate 3, figures 26, 27

For synonymy to 1987, see Rexroad and Horowitz (1990). Additions and exceptions are noted below.

- 1941a *Spathognathodus commutatus* Branson and Mehl, p. 172, pl. V, figs. 19–22.
- 1941b *Spathognathodus commutatus* Branson and Mehl, p. 98, pl. 19, figs. 1–4.
- 1969 *Gnathodus commutatus* (Branson and Mehl). Thompson and Goebel, p. 23, 24, pl. 4, figs. 4, 6, 7.
- 1979 *Gnathodus commutatus* (Branson and Mehl). Aisenverg and others, pl. 6, figs. 3, 4.
- 1979 *Gnathodus commutatus commutatus* (Branson and Mehl). Einor and others, pl. 14, figs. 2, 3.
- 1986 *Paragnathodus commutatus* (Branson and Mehl). Ji, pl. 2, figs. 1–4, 5?, 6.
- 1987 *Lochriea commutata* (Branson and Mehl). Armstrong and Purnell, pl. 3, fig. 1.
- 1987 *Paragnathodus commutatus* (Branson and Mehl). Riley and others, pl. 2, figs. 1, 3.
- 1987 *Paragnathodus commutatus* (Branson and Mehl). Wang and others, p. 130, 131, pl. 2, fig. 12.
- 1988 *Gnathodus commutatus commutatus* (Branson and Mehl). Dong and Ji, pl. 5, figs. 1–3.
- 1989 *Paragnathodus commutatus* (Branson and Mehl). Wang and Higgins, p. 285, pl. 8, figs. 4, 5.
- 1990 *Lochriea commutata* (Branson and Mehl). Grayson, pl. 1, figs. 14–24.
- 1990a *Lochriea commutata* (Branson and Mehl). Ramovs, p. 94, 95, pl. 4, figs. 6, 7, 10, 11.
- 1990b *Lochriea commutata* (Branson and Mehl). Ramovs, p. 110, pl. 1, figs. 6, 7, 9, 12–14.
- 1990 *Lochriea commutata* (Branson and Mehl). Rexroad and Horowitz, p. 508–510, pl. 2, figs. 10–24.
- 1990 *Lochriea commutata*. Whiteside and Grayson, pl. 1, figs. 1, 2.

- 1991 *Paragnathodus commutatus* (Branson and Mehl). Nemirovskaya and others, pl. 3, fig. 4.
- 1991 *Paragnathodus commutatus* (Branson and Mehl). Varker and others, pl. 1, figs. 13–15.
- ?1992a *Paragnathodus* aff. *commutatus* (Branson and Mehl). Nigmatganov and Nemirovskaya, pl. 1, fig. 5.
- 1992 *Lochriea commutata* (Branson and Mehl). Weibel and Norby, pl. 2, figs. 35?, 36.
- 1993 *Paragnathodus commutatus* (Branson and Mehl). Alekseev and Kononova, pl. 29, fig. 11.
- 1994 *Lochriea commutata* (Branson and Mehl). Kolar-Jurkovsek and Jurkovsek, 432–433, pl. 1, figs. 3, 4.
- 1994 *Lochriea commutata* (Branson and Mehl). Nemirovskaya and others, pl. 2, fig. 1.
- 1994 *Lochriea commutata* (Branson and Mehl). von Bitter and Norby, p. 861–869, figs. 2–7.

Remarks.—All Pa and M elements conform to those listed in the above synonymy.

Distribution in the study section.—0.4 to 54.9 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Known stratigraphic range.—lower Meramecian (lower Arundian in England according to Metcalfe, 1981) into the lowermost Morrowan (*noduliferus* Zone or earliest Bashkirian in the Donets basin, Ukraine (Nemirovskaya and others, 1991), and South Tianshan, Uzbekistan (Nigmatganov and Nemirovskaya, 1992a).

Material.—8 Pa and 2 M elements.

Genus *NEOGNATHODUS* Dunn, 1970b

Type species.—*Polygnathus bassleri* Harris and Hollingsworth, 1933
p. 198, 199, pl. 1, figs. 13a–e
Neognathodus? sp. indet.

Remarks.—A single posterior Pa element fragment is assigned to *Neognathodus?* sp. indet.

Distribution in the study section.—257.5 m above the base of the Wahoo Limestone (lower Atokan; *Idiognathodus* Fauna).

Known stratigraphic range.—Morrowan (*N. symmetricus* Zone) to Desmoinesian.

Material.—1 Pa element fragment.

Genus *RHACHISTOGNATHUS* Dunn, 1966

Type species.—*Rhachistognathus prima* Dunn, 1966
p. 1301, 1302, pl. 157, figs. 1, 2
Rhachistognathus minutus (Higgins and Bouckaert, 1968)

Remarks.—Baesemann and Lane (1985) recognized three subspecies of *Rhachistognathus minutus*—*R. m. declinatus*, *R. m. havlenai*, and *R. m. minutus*—on the basis of the position of the blade attachment and the degree of

curvature of the anterior part of the left platform margin. They reported (p. 107) that "All specimens in our collections are comparatively small." In contrast, adult to gerontic specimens from the Wahoo Limestone are quite large (some incomplete specimens are at least 1 mm long; pl. 4, figs. 5–8). Many specimens exhibit transitional subspecies characteristics so that subspecific assignment of such forms was arbitrary. In addition, some specimens of *R. m. minutus* are similar to *R. muricatus* (pl. 4, fig. 15; Higgins, 1985, pl. 6.2, fig. 9). Regularly nodose specimens were cosmopolitan (*R. m. minutus*) and probably lived in relatively uniform, normal-marine shallow-water environments, whereas increasingly asymmetrical forms (*R. muricatus* to *R. primus*) occupied more variable shallow-water environments and were chiefly North American Cordilleran and southern Midcontinent inhabitants.

We are unable to evaluate the biostratigraphic utility, if any, of the subspecies of *R. minutus* from the Wahoo Limestone. All subspecies appear between 84 and 85 m above the base of the section and continue to near the top. We suppose that any paleoecologic partitioning of these subspecies was obliterated by hydraulic mixing across the Wahoo carbonate platform. The distribution of *R. minutus* subspp. in the Arrow Canyon section, Nevada (Baesemann and Lane, 1985), is quite different from that of our section. At Arrow Canyon, *R. m. minutus* and *R. m. havlenai* make their appearance about 105 m below that of *R. m. declinatus*, co-occur for about 90 m, and disappear about 15 m below the first *R. m. declinatus*. *R. m. declinatus* continues as the only rhachistognathid in the succeeding 75 m. Unfortunately, Baesemann and Lane (1985) do not explain the stratigraphic succession of these subspecies nor the paleoenvironmental implications. Varker and others (1991) report all three subspecies together in several samples.

***Rhachistognathus minutus declinatus* Baesemann and Lane, 1985**

Plate 4, figures 1–9

For synonymy through 1975, see Baesemann and Lane (1985).

- 1985 *Rhachistognathus minutus declinatus* Baesemann and Lane, p. 108, 109, pl. 1, figs. 1–10.
- 1987 *Rhachistognathus minutus declinatus* Baesemann and Lane. Nemirovskaya, pl. 1, figs. 1, 4.
- 1987 *Rhachistognathus minutus declinatus* Baesemann and Lane. Riley and others, pl. 3, figs. 10?, 11.
- 1991 ?*Rhachistognathus minutus declinatus* Baesemann and Lane. Nemirovskaya and others, pl. 4, figs. 1, 2.
- 1991 *Rhachistognathus minutus declinatus* Baesemann and Lane. Varker and others, pl. 1, figs. 30, 31.

Remarks.—*Rhachistognathus minutus declinatus* is the most abundant rhachistognathid in the Wahoo Limestone. One sample from the upper member yielded 276 Pa elements of *R. m. declinatus*; some specimens are transi-

tional to *R. m. havlenai* (table 1, USGS colln. 30786–PC). The free blade joins the platform subcentrally and, with few exceptions, the anterior end of the left parapet is deflected to the left. A few gerontic specimens have the anterior end of the right parapet deflected to the right (pl. 4, fig. 6). The inner platform margin of some gerontic Pa elements have one or two nodes (pl. 4, figs. 7, 8); a transverse ridge may extend from the node(s) to the parapet (pl. 4, fig. 7).

A form geometrically similar to *R. m. declinatus* was described from Lower and Middle Pennsylvanian rocks in southeast Alaska by Savage and Barkeley (1985). The platform margin of their species, "*Taphrognathus alaskensis*," however, is ornamented by closely spaced, delicate transverse ridges, whereas *R. m. declinatus* has noded or transversely ridged and noded parapets. The new species may represent a part of the *R. minutus* plexus that occupied quiet, open-marine environments.

Distribution in the study section.—85 to 261.5 m above the base of the Wahoo Limestone (lower Morrowan to lower Atokan; lower *minutus* Fauna to *Idiognathodus* Fauna).

Known stratigraphic range.—lower Morrowan (base of *sinuatus-minutus* Zone in North America, but below the mid-Carboniferous boundary and within the lowermost Chokierian in England; Varker and others, 1991) to lower Atokan.

Material.—518 Pa elements.

***Rhachistognathus minutus havlenai* Baesemann and Lane, 1985**

Plate 4, figures 10–12

For synonymy through 1975, see Baesemann and Lane (1985). Additions and exceptions are noted below.

- 1969 *Streptognathodus lanceolatus* Webster, p. 47, 48, pl. 6, fig. 14 (only).
- 1985 *Rhachistognathus minutus havlenai* Baesemann and Lane, p. 109–111, pl. 2, figs. 1–6, 8, 9.
- 1987 *Rhachistognathus minutus havlenai* Baesemann and Lane. Riley and others, pl. 3, figs. 8, 9.
- 1991 *Rhachistognathus minutus havlenai* Baesemann and Lane. Varker and others, pl. 1, figs. 26–29.

Remarks.—According to Baesemann and Lane (1985), the offset of the free blade from the left parapet distinguishes *Rhachistognathus minutus havlenai* from *R. m. minutus* and *R. muricatus*. The anterior margin of the left parapet in *R. m. havlenai* is straight as opposed to *R. m. declinatus* in which it curves strongly outward (compare pl. 4, figs. 1, 10).

Distribution in the study section.—85 to 261.5 m above the base of the Wahoo Limestone (lower Morrowan to lower Atokan; lower *minutus* Fauna to *Idiognathodus* Fauna).

Known stratigraphic range.—lower Morrowan (base of *sinuatus-minutus* Zone in North America, but below the

mid-Carboniferous boundary and within the lowermost Chokierian in England; Varker and others, 1991) to lower Atokan.

Material.—228 Pa elements.

***Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968)**

Plate 4, figures 13–15

For synonymy through 1975, see Baesemann and Lane (1985). Additions and exceptions are noted below.

- 1969 *Streptognathodus lanceolatus* Webster, p. 47, 48, pl. 6, fig. 15 (only).
 1985 *Rhachistognathus minutus minutus* (Higgins and Bouckaert). Baesemann and Lane, p. 111, 112, pl. 2, figs. 7, 10, 11; pl. 3, figs. 1–12.
 1985 *Rhachistognathus minutus* (Higgins and Bouckaert). Higgins, p. 220, pl. 6.2, figs. 3–9.
 ?1985 *Rhachistognathus minutus* n. subsp. C. Skipp and others, pl. 8, fig. 5.
 1987 *Rhachistognathus minutus minutus* (Higgins and Bouckaert). Riley and others, pl. 3, figs. 1–7.
 1991 *Rhachistognathus minutus minutus* (Higgins and Bouckaert). Varker and others, pl. 1, figs. 16?, 17?, 20–22, 25.

Remarks.—Specimens from the Wahoo Limestone assigned to this subspecies conform to the diagnosis and description given in Baesemann and Lane (1985). Also see remarks above for *Rhachistognathus minutus*.

Distribution in the study section.—84 to 260.5 m above the base of the Wahoo Limestone (lower Morrowan to lower Atokan; lower *minutus* Fauna to *Idiognathodus* Fauna).

Known stratigraphic range.—lower Morrowan (base of *sinuatus-minutus* Zone in North America, but below the mid-Carboniferous boundary and within the lowermost Chokierian in England; Varker and others, 1991) to lower Atokan.

Material.—300 Pa elements.

***Rhachistognathus minutus* subsp. indet.**

Remarks.—Included are broken, abraded, or juvenile Pa elements.

Distribution in the study section.—107 to 261.5 m above the base of the Wahoo Limestone (Morrowan to lower Atokan; lower *minutus* Fauna to *Idiognathodus* Fauna).

Known stratigraphic range.—lower Morrowan (base of *sinuatus-minutus* Zone in North America, but below the mid-Carboniferous boundary and within the lowermost Chokierian in England; Varker and others, 1991) to lower Atokan.

Material.—33 Pa elements.

***Rhachistognathus muricatus* (Dunn, 1965)**

Plate 4, figures 27–30

For synonymy through 1980, see Baesemann and Lane (1985). Additions and exceptions are noted below.

- ?1966 *Cavusgnathus transitoria* Dunn, p. 1299, pl. 157, fig. 9.
 1985 *Rhachistognathus minutus minutus* (Higgins and Bouckaert). Baesemann and Lane, pl. 2, figs. 7, 10 (only).
 1985 *Rhachistognathus muricatus* (Dunn). Skipp and others, pl. 8, fig. 9.
 1985 *Rhachistognathus muricatus* (Dunn). Wardlaw, pl. 1, fig. 9.
 1987 *Rhachistognathus muricatus* (Dunn). Grayson and others, pl. 4, figs. 23, 30?, 32, 38.
 ?1987 *Rhachistognathus* aff. *muricatus* (Dunn). Wang and others, p. 131, 132, pl. 7, figs. 5, 6.
 1991 *Rhachistognathus muricatus* (Dunn). Higgins and others, pl. 3, figs. 8, 13.
 1991 *Rhachistognathus muricatus* (Dunn). Morrow and Webster, pl. 4, figs. 1–5.
 1992 *Rhachistognathus muricatus* (Dunn). Morrow and Webster, pl. 1, fig. 6.
 1993 *Rhachistognathus muricatus* (Dunn). Lemos, p. 88, 90, pl. 4, figs. 3, 4, 5?.

Remarks.—This species is the most morphologically variable rhachistognathid and is intermediate between *Rhachistognathus minutus* and *R. primus*. Many specimens in the collections from the Wahoo Limestone conform to the species diagnosis, whereas others are transitional to *R. minutus*, *R. primus*, or *R. websteri*. Transition forms are discussed below.

Distribution in the study section.—6 to 133.5 m above the base of the Wahoo Limestone (uppermost Chesterian to Morrowan; Upper *muricatus* Subzone to lower *minutus* Fauna).

Known stratigraphic range.—uppermost Chesterian (base of *muricatus* Zone) to lower Atokan.

Material.—336 Pa elements.

***Rhachistognathus muricatus* (Dunn) transitional to *R. primus* Dunn**

Plate 4, figure 25

- 1974 *Rhachistognathus muricatus* (Dunn). Lane and Straka, p. 97, 98, figs. 35: 16, 17.
 1985 *Rhachistognathus muricatus* (Dunn) transitional to *R. primus* Dunn. Baesemann and Lane, p. 115, pl. 4, figs. 8, 9.
 1987 *Rhachistognathus minutus* (Higgins and Bouckaert). Grayson and others, pl. 4, fig. 31.
 1991 *Rhachistognathus minutus havlenai* Baesemann and Lane. Higgins and others, pl. 3, figs. 7, 11.

Remarks.—The absence of a narrow, medial trough distinguishes *R. primus* from *R. muricatus*. Specimens considered transitional between *R. muricatus* and *R. primus* have a moderate trough on the anterior half of the platform and a shallow trough containing a row of low nodes on the posterior half.

Distribution in the study section.—85 to 95 m above the base of the Wahoo Limestone (Morrowan; lower *minutus* Fauna).

Material.—4 Pa elements.

***Rhachistognathus muricatus* (Dunn) transitional to *R. websteri* Baesemann and Lane**

Plate 4, figure 16

Remarks.—*Rhachistognathus websteri* is distinguished from other rhachistognathids by a prominent marginal node that is distinctly offset from the posterior part of the outer parapet. This node is only slightly offset in the figured specimen.

Distribution in the study section.—6 m above the base of the Wahoo Limestone (uppermost Chesterian; Upper *muricatus* Subzone).

Material.—1 Pa element.

***Rhachistognathus prolixus* Baesemann and Lane, 1985?**

Remarks.—Two posterior platform fragments resemble *Rhachistognathus prolixus* but are too incomplete for positive identification.

Distribution in the study section.—6 to 157 m above the base of the Wahoo Limestone (uppermost Chesterian to Morrowan; Upper *muricatus* Subzone to lower *minutus* Fauna).

Known stratigraphic range.—lower Chesterian to middle Morrowan.

Material.—3 Pa element fragments.

***Rhachistognathus websteri* Baesemann and Lane, 1985**

Plate 4, figures 17–21

For synonymy through 1980, see Baesemann and Lane (1985).

1983 *Rhachistognathus primus* Dunn. Metcalfe, pl. 2, fig. 18.

1985 *Rhachistognathus websteri* Baesemann and Lane, p. 117–119, pl. 5, figs. 1, 2, 8–12.

1985 *Rhachistognathus muricatus* (Dunn)-*Rhachistognathus primus* Dunn plexus. Plafker and others, figs. 48C, D.

?1985 *Rhachistognathus minutus* (Higgins and Bouckaert). Wardlaw, pl. 1, fig. 7.

1991 *Rhachistognathus muricatus* (Dunn). Higgins and others, pl. 3, fig. 13.

1991 *Rhachistognathus websteri* Baesemann and Lane. Higgins and others, pl. 3, fig. 17.

1991 *Rhachistognathus websteri* Baesemann and Lane. Morrow and Webster, pl. 3, figs. 14, 15.

1992 *Rhachistognathus websteri* Baesemann and Lane. Morrow and Webster, pl. 1, fig. 8.

1992 *Rhachistognathus* cf. *R. websteri* Baesemann and Lane. Weibel and Norby, pl. 2, fig. 37.

Remarks.—The morphology of Pa elements agrees with those synonymized above; most specimens are relatively small. *Rhachistognathus websteri* may be an ecophenotype of *R. muricatus*. Collections containing abundant *R. muricatus* generally contain relatively abundant *R. websteri* and visa versa (compare table 1, USGS collns. 30770–PC and 30773–PC). The same relationships persist in the north-east Brooks Range (app. 1, loc. 5d).

Distribution in the study section.—59 to 162 m above the base of the Wahoo Limestone (lowermost Morrowan; *noduliferus-primus* Zone to lower *minutus* Fauna).

Known stratigraphic range.—uppermost Chesterian (Upper *muricatus* Subzone; app. 1, loc. 4A1c) to lower and possibly middle Morrowan (this report).

Material.—187 Pa elements.

***Rhachistognathus* spp. indet.**

Plate 4, figures 22–24

Remarks.—Included are broken, abraded, or juvenile (pl. 4, figs. 22–24) nodose Pa elements, chiefly posterior platform fragments.

Distribution in the study section.—6 to 260.5 m above the base of the Wahoo Limestone (uppermost Chesterian to lower Atokan; Upper *muricatus* Subzone to *Idiognathodus* Fauna).

Known stratigraphic range.—at least lower Chesterian to lower Atokan.

Material.—396 Pa elements.

Genus *VOGELGNATHUS* Norby and Rexroad, 1985

Type species.—*Spathognathodus campbelli* Rexroad, 1957

p. 37, 38, pl. 3, figs. 13–15

***Vogelgnathus postcampbelli* (Austin and Husri, 1974)**

Plate 3, figures 28–31

For synonymy to 1985, see Purnell and von Bitter (1992). Additions and exceptions are listed below.

1967 *Spathognathodus campbelli* Rexroad. Koike, p. 310, pl. 3, figs. 26, 27, 29, 32?

1974 *Spathognathodus campbelli* Austin and Husri, p. 57, pl. 5, figs. 1, 3, 4.

1985 *Vogelgnathus* n. sp. Norby and Rexroad, p. 11, 12, pl. 1, figs. 3–5.

- 1985 *Ozarkodina* sp. (*Spathognathodus campbelli* Rexroad). Sada and others, pl. 1, fig. 27 (only).
- 1992 *Vogelgnathus postcampbelli* (Austin and Husri). Purnell and von Bitter, p. 327, 328, figs. 13: 1–4, fig. 14 (part).
- 1992 *Vogelgnathus* n. sp. of Norby and Rexroad. Weibel and Norby, pl. 1, fig. 23.

Remarks.—Purnell and von Bitter (1992, their table 1) summarize the characteristics of species of *Vogelgnathus* spp. Specimens of *V. postcampbelli* from the Wahoo Limestone are poorly preserved Pa elements having 10 to 14 denticles. The upper margin profile of most specimens gradually increases in height posteriorly toward the cusp and then sharply decreases from the cusp to the posterior tip (pl. 3, figs. 28, 30). Some specimens have a cusp that is slightly higher and wider than adjacent denticles.

Vogelgnathus postcampbelli is locally common to abundant in beds above and below the Mississippian-Pennsylvanian boundary in the northeast Brooks Range (for example, app. 1, loc. 7a, 50 km southwest of the study section in the Fourth Range, 20 m below the Mississippian-Pennsylvanian boundary; app. 1, loc. 1B1g, 1 km west of the study section—53 Pa elements from 2.8 m above the boundary, pl. 3, fig. 31). All specimens are nearly identical to and some are even more poorly preserved than those from the study section.

Distribution in the study section.—0.4 to 76.5 m above the base of the Wahoo Limestone (uppermost Chesterian to lower Morrowan; Upper *muricatus* Subzone to *noduliferus-primus* Zone).

Known stratigraphic range.—At least Chesterian into the lowermost Morrowan (no younger than *noduliferus-primus* Zone).

Material.—16 Pa elements.

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APPENDIX 1

APPENDIX 1. CONODONT FAUNAS, BIOFACIES, AND AGE AND LITHOLOGY OF COLLECTIONS MENTIONED IN TEXT BUT NOT DESCRIBED ELSEWHERE IN THIS REPORT

[Map locality number keyed to figures 1 and 2. Letters in field numbers refer to collector: JC, James Clough; ME, M.K. Eckstein; PG, P.D. Gruzlovic; AK, A.P. Krumhardt; ADL, D.L. LePain; SKM, S.K. Morgan; MR, Mark Robinson; TR, J.L. Tailleux; KW, K.F. Watts. CAI, color alteration index]

MAP LOC. NO., FIELD NO., (USGS COLL. NO.)	QUADRANGLE LATITUDE N/ LONGITUDE W.	FORMATION	LITHOLOGY	CONODONTS	AGE	BIOFACIES	CAI	REMARKS
Eastern Sadlerochit Mountains								
loc. 1A1a, AK90D-29 (31718-PC)	Mt. Michelson C-1, 69°38'24"/ 144°34'45"	Alapah Limestone, 72 m below base of Wahoo Limestone	Poorly-sorted, dolomitized bryozoan, pelmatozoan packstone containing minor ostracodes, brachiopods, and algae.	8 Pa elements <i>Adeognathus laevis</i> (Gunnell) 12 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller 16 Pa element fragments of <i>cavusgnathoids</i> 2 M elements <i>Griathodus</i> sp. indet. 4 Pa elements <i>Hindeodus</i> sp. indet. 5 Sb-Sc elements <i>Kladognathus</i> sp. indet. UNASSIGNED ELEMENTS: 2 Pb, 1 M, and 2 Sc 75 indet. bar, blade, and platform fragments	Upper <i>R. muricatus</i> Subzone (very latest Chesterian)	Cavusgnathid; open- platform, near restricted depositional environment.	3.5-4	Collections from study section (fig. 2, loc. 1A) place upper 72 m of Alapah Limestone within the Upper <i>R. muricatus</i> Subzone.
loc. 1A1b, AK90D-36 (31719-PC)		Alapah Limestone, 65 m below base of Wahoo Limestone	Partly silicified, well- sorted, fine-grained bryozoan, pelmatozoan packstone. Grains recrystallized and highly fragmented.	2 Pa elements <i>Adeognathus laevis</i> (Gunnell) 18 Pa element fragments of <i>cavusgnathoids</i> 2 unassigned M elements (2 morphotypes) 106 indet. bar, blade, and platform fragments		Winnow within or from adetognathid and (or) cavusgnathid biotacles; open-platform, near- restricted depositional environment.	4	
loc. 1A1c, AK92-3 (31859-PC)		Wahoo Limestone, 53.4 m above base of lower member	Medium-bedded, medium- grained, bryozoan, pelmatozoan, and peloid grainstone containing minor trilobites and <i>Asphalites</i> sp. and rare ostracodes and gastropods.	1 Pa element <i>Adeognathus laevis</i> (Gunnell) 3 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller 3 Pa element fragments of <i>cavusgnathoids</i> 3 indet. bar fragments		Indeterminate (too few conodonts); open-platform, possibly near restricted depositional environment.	4 and minor 6	Collected 50 m along strike from study section sample at 53 m above base of Wahoo Limestone (table 1, USGS coll. 30757-PC; fig. 2, loc. 1A).
loc. 1A2, 90ADL1-25.3 (32227-PC)	Mt. Michelson C-1, 69°38'05"/ 144°35'00"	Alapah Limestone, ~24 m above base	Lime mudstone.	6 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller 1 Pa element <i>Cavusgnathus</i> sp. indet. 16 Pa element fragments of <i>cavusgnathoids</i> 5 Pa elements <i>Griathodus girtyi</i> Hass 2 Pa elements <i>Griathodus</i> sp. indet. 1 Sa element <i>Hindeodus</i> sp. indet. 8 Sb-Sc elements <i>Kladognathus</i> spp. 1 Pa element <i>Rhachistognathus muricatus</i> (Dunn) UNASSIGNED ELEMENTS: 1 Pb and 3 M (2 morphotypes) 195 moderately to well-rounded bar, blade, and platform fragments	<i>R. muricatus</i> Zone (very late Chesterian)	Extensive postmortem hydraulic transport within the cavusgnathid- kladognathid biotacles; normal-marine, near restricted, relatively shallow water depositional environment.	5.5- 6.5 and minor 4	Collection places lower part of Alapah Limestone near the study section within the <i>R. muricatus</i> Zone.
loc. 1B1a, AK92-14 (32223-PC)	Mt. Michelson C-1, 69°38'05"/ 144°36'3"	Wahoo Limestone, ~52.0 m above base of lower member and 2 m below key bed containing reddish-brown and gray chert	Bryozoan-pelmatozoan grainstone.	2 Pa elements <i>Griathodus bilineatus</i> subsp. indet. 16 Pa elements <i>Griathodus girtyi</i> Hass 2 Pa elements <i>Griathodus girtyi simplex</i> Dunn 2 Pa elements <i>Hindeodus minutus</i> (Ellison) 1 idopriodontid element <i>Kladognathus</i> sp. indet. 2 Sb-Sc elements UNASSIGNED ELEMENTS: 3 M (two morphotypes) and 1 Sc 105 indet. bar, blade, and platform fragments	Upper <i>R. muricatus</i> Subzone (very latest Chesterian); based on underlying samples from study section AK88a (this report)	Postmortem transport within or from the gnathodid biotacles; normal-marine, depositional environment, above wave base.	4 and rare 6	Carlson's (1987) measured section at Sunset Pass, 1 km west of study section (fig. 2, loc. 1B). These collections straddle the Mississippian- Pennsylvanian boundary.

loc. 1B1b, AK92-13 (32224-PC)	Mt. Michelson C-1, 69°38.05' / 144°36.3'	Wahoo Limestone, -52.5 m above base of lower member and 1.5 m below key bed containing reddish-brown and gray chert	Bryozoan, pelmatozoan, and peloid grainstone.	6 Pa elements <i>Cavusgnathus</i> ? <i>tythus</i> Brown and Rexroad 17 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) 27 Pa elements <i>Gnathodus giryi simplex</i> Dunn transitional to <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) <i>Hindeodus minutus</i> (Ellison) 2 Pa, 1 Sa, and 1 Sb elements 1 <i>Idioproniodid</i> element 1 M element <i>Kladognathus</i> ? sp. <i>indet.</i> 6 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 1 Pa element <i>Vogelgnathus postcampbelli</i> (Austin and Husr) UNASSIGNED ELEMENTS: 2 Pb, 1 M, and 1 Sb 126 <i>indet.</i> bar, blade, and platform fragments 1 Pa element <i>Cavusgnathus</i> ? <i>tythus</i> Brown and Rexroad 9 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) (8 juveniles) 1 Pa element <i>Hindeodus</i> sp. <i>indet.</i> 2 Sb-Sc elements <i>Kladognathus</i> sp. <i>indet.</i> 2 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) UNASSIGNED ELEMENTS: 1 Pb 45 <i>indet.</i> bar, blade, and platform fragments	Lower part of <i>noduliferus-primus</i> Zone (very earliest Morrowan)	4 and minor 6	Gnathodid-declinognathodid; normal-marine depositional environment, above wave base.	Collection marks the base of the Pennsylvanian in the eastern Sadlerochit Mountains.
loc. 1B1c, AK92-12 (32225-PC)		Wahoo Limestone, -53 m above base of lower member and 1 m below key bed containing reddish-brown and gray chert	Bryozoan-pelmatozoan grainstone.	5 Pa elements <i>Cavusgnathus</i> ? <i>tythus</i> Brown and Rexroad 13 Pa element fragments of <i>cavusgnathoids</i> 7 Pa and 1 Sc elements <i>Declinognathodus</i> <i>noduliferus japonicus</i> (Igo and Koike) (3 juveniles) 4 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) (2 juveniles) UNASSIGNED ELEMENTS: 1 M and 1 Sc 36 <i>indet.</i> bar, blade, and platform fragments		4-4.5 and rare 6	Indeterminate (too few conodonts); normal-marine depositional environment, above wave base.	
loc. 1B1d, AK92-11 (32226-PC)		Wahoo Limestone, -53.5 m above base of lower member and 50 cm below key bed containing reddish-brown and gray chert	Bryozoan-pelmatozoan grainstone.	5 Pa elements <i>Cavusgnathus</i> ? <i>tythus</i> Brown and Rexroad 2 Pa element fragments of <i>cavusgnathoids</i> 2 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) transitional to <i>Gnathodus giryi simplex</i> Dunn 2 Pa element <i>Rhachistognathus muricatus</i> (Dunn) 1 unassigned Pb element 15 <i>indet.</i> bar, blade, and platform fragments		4 and rare 6	Indeterminate (too few conodonts); postmortem mixing of generally small forms, probably a winnow representing a normal- marine depositional environment, above wave base.	
loc. 1B1e, AK90E-54 (31834-PC)		Wahoo Limestone, -54 m above base of lower member and 30 cm below key bed containing reddish-brown and gray chert	Skeletal grainstone.	6 juvenile Pa elements <i>Cavusgnathus</i> ? <i>tythus</i> Brown and Rexroad 5 Pa element fragments of <i>cavusgnathoids</i> 1 juvenile Pa element <i>Rhachistognathus</i> <i>muricatus</i> (Dunn) 2 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Husr) UNASSIGNED ELEMENTS: 2 Pb and 1 M 8 <i>indet.</i> bar, blade, and platform fragments		4-4.5	Indeterminate, too few conodonts; probably a winnow as all elements are small and relatively delicate. Relatively shallow-water, probably normal-marine but near restricted marine depositional environment.	
loc. 1B1f, AK90E-55 (31835-PC)		Wahoo Limestone, -55 m above base of lower member and within key bed containing reddish-brown and gray chert, 20 cm below its top	Peloid, spiculitic wackestone.					

**APPENDIX 1. CONODONT FAUNAS, BIOFACIES, AND AGE AND LITHOLOGY OF COLLECTIONS MENTIONED IN TEXT
BUT NOT DESCRIBED ELSEWHERE IN THIS REPORT—CONTINUED**

MAP LOC. NO., FIELD NO., (USGS COLL. NO.)	QUADRANGLE, LATITUDE N./ LONGITUDE W.	FORMATION	LITHOLOGY	CONODONTS	AGE	BIOFACIES	CAI	REMARKS
loc. 1B1g, AK90E-55.3 (31836-PC)	Mt. Michelson C-1, 69°38.05'N/ 144°36.3'W	Wahoo Limestone, ~55.3 m above base of lower member and 0-30 cm above key bed containing reddish-brown and gray chert	Peloidal grainstone and lesser packstone- wackestone containing minor echinoderm debris and spicules.	9 juvenile Pa elements <i>Cavusgnathus?</i> <i>tythius</i> Brown and Rexroad 89 Pa element fragments of cavusgnathoids 36 chiefly juvenile Pa elements <i>Declinognathodus</i> <i>noduliferus japonicus</i> (Igo and Koike), many transitional to <i>Gnathodus girtyi</i> <i>simplex</i> Dunn 1 Pa element <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) 6 juvenile Pa elements <i>Rhachistognathus</i> <i>muricatus</i> (Dunn) 53 chiefly juvenile Pa elements <i>Vogelgnathus</i> <i>postcampbelli</i> (Austin and Husri) UNASSIGNED ELEMENTS: 13 Pb (2 morphotypes), 1 M, 3 Sa and 3 Sc (3 morphotypes) +150 indet. bar, blade, and platform fragments 1 Pa element <i>Adelognathus spathus</i> (Dunn) 1 Pa element fragment <i>Adetognathus</i> sp. indet. 3 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) 4 Pa element fragments <i>Idognathodus</i> sp. indet. 3 element fragments <i>Idioprioidus</i> sp. indet. 2 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 3 juvenile Pa elements <i>Rhachistognathus</i> <i>minutus</i> (Higgins and Bouckaert) 5 juvenile Pa elements <i>Rhachistognathus</i> sp. indet. 14 Pa element fragments (generally posterior part of platform) of cavusgnathoids and rhachistognathids UNASSIGNED ELEMENTS: 1 Pb and 1 Sc 26 indet. bar, blade, and platform fragments	Lower part of <i>noduliferus-primus</i> Zone (very earliest Morrowan)	Probable postmortem winnow within or from the vogelgnathid-declinognathoid biofacies; normal-marine to near restricted depositional environment.	4 and minor 6	Collection dates top of Wahoo Limestone near study section (fig. 2, loc. 1C)
loc. 1C, 90MR28A (31266-PC)	Mt. Michelson C-2, 69°37.3'N/ 144°38.7'W	Top of Wahoo Limestone at contact with Echhooka Formation	Bioclastic, bryozoan grainstone.	1 juvenile Pa element <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Graves and Ellison) 1 Pa element <i>Hindodius minutus</i> (Ellison) 3 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 11 indet. bar, blade, and platform fragments BEDEPOSITED ELEMENTS?: 4 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller 5 Pa elements <i>Cavusgnathus?</i> <i>tythius</i> Brown and Rexroad 4 Pa element fragments of cavusgnathoids <i>Kladognathus</i> sp. indet. 3 M and 6 Sb-Sc elements	lower <i>R. minutus</i> Fauna (early Morrowan)	Indeterminate; much of faunule is probably redeposited.	3-3.5	Measured section, 102 m thick, on west wall of Katakturuk River at south end of canyon through Sadlerochit Mountains (fig. 2, loc. 2). Contact with overlying Echhooka Formation is not exposed at the measured section. Less than 1 km to the west, however, the contact is exposed (see below, USGS colln. 29874-PC). Samples collected and described by I.L. Tailleux.
Western Sadlerochit Mountains								
loc. 2a, 84TR23-3 (29626-PC)	Mt. Michelson C-3, 69°35.27'N/ 31°14.5'W 34°30'N-36°	Wahoo Limestone, 3 m above base of measured section	Medium-light-brownish- gray, thick- to massive- bedded, crinoidal, fine- grained limestone.	1 juvenile Pa element <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Graves and Ellison) 1 Pa element <i>Hindodius minutus</i> (Ellison) 3 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 11 indet. bar, blade, and platform fragments BEDEPOSITED ELEMENTS?: 4 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller 5 Pa elements <i>Cavusgnathus?</i> <i>tythius</i> Brown and Rexroad 4 Pa element fragments of cavusgnathoids <i>Kladognathus</i> sp. indet. 3 M and 6 Sb-Sc elements	lower <i>R. minutus</i> Fauna (early Morrowan)	Indeterminate; much of faunule is probably redeposited.	3-3.5	Measured section, 102 m thick, on west wall of Katakturuk River at south end of canyon through Sadlerochit Mountains (fig. 2, loc. 2). Contact with overlying Echhooka Formation is not exposed at the measured section. Less than 1 km to the west, however, the contact is exposed (see below, USGS colln. 29874-PC). Samples collected and described by I.L. Tailleux.

loc. 2b, 84TR23-8 (29627-PC)	Mt. Michelson C-3, 69°35'27"- 31°14.5° 34°30'36"	Wahoo Limestone, 8 m above base of measured section	Crinoidal grainstone containing irregular shaly partings and glauconitic grains and layers.	2 Pa elements <i>Gnathodus girtyi</i> Hass transitional to <i>Declinognathodus inaequalis</i> (Higgins)? 1 Pa element <i>Idiophrionolodus</i> sp. indet. 1 Pa element <i>Rhachistognathus prolixus</i> Baesemann and Lane 9 indet. bar, blade, and platform fragments REDEPOSITED ELEMENTS? 2 Pa <i>Gnathodus bilineatus</i> (Roundy) 3 Pa elements <i>Gnathodus girtyi simplex</i> Dunn	lower <i>R. minutus</i> Fauna (early Morrowan)	Indeterminate.	3-3.5	Two collections from the lower 8 m of the section contain many Mississippian and Mississippian to Pennsylvanian conodonts. In other sections in the northeast Brooks Range, <i>R.</i> <i>minutus</i> first appears considerably above <i>Declinognathodus</i> <i>noduliferus</i> so that <i>R.</i> <i>minutus</i> is considered indigenous and the Mississippian elements of the faunule redeposited. However, in England, <i>R.</i> <i>minutus</i> appears before <i>D.</i> <i>noduliferus</i> (Varker and others, 1991) and in the Ukraine it appears at the same time as <i>D. nodu-</i> <i>liferus</i> (Nemirovskaya and others, 1991). This faunule may represent the oldest occurrence of <i>R.</i> <i>minutus</i> in the northeast Brooks Range.
loc. 2c, 84TR23-32.5 (29628-PC)		Wahoo Limestone, 32.5 m above base of measured section	Medium-brownish-gray, fine-grained crinoidal limestone.	31 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) including some forms transitional to <i>R. primus</i> Dunn 2 Pa element fragments <i>Rhachistognathus aff. R.</i> <i>minutus</i> (Higgins and Bouckaert) 2 unassigned Pb elements 16 indet. bar, blade, and platform fragments 1 Pa element fragment <i>Adelognathus</i> sp. indet. 1 Pa element <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 7 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 1 Pa element <i>Rhachistognathus websteri</i> Baesemann and Lane 1 unassigned Sc element 4 indet. bar, blade, and platform fragments		Rhachistognathid: high- energy, normal-marine, probable shoal to shoal- apron depositional environment.	3-3.5	
loc. 2d, 84TR23-37.5 (29629-PC)		Wahoo Limestone, 37.5 m above base of measured section	Slabby bedded interval within massive limestone; contains bryozoans and brachiopods.	13 Pa elements <i>Adelognathus lautus</i> (Gunnell) 3 Pa elements <i>Adelognathus spathus</i> (Dunn) 40 Pa elements <i>Rhachistognathus minutus</i> subsp. 4 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) UNASSIGNED ELEMENTS: 4 Pb (2 morphotypes), 1 M, 3 Sb, and 1 Sc 76 indet. bar, blade, and platform fragments	<i>R. minutus</i> Fauna (Morrowan to early Atokan)	Rhachistognathid- adetognathid biofacies; because all the rhachistognathids are small and the adetognathids are large this probably represents a near-shoal depositional environment. The rhachistognathids were brought to the depositional site as winnows.	3-3.5	
loc. 2f, 84TR23-66.5 (29631-PC)		Wahoo Limestone, 66.5 m above base of measured section	Medium-light-gray, crinoidal limestone containing some brachiopods.	24 juvenile Pa elements <i>Declinognathodus</i> <i>noduliferus japonicus</i> (Igo and Kolke) 3 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 1 unassigned Pb element 19 indet. bar, blade, and platform fragments 5 Pa elements <i>Adelognathus lautus</i> (Gunnell) 13 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke) 3 Pa elements <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Graves and Ellison) 7 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 22 indet. bar, blade, and platform fragments		Declinognathid; open- marine depositional environment near shoal.	3-3.5	
loc. 2g, 84TR23-73 (29632-PC)		Wahoo Limestone, 73 m above base of measured section	Dark-gray, very fine grained limestone containing only a few shelly fragments.			Declinognathid; open- marine depositional environment near shoal.	3-3.5	

APPENDIX 1. CONODONT FAUNAS, BIOFACIES, AND AGE AND LITHOLOGY OF COLLECTIONS MENTIONED IN TEXT BUT NOT DESCRIBED ELSEWHERE IN THIS REPORT—CONTINUED

MAP LOC. NO., FIELD NO., (USGS COLLN. NO.)	QUADRANGLE LATITUDE N/ LONGITUDE W.	FORMATION	LITHOLOGY	CONODONTS	AGE	BIOFACIES	CAI	REMARKS
loc. 2h, 84TR23-96 (29633-PC)	Mt. Michelson C-3, 69°35'27". 31°/145° 34°30'-36°	Wahoo Limestone, 96 m above base of measured section	Medium-gray, line- grained, massive, fossiliferous limestone.	1 Pa element <i>Adeognathus</i> aff. <i>A. laetus</i> (Gunnell) 1 Pa element <i>Adelognathus spathus</i> (Dunn) 11 Pa elements <i>Declinognathus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) 1 late juvenile Pa element <i>Idiognathodus</i> sp. indet. 48 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 unassigned Pb elements 67 indet. bar, blade, and platform fragments 14 Pa elements <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) 1 Pa element <i>Idiognathodus</i> sp. indet. 4 element fragments <i>Idioprioidus</i> sp. indet. 2 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 unassigned Pb elements 4 indet. bar, blade, and platform fragments 3 Pa elements <i>Idiognathodus sinuosus</i> Ellison and Graves 1 Pa element <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 32 indet. bar, blade, and platform fragments	<i>Idiognathodus</i> Fauna (late Morrowan to early Atokan)	Rhachistognathid; normal- marine, near-shoal depositional environment.	3-3.5	This and the following collection place in the upper 6 m of the section in the <i>Idiognathodus</i> Fauna.
loc. 2i, 84TR26A (29634-PC)		Wahoo Limestone, 102 m above base of measured section	Dark, crinoidal layer in generally light-colored rubbly unit.			Declinognathid; open- marine depositional environment, possibly near shoal.	3-3.5	
loc. 2j, 84TR26A (29873-PC)	Mt. Michelson C-3, 69°35.5'/ 145°36.8'	Wahoo Limestone, 0.25 m below contact of Wahoo Limestone and Echooka Formation	Crinoidal grainstone.			Indeterminate (too few conodonts).	3-3.5	Collection from less than 1 km west of measured section described immediately above. From NW 1/4 sec. 28, T. 3 N., R. 27 E. (fig. 2, loc. 2). Collection dates uppermost part of Wahoo Limestone in Katakuruk River gorge area.
Northwestern Philip Smith Mountains								
loc. 3A, 89JC501-37b (30894-PC)	Sagavanirktok A-1, 68°55.6'/ 148°04.8'	Uppermost part of Wahoo Limestone	Limestone.	2 Pa element fragments <i>Hindeodus</i> sp. indet. <i>Idiognathodus sinuosus</i> Ellison and Graves 52 Pa and 4 Pb elements <i>Idioprioidus</i> sp. indet. 1 Sa and 1 Sb elements 81 indet. bar, blade, and platform fragments 32 Pa elements <i>Idiognathodus sinuosus</i> Ellison and Graves 13 element fragments <i>Idioprioidus</i> sp. indet. 11 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 unassigned Pb elements 102 indet. bar, blade, and platform fragments	<i>Idiognathodus</i> Fauna (late Morrowan to at least early Atokan)	Idiognathid; open-marine, moderate-energy depositional environment.	6, 6.5, minor 4	Collection dates uppermost part of Wahoo Limestone (fig. 1, loc. 3).
loc. 3B, 89MR-42C (30903-PC)	Sagavanirktok A-2, 69°06.4'/ 147°39.6'	Lisburne Group, 1 m below contact with Echooka Formation	Bioclastic, bryozoan grainstone.		<i>Idiognathodus</i> Fauna (late Morrowan to early Atokan)	Idiognathid- rhachistognathid; normal- marine depositional environment, possibly near shoal.	4.5 minor 5	Collection dates uppermost part of Wahoo Limestone (fig. 1, loc. 3).
Philip Smith Mountains, Wahoo Lake area								
loc. 4A1a, SKM91D-70 (31826-PC)	Sagavanirktok A-1, 69°01.4'/ 147°00.1'	Alapah Limestone, 70 m below base of Wahoo Limestone	Thick- to medium-bedded, crinoidal grainstone containing faint laminations.	2 Pa elements <i>Cavusgnathus? tythius</i> Brown and Rexroad 4 Pa element fragments <i>cavusgnathoids</i> 2 Pa elements <i>Gnathodus girtyi simplex</i> Dunn 1 Pa element <i>Gnathodus</i> aff. <i>G. girtyi</i> Hass <i>Hindeodus minutus</i> (Ellison)? 2 Pa (fragments) 5 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 5 indet. bar, blade, and platform fragments	<i>R. muricatus</i> Zone (very late Chesterian)	Indeterminate (too few conodonts); relatively shallow-water, normal- marine depositional environment.	6 and rare 5.5 and 7	Measured section about 1.5 km west of type section of the Wahoo Limestone (fig. 1, loc. 4). Section includes about +140 m of the Alapah Limestone and 281 m of the lower member and 48 m of the upper member of the Wahoo Limestone. The contact between the Wahoo and Echooka Formation is 469 m above the base of the section. Section from Morgan (1992). Collection places base of Wahoo Limestone in the area of its type section within the <i>R. muricatus</i> Zone.

loc. 4A1b, SKM91D-155 (31828-PC)	Sagavanirktok A-1, 69°01.4' / 147°00.1'	Wahoo Limestone, 15 m above base of lower member	Thick- to medium-bedded, pelmatozoan-bryozoan packstone/wackestone containing abundant gray chert.	1 Pa element <i>Adetognathus laevis</i> (Gunnell) 10 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller 7 Pa element fragments of <i>cavusgnathoids</i> <i>Hindeodus</i> aff. <i>H. minutus</i> (Ellison) 2 Pa and 4 Pb elements <i>Kladognathus</i> sp. indet. 5 P, 2 Sa, and 1 Sb-Sc elements UNASSIGNED ELEMENTS: 5 Pb (2 morphotypes), 6 M (3 morphotypes), 1 Sb, and 4 Sc (2 morphotypes) 49 indet. bar, blade, and platform fragments 26 Pa elements <i>Cavusgnathus? tythius</i> Brown and Rexroad 1 Pa element <i>Gnathodus bilineatus bilineatus</i> (Roundy) 7 Pa elements <i>Gnathodus girtyi girtyi</i> Hass 7 Pa elements <i>Gnathodus girtyi simplex</i> Dunn 7 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 1 juvenile Pa element <i>Rhachistognathus prolixus</i> Baesemann and Lane 2 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 69 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huser) UNASSIGNED ELEMENTS: 25 Pa (fragments), 6 Pb, 1 M, and 2 Sc 161 indet. bar, blade, and platform fragments <i>Declinognathodus noduliferus japonicus</i> (Igo and Koike) 100 Pa, 4 M, and 1 Sc elements 3 juvenile Pa elements of <i>Gnathodus girtyi</i> <i>simplex</i> (Dunn) 1 M element <i>Gnathodus</i> sp. indet. 42 gnathodontid Pa element fragments <i>Hindeodus minutus</i> (Ellison) 2 Pa (fragments), 1 M, and 1 Sb elements 7 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huser) UNASSIGNED ELEMENTS: 3 Pb (3 morphotypes) and 3 M 84 indet. bar, blade, and platform fragments 5 Pa elements <i>Cavusgnathus? tythius</i> Brown and Rexroad 2 Pa element fragments of <i>cavusgnathoids</i> 1 Pa element <i>Gnathodus girtyi simplex</i> Dunn 1 Sb element <i>Hindeodus</i> sp. indet. 1 Pa element <i>Rhachistognathus primus</i> Dunn UNASSIGNED ELEMENTS: 1 Pb and 1 Sc 6 indet. bar, blade, and platform fragments	Upper <i>R. muricatus</i> Subzone (very late Chesterian)	Postmortem transport within or from the <i>cavusgnathid</i> biofacies; shallow- to moderate-depth, probably normal-marine depositional environment.	5.5 and minor 6	Collection contains first appearance of <i>Adetognathus</i> <i>laevis</i> and marks the base of the Upper <i>R. muricatus</i> Subzone at 15 m above the base of the Wahoo Limestone in the area of its type section.
loc. 4A1c, SKM91D-279.5 (31837-PC)		Wahoo Limestone, about 139.5 m above base of lower member	Sample is mottled and contains two microolithofacies: (1) bryozoan-echinoderm grainstone containing rare trilobite and brachiopod fragments and peloids, spicullitic wackestone, intraclasts, and detrital quartz and (2) spicullitic wackestone containing minor ostracodes, calciophores, and brachiopod, echinoderm, and bryozoan frond fragments.	1 Pa element <i>Gnathodus bilineatus bilineatus</i> (Roundy) 7 Pa elements <i>Gnathodus girtyi girtyi</i> Hass 7 Pa elements <i>Gnathodus girtyi simplex</i> Dunn 7 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 1 juvenile Pa element <i>Rhachistognathus prolixus</i> Baesemann and Lane 2 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 69 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huser) UNASSIGNED ELEMENTS: 25 Pa (fragments), 6 Pb, 1 M, and 2 Sc 161 indet. bar, blade, and platform fragments <i>Declinognathodus noduliferus japonicus</i> (Igo and Koike) 100 Pa, 4 M, and 1 Sc elements 3 juvenile Pa elements of <i>Gnathodus girtyi</i> <i>simplex</i> (Dunn) 1 M element <i>Gnathodus</i> sp. indet. 42 gnathodontid Pa element fragments <i>Hindeodus minutus</i> (Ellison) 2 Pa (fragments), 1 M, and 1 Sb elements 7 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huser) UNASSIGNED ELEMENTS: 3 Pb (3 morphotypes) and 3 M 84 indet. bar, blade, and platform fragments 5 Pa elements <i>Cavusgnathus? tythius</i> Brown and Rexroad 2 Pa element fragments of <i>cavusgnathoids</i> 1 Pa element <i>Gnathodus girtyi simplex</i> Dunn 1 Sb element <i>Hindeodus</i> sp. indet. 1 Pa element <i>Rhachistognathus primus</i> Dunn UNASSIGNED ELEMENTS: 1 Pb and 1 Sc 6 indet. bar, blade, and platform fragments	<i>D. noduliferus-R.</i> <i>primus</i> Zone, probably lower part of zone (very earliest Morrowan)	Probable postmortem transport within or from the <i>vogelgnathid-cavusgnathid</i> biofacies; normal-marine to near-restricted depositional environment.	6-7	Collection is significant because it contains: (1) <i>Cavusgnathus? tythius</i> in the lower member of the Wahoo Limestone in the area of its type section. (2) <i>Rhachistognathus</i> <i>websteri</i> below the first appearance of <i>Declinognathodus</i> <i>noduliferus</i> in the area of the type section of the Wahoo. (3) Abundant <i>Vogelgnathus</i> <i>postcampbelli</i> and its biofacies associates.
loc. 4A1d, SKM91D-295 (31830-PC)		Wahoo Limestone, 155 m above base of lower member	Massive to thick-bedded bryozoan wackestone containing minor pelmatozoans, articulated brachiopods, and rare bivalves.	1 Pa element <i>Gnathodus bilineatus bilineatus</i> (Roundy) 7 Pa elements <i>Gnathodus girtyi girtyi</i> Hass 7 Pa elements <i>Gnathodus girtyi simplex</i> Dunn 7 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 1 juvenile Pa element <i>Rhachistognathus prolixus</i> Baesemann and Lane 2 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 69 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huser) UNASSIGNED ELEMENTS: 25 Pa (fragments), 6 Pb, 1 M, and 2 Sc 161 indet. bar, blade, and platform fragments <i>Declinognathodus noduliferus japonicus</i> (Igo and Koike) 100 Pa, 4 M, and 1 Sc elements 3 juvenile Pa elements of <i>Gnathodus girtyi</i> <i>simplex</i> (Dunn) 1 M element <i>Gnathodus</i> sp. indet. 42 gnathodontid Pa element fragments <i>Hindeodus minutus</i> (Ellison) 2 Pa (fragments), 1 M, and 1 Sb elements 7 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huser) UNASSIGNED ELEMENTS: 3 Pb (3 morphotypes) and 3 M 84 indet. bar, blade, and platform fragments 5 Pa elements <i>Cavusgnathus? tythius</i> Brown and Rexroad 2 Pa element fragments of <i>cavusgnathoids</i> 1 Pa element <i>Gnathodus girtyi simplex</i> Dunn 1 Sb element <i>Hindeodus</i> sp. indet. 1 Pa element <i>Rhachistognathus primus</i> Dunn UNASSIGNED ELEMENTS: 1 Pb and 1 Sc 6 indet. bar, blade, and platform fragments	<i>D. noduliferus-R.</i> <i>primus</i> Zone, probably lower part of zone (very earliest Morrowan)	Declinognathodid; open- marine depositional environment, near wave base (virtually all ramiform elements have been winnowed away).	7 and minor 6 and 6.5	Collection contains: (1) First appearance of <i>Declinognathodus</i> <i>noduliferus</i> in the area of the section of the Wahoo Limestone, marking the base of the Pennsylvanian. (2) <i>Gnathodus girtyi</i> <i>simplex</i> in the <i>noduliferus-</i> <i>primus</i> Zone.
loc. 4B, KW90D-0.5 (31214-PC)	Sagavanirktok A-1, 69°01'00" / 147°00.8'	Wahoo Limestone, stratigraphic level not known	Light-medium-gray, massive- to medium- bedded (beds 15-50 cm thick), skeletal- pelmatozoan packstone- grainstone containing silicified skeletal grains including articulated crinoids.	5 Pa elements <i>Cavusgnathus? tythius</i> Brown and Rexroad 2 Pa element fragments of <i>cavusgnathoids</i> 1 Pa element <i>Gnathodus girtyi simplex</i> Dunn 1 Sb element <i>Hindeodus</i> sp. indet. 1 Pa element <i>Rhachistognathus primus</i> Dunn UNASSIGNED ELEMENTS: 1 Pb and 1 Sc 6 indet. bar, blade, and platform fragments	lower <i>D. noduliferus-</i> <i>R. primus</i> Zone (very earliest Morrowan)	Indeterminate (too few conodonts).	6.5-8	Single collection in vicinity of Wahoo Lake (fig. 1, loc. 4) that includes one of the few occurrences of <i>Rhachistognathus primus</i> in our collections from the northeast Brooks Range and also records <i>Gnathodus</i> <i>girtyi simplex</i> in the <i>noduliferus-primus</i> Zone.
loc. 4C1a, KW90A-26 (31210-PC)	Mt. Michelson A-5, 69°09.5' / 146°56.9'	Wahoo Limestone, 106 m below contact with Echooka Formation	Massive- to thick-bedded, skeletal-pelmatozoan packstone.	5 Pa element fragments <i>Adetognathus</i> sp. indet. 8 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 11 Pa elements <i>Rhachistognathus minutus</i> <i>haverlandi</i> Baesemann and Lane 5 Pa elements <i>Rhachistognathus primus</i> Dunn transitional to <i>R. muricatus</i> (Dunn) 35 Pa element fragments <i>Rhachistognathus</i> sp. indet. 61 indet. bar, blade, and platform fragments	<i>R. minutus</i> Fauna (early, but not earliest Morrowan to early Atokan, most likely early to middle Morrowan)	Postmortem transport within the rhachistognathid biofacies; high-energy, shallow-water, probable shoal depositional environment.	4.5	From measured section that includes the upper 132 m of the Wahoo Limestone and the contact between the Wahoo and overlying Echooka Formation; about 10 km north of Wahoo Lake (fig. 1, loc. 4). Collections place a 79-m- thick interval in the upper part of the Wahoo Limestone within the <i>R.</i> <i>minutus</i> Fauna.

APPENDIX 1. CONODONT FAUNAS, BIOFACIES, AND AGE AND LITHOLOGY OF COLLECTIONS MENTIONED IN TEXT BUT NOT DESCRIBED ELSEWHERE IN THIS REPORT—CONTINUED

MAP LOC. NO., FIELD NO., (USGS COLLN. NO.)	QUADRANGLE LATITUDE N/ LONGITUDE W.	FORMATION	LITHOLOGY	CONODONTS	AGE	BIOFACIES	CAI	REMARKS
loc. 4C1b, KW90A-68 (31211-PC)	Mt. Michelson A-5, 69°09.5'N/ 146°56.9'W	Wahoo Limestone, 64 m below contact with Echhooka Formation	Massive- to thick-bedded, skelatal-pelmatozoan packstone to grainstone containing brachiopods.	2 Pa elements <i>Adetognathus lautus</i> (Gunnell) 2 Pa elements <i>Adetognathus spathus</i> (Dunn) 2 Pa element fragments <i>Adetognathus</i> sp. indet. 4 Pa elements <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) 1 Sa element <i>Idiopriodontus</i> sp. indet. 3 Pa elements <i>Rhachistognathus minutus</i> <i>havenai</i> Baesemann and Lane 1 Pa element <i>Rhachistognathus minutus minutus</i> (Higgins and Bouckaert) 4 Pa elements <i>Rhachistognathus primus</i> Dunn 35 Pa element fragments <i>Rhachistognathus</i> sp. indet. 1 unassigned Sc element 24 indet. bar, blade, and platform fragments	<i>R. minutus</i> Fauna (early, but not earliest Morrowan to early Atokan, most likely early to middle Morrowan)	Postmortem transport within the rhachistognathid biofacies; high-energy, shallow-water, probable shoal depositional environment.	4.5	
loc. 4C1c, KW90A-105.3 (31212-PC)		Wahoo Limestone, 27 m below contact with Echhooka Formation	Bryozoan-echinoderm packstone containing minor grains of foraminifers, brachiopods, intraclasts, superficial ooids, and peloids. Grains are strongly recrystallized, poorly sorted, and moderately abraded.	1 Pa element <i>Adetognathus lautus</i> (Gunnell) 3 Pa elements <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) <i>Idiopriodontus</i> sp. indet. 1 M and 1 Sp? elements 2 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane		Indeterminate (too few conodonts); microfacies indicates open-platform near-shoal depositional environment.	4.5 and minor 6	
loc. 4D, KW90B-4.5 (31213-PC)	Sagavaniktok A-1, 69°02'N/ 147°03.5'W	Wahoo Limestone, 4.5 m below top of upper member	Recrystallized limestone; the only recognizable grains are common echinoderms, indeterminate bioclasts, and rare quartz.	10 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke) 9 Pa <i>Declinognathodus noduliferus noduliferus</i> (Ellison and Graves) 5 Pa elements <i>Idiogathodus sinuosus</i> Ellison and Graves 43 indet. bar, blade, and platform fragments 2 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke) 5 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 Pa element fragments <i>Rhachistognathus</i> sp. indet. 1 unassigned Sb element 6 indet. bar, blade, and platform fragments	<i>Idiogathodus</i> Fauna (late Morrowan to early Desmoinesian, probably no younger than early Atokan)	Declinognathodid; open- marine depositional environment.	6 and 6.5 and minor 5.5 and 7	Collection helps constrain the age of the uppermost part of the Wahoo Limestone near its type section (fig. 1, loc. 4).
loc. 4E, 87KWZ-0.0 (30184-PC)	Mt. Michelson A-5, 69°01.2'N/ 146°56.2'W	Top of Wahoo Limestone	Bryozoan-pelmatozoan grainstone containing micritized intraclasts of spiculitic mudstone and relatively large ramose and fenestrate bryozoans, corals, and brachiopods.	2 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke) 5 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 Pa element fragments <i>Rhachistognathus</i> sp. indet. 1 unassigned Sb element 6 indet. bar, blade, and platform fragments	early Morrowan (no older than lower <i>minutus</i> Fauna) to early Atokan	Indeterminate (too few conodonts); microlithofacies indicate redeposited grainstone (storm deposit?) interbedded with black argillaceous lime mudstone.	5	Collection dates top of Wahoo Limestone at type section (fig. 1, loc. 4).
Franklin Mountains								
loc. 5a, SKW91C-10 (31824-PC)	Mt. Michelson A-5, 69°07.6'N/ 146°26.0'W	Lower member of Wahoo Limestone, 299.5 m below contact between Wahoo and Echhooka Formation	Thick- to medium-bedded bryozoan packstone/wackestone.	69 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke), some trans- itional to <i>Gnathodus girtyi simplex</i> Dunn 3 Pa elements <i>Hindeodus minutus</i> (Ellison) 1 Pa element <i>Rhachistognathus prolixus</i> Baesemann and Lane 11 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Husri) UNASSIGNED ELEMENTS: 3 Pb and 5 Sc (3 morphotypes) 56 indet. bar, blade, and platform fragments	<i>D. noduliferus-R.</i> <i>primus</i> Zone (lower part of zone on the basis of <i>Gnathodus</i> <i>girtyi simplex</i> in sample 80 m higher in section)	Declinognathodid; probably open-marine depositional environment, near or below wave base.	5.5 and 6 and minor 6.5 and 7 and rare 5	From measured section at Pogopuk Creek (Morgan, 1992) (fig. 2, loc. 5). Collection marks base of <i>noduliferus-primus</i> Zone in section.

loc. 5b, SKM91C-90 (32222-PC)	Mt. Michelson A-5, 69°07.6'N 146°26.0'W	Lower member of Wahoo Limestone, 219.5 m below contact between Wahoo and Echoka Formation	Coarse-grained bryozoan and pelmatozoan grainstone-packstone containing minor algae and rare foraminifers and trilobite fragments; moderately abraded and poorly sorted.	1 Pa element <i>Cavusgnathus</i> ? <i>lythus</i> Brown and Rexroad 8 Pa elements <i>Declinognathodus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) 1 Pa element <i>Gnathodus girtyi simplex</i> Dunn 1 Pa element <i>Hindeodus</i> sp. indet. 2 Sb-Sc elements <i>Kladognathus</i> sp. 2 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) UNASSIGNED ELEMENTS: 5 Pa, 4 Pb, 1 M, and 2 Sc 21 indet. bar. blade, and platform fragments	<i>D. noduliferus</i> - <i>R. primus</i> Zone (lower part of zone? on the basis of <i>Gnathodus girtyi simplex</i>)	Indeterminate (too few conodonts); relatively shallow-water, normal-marine depositional environment.	5-6.5	Collection shows occurrence of <i>Gnathodus girtyi simplex</i> in the <i>noduliferus-primus</i> Zone.
loc. 5c, SKM91C-175.5 (32231-PC)		Lower member of Wahoo Limestone, 134 m below contact between Wahoo and Echoka Formation	Bryozoan and pelmatozoan packstone-grainstone containing minor brachiopod and bivalve fragments, intraclasts, and detrital clasts; moderately abraded and poorly sorted.	1 Pa element <i>Adetognathus lautus</i> (Gunnell) 1 Idiopriodontid element 2 Pa elements <i>Rhachistognathus minutus</i> <i>minutus</i> (Higgins and Bouckaert)? 33 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 2 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 11 Pa elements <i>Rhachistognathus</i> sp. indet. 10 indet. bar. blade, and platform fragments 5 Pa elements <i>Gnathodus defectus</i> Dunn <i>Idiopriodontus conjunctus</i> (Gunnell) 1 Pa, 3 Pb, 1 M, 4 Sa, 1 Sb, and 3 Sc elements 2 Pa elements <i>Rhachistognathus minutus</i> <i>haverai</i> Baesemann and Lane 3 Pa elements <i>Rhachistognathus minutus</i> <i>minutus</i> Baesemann and Lane 59 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 15 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane UNASSIGNED ELEMENTS: 2 M (2 morphotypes) 121 indet. bar. blade, and platform fragments 6 Pa elements <i>Adetognathus lautus</i> (Gunnell) 1 Pa element <i>Hindeodus</i> sp. indet. 2 Idiopriodontid elements 18 Pa elements <i>Rhachistognathus minutus</i> subsp. 14 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 6 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 1 Pa element fragment <i>Declinognathodus</i> <i>noduliferus</i> (Ellison and Graves)? 10 Pa element fragments <i>Rhachistognathus</i> spp. indet. 54 indet. bar. blade, and platform fragments	lower <i>R. minutus</i> Fauna (Morrowan, but not earliest Morrowan)	Postmortem transport from or within the rhachistognathid biofacies; normal-marine, possible shoal-apron depositional environment.	4-4.5 6	Collection marks base of lower <i>minutus</i> Fauna.
loc. 5d, SKM91C-187 (31860-PC)		Lower member of Wahoo Limestone, 122.5 m below base of Echoka Formation	Bryozoan and pelmatozoan, superficial ooid grainstone containing minor brachiopod, bivalve, and algal fragments; strongly abraded and well sorted.	1 Pa element <i>Adetognathus lautus</i> (Gunnell) 1 Pa element <i>Hindeodus</i> sp. indet. 2 Idiopriodontid elements 18 Pa elements <i>Rhachistognathus minutus</i> subsp. 14 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 6 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 1 Pa element fragment <i>Declinognathodus</i> <i>noduliferus</i> (Ellison and Graves)? 10 Pa element fragments <i>Rhachistognathus</i> spp. indet. 54 indet. bar. blade, and platform fragments	Collection shows occurrence of <i>Gnathodus defectus</i> in lower <i>minutus</i> Fauna.			
loc. 5e, SKM91C-219 (32232-PC)		Lower member of Wahoo Limestone, 90.5 m below base of Echoka Formation	Bryozoan and pelmatozoan grainstone; moderately abraded and sorted.	1 Pa element <i>Adetognathus lautus</i> (Gunnell) 1 Pa element <i>Hindeodus</i> sp. indet. 2 Idiopriodontid elements 18 Pa elements <i>Rhachistognathus minutus</i> subsp. 14 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) 6 Pa elements <i>Rhachistognathus websteri</i> Baesemann and Lane 1 Pa element fragment <i>Declinognathodus</i> <i>noduliferus</i> (Ellison and Graves)? 10 Pa element fragments <i>Rhachistognathus</i> spp. indet. 54 indet. bar. blade, and platform fragments	Collection marks top of lower <i>minutus</i> Fauna.			
loc. 5f, SKM91C-309.5 (32233-PC)		Upper member of Wahoo Limestone, 49.5 m above base	Oolitic, brachiopod, bivalve grainstone containing minor bryozoan and pelmatozoan fragments, gastropods, superficial ooids, and intraclasts; moderately abraded and very poorly sorted.	1 Pa element <i>Adetognathus lautus</i> (Gunnell)? 1 Pa element <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) 1 juvenile Pa element <i>Idiogathodus</i> sp. indet. 1 Pb? element <i>Idiopriodontus</i> sp. indet. 3 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 Pa elements <i>Rhachistognathus minutus</i> <i>haverai</i> Baesemann and Lane 1 Pa element <i>Rhachistognathus minutus minutus</i> (Higgins and Bouckaert) 47 indet. bar. blade, and platform fragments	<i>Idiogathodus</i> Fauna (late Morrowan to early Atokan)	Indeterminate (too few conodonts); normal-marine, shallow-water, probably high-energy depositional environment. Microlithofacies indicates a storm-induced spill-over lobe.	4-4.5	Collection dates uppermost part of Wahoo Limestone at Pogopuk Creek section.

APPENDIX 1. CONODONT FAUNAS, BIOFACIES, AND AGE AND LITHOLOGY OF COLLECTIONS MENTIONED IN TEXT BUT NOT DESCRIBED ELSEWHERE IN THIS REPORT—CONTINUED

MAP LOC. NO., FIELD NO. (USGS COLLN. NO.)	QUADRANGLE, LATITUDE N/ LONGITUDE W.	FORMATION	LITHOLOGY	CONODONTS	AGE	BIOFACIES	CAI	REMARKS
loc. 6, 87PG-F-112.0 (30266-PC)	Mt. Michelson B-4, 69°15.1'N/ 146°10.6'W	Uppermost part of lower member of Wahoo Limestone, within upper 0.5 m	Pelmatozoan packstone containing common ooids, bryozoans, intracrystals and minor peloids, algae, trilobites, foraminifers, gastropods, bivalves, and bryozoans.	14 Pa elements <i>Cavusgnathus? tythus</i> Brown and Hexroad 18 Pa element fragments of <i>cavusgnathoids</i> 1 Sc element <i>Hindeodus minutus</i> (Ellison) 6 indet. bar, blade, and platform fragments	Upper <i>muricatus</i> Subzone to lower <i>noduliferus-primus</i> Zone (very latest Chesterian to very earliest Morrowan)	Cavusgnathid biofacies; relatively shallow-water, probably near-restricted depositional environment.	6 and minor 4	From measured section at Plunge Creek (Gruzovic, 1991; fig. 2, loc. 6); includes 43 m of upper part of Alapah Limestone and 245.5 m of the Wahoo Limestone. Collection dates uppermost part of lower member and contains abundant <i>Cavusgnathus? tythus</i> .
Fourth Range								
loc. 7a, AK90A-353 (32473-PC)	Mt. Michelson B-3, 69°21.1'N/ 145°38.7'W	Wahoo Limestone, lower member, 49 m above contact with Alapah Limestone and 19.5 m below lowest Pennsylvanian collection in the section	Slightly dolomitic bryozoan-pelmatozoan packstone containing chert replacement grains; minor grain types include fenestrate bryozoans, and brachiopods.	26 Pa elements <i>Gnathodus girtyi</i> Girty Hass 15 Pa elements <i>Gnathodus girtyi simplex</i> Dunn <i>Hindeodus minutus</i> (Ellison) 4 Pa, 3 M, 1 Sb, and 1 Sc elements <i>Idiopriolodus</i> sp. indet. 1 Sb and 1 Sc elements <i>Kladognathus</i> sp. indet. 1 P and 1 Sb-Sc element fragments 136 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Huxley) 165 indet. bar, blade, and platform fragments	late Chesterian	Postmortem winnow within or from the vogelgnathid- gnathodid biofacies; normal- marine depositional environment.	5.5-7	Conodont collection from Gruzovic's (1991) section (fig. 2, loc. 7). Collection contains abundant <i>Vogelgnathus</i> <i>postcampbelli</i> and shows its biofacies associates.
loc. 7b, AK90A-490 (31838-PC)		Wahoo Limestone, 117.5 m above base of upper member and immediately below contact with Echooka Formation	Oolitic grainstone containing abundant superficial ooids and minor pelmatozoans, bryozoans, foraminifers, bivalves, ostracodes, and intracrystals.	4 Pa elements <i>Declingnathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) 19 Pa elements <i>Declingnathodus noduliferus</i> <i>noduliferus</i> (Ellison and Graves) 1 Pa element <i>Idiogonathodus incurvus</i> Dunn? 36 Pa elements <i>Idiogonathodus sinuosus</i> Ellison and Graves (subadult and abraded specimens) 2 <i>Idiopriolodus</i> sp. indet. elements 1 unassigned Pb element 40 indet. bar, blade, and platform fragments	<i>Idiogonathodus</i> Fauna (early Atokan to early Desmoinesian?)	Idiogonathid- declingnathodid biofacies; normal-marine, near-shoal depositional environment.	4-4.5	Collection dates top of Wahoo Limestone.
Shublik Mountains								
loc. 8, 89MR-36A (30895-PC)	Mt. Michelson B-4, 69°29.3'N/ 145°54.5'W	Uppermost part of Wahoo Limestone	Medium-grained bioclastic grainstone.	1 Pa element <i>Adelognathus laevis</i> (Gunnell) 4 Pa element fragments <i>Adelognathus</i> sp. indet. 1 juvenile Pa element <i>Idiogonathodus</i> sp. indet. 9 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 1 unassigned M element 16 indet. bar, blade, and platform fragments	<i>Idiogonathodus</i> Fauna (late Morrowan to early Atokan)	Indeterminate (too few conodonts).	3.5	Collection dates uppermost part of Wahoo Limestone (fig. 2, loc. 8).
Romanzof Mountains								
loc. 9A, 88KWF-0.0 (30277-PC)	Demarcation Point B-4, 69°23.1'N/ 143°02.7'W	Wahoo Limestone, 1 m below contact with Echooka Formation	Oolitic, pelmatozoan grainstone containing strongly abraded and well- sorted grains.	3 Pa fragments <i>Adelognathus laevis</i> (Gunnell) 1 Pa element <i>Declingnathodus noduliferus</i> <i>japonicus</i> (Igo and Koike) 1 Pa element fragment <i>Idiogonathodus</i> sp. indet. 5 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 rhachistognathid Pa element fragments UNASSIGNED ELEMENTS: 1 M 30 indet. bar, blade, and platform fragments	<i>Idiogonathodus</i> Fauna (late Morrowan to early Atokan)	Indeterminate (too few conodonts). Microlithofacies indicates a shoal environment.	4.5 and minor 5.5 and 6	Collection dates Wahoo Limestone 1 m below contact with Echooka Formation; Aichilik River area (fig. 1, loc. 9A).

loc. 9B1a, ME92C-776 (32228-PC)	Demarcation Point A-3, 69°08.7'N 142°18.2'W	Alapah Limestone, 776 m above base	Brzoan packstone.	<p>2 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller</p> <p>2 Pa element fragments of <i>cavusgnathoids</i></p> <p>1 Pb element <i>Idiopriodontus cf. l. healdi</i> (Roundy)</p> <p>1 Pb element <i>Idiopriodontus</i> sp. indet.</p> <p>1 Sb-Sc element <i>Kladognathus</i> sp.</p> <p>1 Pa element <i>Rhachistognathus muricatus</i> (Dunn)</p> <p>1 Pa element <i>Rhachistognathus prolixus</i> Baesemann and Lane</p> <p>2 <i>rhachistognathid</i>? Pa elements</p> <p>33 indet. bar, blade, and platform fragments</p> <p>26 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller (juveniles and adults)</p> <p>32 Pa element fragments of <i>cavusgnathoids</i></p> <p>11 Pa elements <i>Gnathodus girtyi</i> Hess</p> <p>2 Pa elements <i>Gnathodus girtyi simplex</i> Dunn</p> <p>13 Pa elements <i>Gnathodus girtyi</i> subsp. (12 juveniles)</p> <p>1 <i>Idiopriodontid</i> element</p> <p><i>Kladognathus</i> sp. indet.</p> <p>1 P, 1 M, 2 Sa, and 6 Sb-Sc elements</p> <p>1 <i>kladognathid</i> element</p> <p>6 Pa elements <i>Rhachistognathus muricatus</i> (Dunn)</p> <p>24 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Husri)</p> <p>UNASSIGNED ELEMENTS: 2 Pb and 1 M</p> <p>187 indet. bar, blade, and platform fragments</p>	<i>R. muricatus</i> Zone (very late Chesterian)	Indeterminate (too few conodonts); shallow-water, normal-marine, moderate- to high-energy depositional environment.	4.5 and minor 6	From measured section at North Bathub Ridge (fig. 1, loc. 9B). Section 1,249 m thick, includes entire Alapah Limestone (935 m) and entire Wahoo Limestone (314 m). Section measured and sampled by Eckstein (1993). These two collections mark the base and top of the thickest interval of the <i>R. muricatus</i> Zone in the northeast Brooks Range.
loc. 9B1b, ME92C-974.5 (32229-PC)		Wahoo Limestone, 39.5 m above base	Pelmatozoan packstone.	<p>4 Pa elements <i>Adelognathus lautus</i> (Gunnell)</p> <p>13 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller</p> <p>5 Pa fragments of <i>cavusgnathoids</i></p> <p><i>Hindeodus minutus</i> (Ellison)</p> <p>3 Pa, 1 Pb, 1 M, 1 Sa, 5 Sb, and 2 Sc elements</p> <p>1 Sb-Sc element <i>Kladognathus</i> sp. indet.</p> <p>1 Pa element <i>Vogelgnathus postcampbelli</i> (Austin and Husri)</p> <p>UNASSIGNED ELEMENTS: 5 Pb, 12 M (3 morphotypes), 1 Sb, and 1 Sc</p> <p>63 indet. bar, blade, and platform fragments</p> <p>2 Pa elements <i>Adelognathus lautus</i> (Gunnell)</p> <p>82 Pa elements <i>Cavusgnathus unicornis</i> Youngquist and Miller</p> <p>66 Pa element fragments of <i>cavusgnathoids</i></p> <p>3 Pa elements <i>Cavusgnathus? tythrus</i> Brown and Rexroad</p> <p>20 Pa elements <i>Gnathodus girtyi simplex</i> Dunn</p> <p><i>Hindeodus minutus</i> (Ellison)</p> <p>2 Pa, 1 Sa, and 1 Sc elements</p> <p><i>Kladognathus</i> sp.</p> <p>7 M and 14 Sb-Sc elements</p> <p>2 Pa elements <i>Vogelgnathus postcampbelli</i> (Austin and Husri)</p> <p>UNASSIGNED ELEMENTS: 3 Pb and 4 M (3 morphotypes)</p> <p>~250 indet. bar, blade, and platform fragments</p> <p>1 Pa element <i>Cavusgnathus? tythrus</i> Brown and Rexroad</p> <p>2 Pa <i>cavusgnathid</i> fragments</p> <p>2 indet. bar, blade, and platform fragments</p>	Upper <i>R. muricatus</i> Subzone (very latest Chesterian)	Postmortem winnow from or within the <i>cavusgnathid</i> -hindeodid biotides; relatively shallow water, near intermittently(?) restricted depositional environment.	4.5 and minor 6	From measured section, 349.4 m thick, of upper part of the Alapah Limestone and lower and upper members of the Wahoo Limestone. Section in cliffs on north bank of Clarence River, British Mountains (fig. 1, loc. 10), about 2 km west-northwest of Armstrong and Mamet's (1975) Clarence River section. Section measured by K.F. Watts and J.A. Dumoulin (U.S. Geological Survey). Section also measured and sampled by S.K. Morgan (University of Alaska Fairbanks). The first five collections represent the thickest interval of the Upper <i>R. muricatus</i> Subzone in the northeast Brooks Range.
loc. 10A1a, KW91Y-0.5 (31795-PC)	Demarcation Point B-1, 69°25.5'N 141°04.1'W	Alapah Limestone, 0.5 m above base	Dark-gray to black, massive, full-iron bryozoan wackestone/bafflestone; bedding indistinct and irregular.	<p>Upper part of Alapah Limestone, 9.3 m below contact with Wahoo Limestone</p>				
loc. 10A1b, KW91Y-44 (31796-PC)		Upper part of Alapah Limestone, 9.3 m below contact with Wahoo Limestone	Medium-gray, bioclastic, crinoidal packstone.					
loc. 10A1c, KW91Y-89 (31798-PC)		Lower member of Wahoo Limestone, 35.7 m above base of formation	Brownish-gray to medium-gray, bioclastic, pelmatozoan packstone-grainstone.					

**APPENDIX 1. CONODONT FAUNAS, BIOFACIES, AND AGE AND LITHOLOGY OF COLLECTIONS MENTIONED IN TEXT
BUT NOT DESCRIBED ELSEWHERE IN THIS REPORT—CONTINUED**

MAP LOC. NO., FIELD NO. (USGS COLL. NO.)	QUADRANGLE LATITUDE N/ LONGITUDE W.	FORMATION	LITHOLOGY	CONODONTS	AGE	BIOFACIES	CAI	REMARKS
loc. 10A1d, KW91Y+115 (31799-PC)	Demarcation Point B-1, 69°25.5'/ 141°04.1'	Lower member of Wahoo Limestone, 61.7 m above base of formation	Massive, medium-gray, bioclastic packstone- grainstone; skeletal locally silicified and include crinoids (some articulated columnals) and brachiopods.	11 Pa elements <i>Cavusgnathus unicomis</i> Youngquist and Miller 3 Pa elements <i>Gnathodus girtyi simplex</i> Dunn 17 indet. bar, blade, and platform fragments	Upper <i>R. muricatus</i> Subzone (very latest Chesterian)	Indeterminate (too few conodonts); probably postmortem transport from cavusgnathid biofacies; deposited in relatively shallow or moderate water depths.	4, 4.5, and minor 6	
loc. 10A1e, KW91Y+132.5 (31800-PC)		Lower member of Wahoo Limestone, 79.2 m above base of formation	Light-medium-gray, bioclastic packstone; skeletal include crinoids and ramose bryozoans; contains possible superficial ooids and crossbeds.	11 Pa elements <i>Cavusgnathus unicomis</i> Youngquist and Miller 1 cavusgnathoid Pa element fragment 2 Pa elements <i>Gnathodus girtyi simplex</i> Dunn 1 Pa element <i>Hindeodus minutus</i> (Ellison) 1 Sa and 1 Sb-Sc elements <i>Kladognathus</i> sp. 10 indet. bar, blade, and platform fragments		Indeterminate (too few conodonts); normal-marine depositional environment.	4.5	
loc. 10A1f, SKM92B-196.4 (32230-PC)		Upper member of Wahoo Limestone, 196.4 m above base of formation and 79.4 m above base of upper member	Oolitic, bryozoan, pelmatozoan, intraclastic grainstone containing minor algal, gastropod, and trilobite fragments; strongly abraded and moderately sorted.	8 Pa elements <i>Adelognathus lautus</i> (Gunnell) 3 Pa elements <i>Cavusgnathus? lythius</i> Brown and Hexrood 3 Pa elements <i>Declinognathodus inaequalis</i> (Higgins) 4 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 3 Pa elements <i>Rhachistognathus minutus</i> <i>havelnai</i> Baesemann and Lane 1 Pa element <i>Rhachistognathus minutus minutus</i> Baesemann and Lane 4 Pa elements <i>Rhachistognathus minutus</i> subsp. indet. 8 Pa elements <i>Rhachistognathus muricatus</i> (Dunn) (2 <i>R. websteri</i> morphotypes) 52 indet. bar, blade, and platform fragments	lower <i>minutus</i> Fauna (early, but not earliest Morrowan)	Rhachistognathid- adelognathid biofacies. Relatively shallow water, probably near-shoal to open-platform depositional environment, moderate to high energy.	6 and minor 4	Collection documents lower <i>minutus</i> Fauna.
loc. 10A1g, KW91Y+347.6 (31805-PC)		Upper member of Wahoo Limestone, 294.3 m above base of formation and 124 m above base of upper member	Crimoidal packstone containing 30-40 percent chert in nodules and bands.	8 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke) 9 Pa elements <i>Idiognathodus</i> sp. indet. (juveniles and incomplete adults) 1 Pa element <i>Rhachistognathus minutus</i> subsp. indet. 1 unassigned Sc element 68 indet. bar, blade, and mostly platform fragments	<i>Idiognathodus</i> Fauna (late Morrowan to early Atokan)	Idiognathoid- declinognathoid biofacies; normal-marine, shallow to at least moderately deep depositional environment.	4, 5-5	Collection dates uppermost part of exposed Wahoo Limestone in the measured section.
loc. 10A1h, KW91Y+TOP (31806-PC)		Wahoo Limestone, upper member, about 8-10 m below contact with Echooka Formation; distance above base of section uncertain	<i>Osagila?</i> grainstone.	16 Pa elements <i>Adelognathus lautus</i> (Gunnell) 1 juvenile Pa element fragment <i>Idiognathodus</i> sp. indet. 1 Pa element <i>Rhachistognathus minutus havelnai</i> Baesemann and Lane UNASSIGNED ELEMENTS: 2 Pb (2 morphotypes) and 2 Sc 10 indet. bar, blade, and platform fragments		Adelognathid biofacies; shallow to moderate depth, normal-marine depositional environment.	4-4.5	Collection from 30 m west of section KW91Y dates the highest part of Wahoo Limestone exposed beneath the Echooka Formation in this area.
loc. 10B, 85TR83A1 (29888-PC)	Demarcation Point, 69°25.0'/ 141°00.0'	Near top of Lisburne Group	Olive- to dark-gray, fine- grained limestone.	8 Pa elements <i>Adelognathus lautus</i> (Gunnell) 5 Pa elements <i>Declinognathodus noduliferus</i> <i>japonicus</i> (Igo and Kolke)? 24 Pa elements <i>Idiognathodus sinuosus</i> Ellison and Graves 1 Pa element fragment <i>Idiognathodus</i> sp. indet. 3 element fragments <i>Idiognathodus</i> sp. indet. 10 Pa elements <i>Rhachistognathus minutus</i> <i>declinatus</i> Baesemann and Lane 2 unassigned Pb elements +100 indet. bar, blade, and platform fragments	<i>Idiognathodus</i> Fauna (late Morrowan to early Atokan)	Idiognathoid- rhachistognathid; normal- marine depositional environment, possibly near shoal.	4.5 and 6	Collection from slight bench near summit of weak spur on south side of ridge just west of saddle containing international boundary marker; Yukon, Canada. Collection dates uppermost part of Wahoo Limestone at international border (fig. 1, loc. 10).

PLATES 1–5

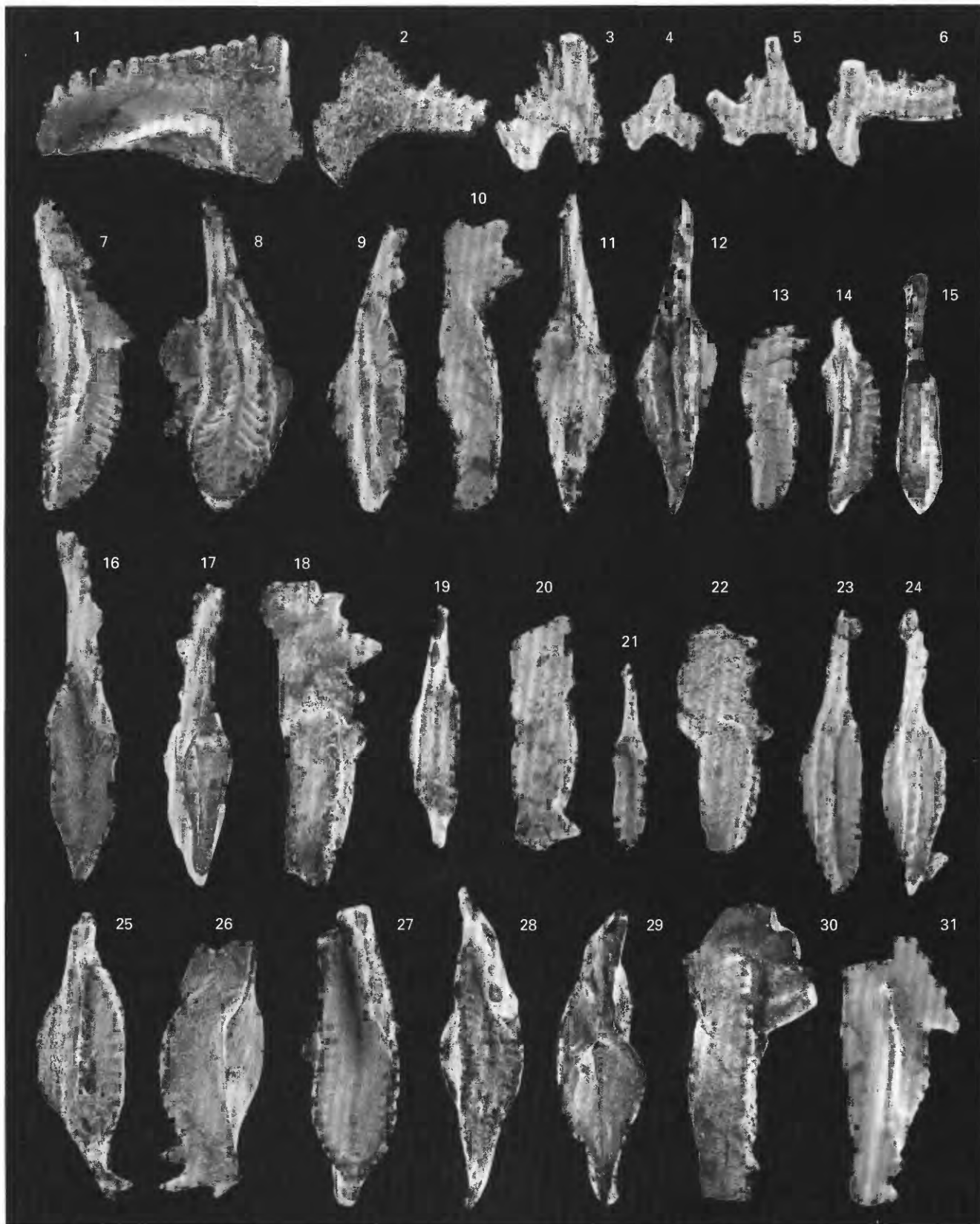
PLATE 1

Conodonts from the Wahoo Limestone, eastern Sadlerochit Mountains, northeast Brooks Range, Alaska.

[Scanning electron microscope photomicrographs of specimens coated
with carbon and gold. Meters shown are above base of formation]

Figures

- 1–6. *Hindeodus minutus* (Ellison), ×50, lower member.
 1. Pa element, outer lateral view, 42 m (USGS colln. 30754–PC), USNM 442115.
 2. Pb element, inner lateral view, 69 m (USGS colln. 30762–PC), USNM 442116.
 - 3–4. M and Sa elements, posterior and lateral views, 53 m (USGS colln. 30757–PC), USNM 442117–118.
 - 5–6. Sb and Sc elements, lateral views, 69 m (USGS colln. 30762–PC), USNM 442119–20.
- 7–12. *Cavusgnathus? tythius* Brown and Rexroad, Pa elements, lower member.
 - 7–8. α morphotype, oblique upper and upper views, 56 m (USGS colln. 30758–PC), USNM 442121–122; figure 7, ×50 and figure 8, ×35.
 - 9–10. β morphotype, ×50, upper and lateral views of specimen with left-trending carinal extension of blade, 22 m (USGS colln. 30750–PC), USNM 442123.
 - 11–12. γ morphotype, ×50, lower and upper views of specimen with central free blade and carina, 50.5 m (USGS colln. 30756–PC), USNM 442124.
- 13–15, 21–24. *Adetognathus lautus* (Gunnell), Pa elements, ×50, upper member.
 13. Left element with short, right-trending carinal extension of blade, lateral view, 113 m (USGS colln. 30775–PC), USNM 442125.
 - 14–15. Left elements with right-trending carinal extension of blade, upper views, 107 m (USGS colln. 30774–PC), USNM 442126–27.
 21. Right element, upper view, 85 m (USGS colln. 30768–PC), USNM 442130.
 22. Right element, inner lateral view, 91 m (USGS colln. 30770–PC), USNM 442131.
 23. Left element, upper view, 133.5 m (USGS colln. 30778–PC), USNM 442132.
 24. Left element, upper view, 85 m (USGS colln. 30768–PC), USNM 442133.
- 16–20, 25–26. *Adetognathus spathus* (Dunn), Pa elements, upper member.
 - 16–18. Right element, upper, lower, and inner lateral views, 157 m (USGS colln. 30781–PC), USNM 442128; figure 16, ×50 and figures 17–18, ×40.
 - 19–20. Left element, upper and outer lateral views, ×50, 157 m (USGS colln. 30781–PC), USNM 442129.
 - 25–26. Left element, upper and oblique lower views, ×50, 246 m (USGS colln. 30795–PC), USNM 442134.
27. *Cavusgnathus altus* Harris and Hollingsworth, Pa element, ×50, upper view, lower member, 7 m (USGS colln. 30747–PC), USNM 442135.
- 28–31. *Cavusgnathus unicornis* Youngquist and Miller, Pa elements, lower member.
 - 28–30. γ morphotype, upper, lower, and inner lateral views, ×35, 22 m (USGS colln. 30750–PC), USNM 442136.
 31. α morphotype, inner lateral view, ×50, 50.5 m (USGS colln. 30756–PC), USNM 442137.



ADETOGNATHUS, CAVUSGNATHUS, CAVUSGNATHUS?, AND HINDEODUS

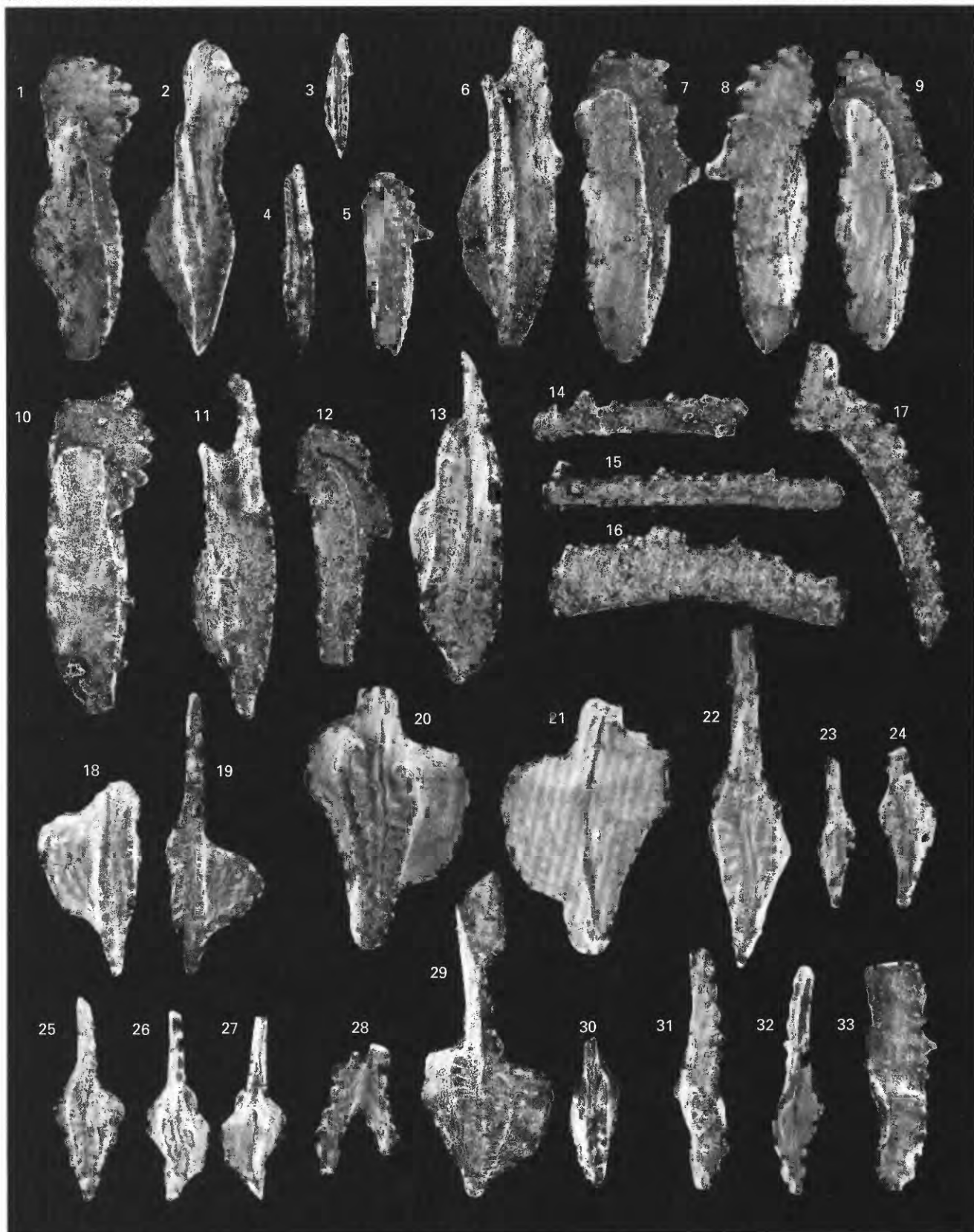
PLATE 2

Conodonts from the Wahoo Limestone, eastern Sadlerochit Mountains, northeast Brooks Range, Alaska.

[Scanning electron microscope photomicrographs of specimens coated
with carbon and gold. Meters shown are above base of formation]

Figures

- 1–17. *Cavusgnathus unicornis* Youngquist and Miller, lower member.
 - 1–2. Pa element, γ morphotype, inner lateral and upper views, $\times 50$, 6 m (USGS colln. 30746–PC), USNM 442138.
 3. Pa element, juvenile, $\times 50$, upper view, 13.2 m (USGS colln. 30748–PC), USNM 442139.
 - 4–7. Pa elements, upper and inner lateral views, 7 m (USGS colln. 30747–PC).
 - 4–5. α morphotype, $\times 50$, USNM 442140.
 - 6–7. β morphotype, $\times 45$, USNM 442141.
 - 8–9. Pa element, α morphotype, $\times 40$, outer and inner lateral views, 42 m (USGS colln. 30754–PC), USNM 442142.
 - 10–12, 14–17. 0.4 m (USGS colln. 30745–PC).
 - 10–12. Pa elements, inner lateral, upper, and inner lateral views.
 - 10–11. γ morphotype, $\times 45$, USNM 442143.
 12. α ? morphotype, $\times 50$, USNM 442144.
 - 14–15. Two Sc elements, $\times 30$, lateral views, USNM 442146–47.
 16. Pb element, $\times 40$, lateral view, USNM 442148.
 17. M element, $\times 50$, lateral view, USNM 442149.
 13. Pa element, $\times 45$, upper view, 22 m (USGS colln. 30750–PC), USNM 442145.
- 18–19. *Gnathodus bilineatus bilineatus* (Roundy), Pa elements, $\times 50$, upper views, lower member.
 18. Left element, 37 m (USGS colln. 30753–PC), USNM 442150.
 19. Right element, 7 m (USGS colln. 30747–PC), USNM 442151.
- 20–22. *Gnathodus girtyi girtyi* Hass, right Pa elements, $\times 50$, lower member.
 - 20–21. Upper and lower views, 53 m (USGS colln. 30757–PC), USNM 442152.
 22. Upper view, 32 m (USGS colln. 30752–PC), USNM 442153.
- 23–24, 31–33. *Gnathodus defectus* Dunn, Pa elements, $\times 75$, upper member.
 - 23–24. Left and right elements, upper views, 102 m (USGS colln. 30773–PC), USNM 442154–155.
 - 31–33. Right element, upper, lower, and inner lateral views, 85 m (USGS colln. 30768–PC), USNM 442160.
- 25–27. *Gnathodus girtyi simplex* Dunn, $\times 50$, right Pa elements, lower member.
 25. Upper view, 32 m (USGS colln. 30752–PC), USNM 442156.
 - 26–27. Upper and lower views, 37 m (USGS colln. 30753–PC), USNM 442157.
28. *Gnathodus* sp. indet., M element, $\times 50$, inner lateral view, lower member, 53 m (USGS colln. 30757–PC), USNM 442158.
29. *Gnathodus girtyi girtyi* Hass transitional to *Declinognathodus inaequalis* (Higgins), right Pa element, $\times 40$, upper view, lower member, 69 m (USGS colln. 30762–PC), USNM 442159.
30. *Gnathodus girtyi simplex* Dunn transitional to *Declinognathodus noduliferus japonicus* (Igo and Koike), left Pa element, $\times 50$, upper view, lower member, 54.9 m (USGS colln. 31698–PC), USNM 483406.



CAVUSGNATHUS AND GNATHODUS

PLATE 3

All conodonts from the Wahoo Limestone at study section,
eastern Sadlerochit Mountains, northeast Brooks Range, Alaska,
except figure 31, which is from 1 km to the west.

[Scanning electron microscope photomicrographs of specimens coated
with carbon and gold. Meters shown are above base of formation]

Figures 1–8, 19–22. *Declinognathodus noduliferus japonicus* (Igo and Koike), Pa elements.

1–8. Right Pa elements, lower member.

1–2. Upper and lower views, ×40, 62 m (USGS colln. 30760–PC), USNM 442161.

3. Upper view, ×50, 59 m (USGS colln. 30759–PC), USNM 442162.

4–8. Figures 4–6 upper views, 7–8 upper and lower views, ×50, 56 m (USGS colln. 30758–PC), USNM 442163–166.

19–22. Upper member.

19–20. Left element, ×40, lower and upper views (blade broken during SEM preparation), 207 m (USGS colln. 30789–PC), USNM 442175.

21. Right element, ×50, upper view, 250 m, (USGS colln. 30796–PC), USNM 442176.

22. Right element, ×50, upper view, 207 m (USGS colln. 30789–PC), USNM 442177.

9. *Declinognathodus noduliferus japonicus* (Igo and Koike) transitional to *D. n. noduliferus* (Ellison and Graves), right Pa element, ×50, upper view, lower member, 62 m (USGS colln. 30760–PC), USNM 442167.

10–14, 32. *Declinognathodus noduliferus noduliferus* (Ellison and Graves), Pa elements, upper views, ×50, upper member.

10. Right element, juvenile, 113 m (USGS colln. 30775–PC), USNM 442168.

11. Left element, 85 m (USGS colln. 30768–PC), USNM 442169.

12. Right element, 133.5 m (USGS colln. 30778–PC), USNM 442170.

13. Left element, 177 m (USGS colln. 30785–PC), USNM 442171.

14. Right element, 250 m (USGS colln. 30796–PC), USNM 442172.

32. Left element (*lateralis* morphotype), 187 m (USGS colln. 30786–PC), USNM 442184.

15–18, 23–25. *Idiognathodus sinuosus* Ellison and Graves, Pa elements, ×50, upper member.

15–16. Juvenile, upper and lower views, 207 m (USGS colln. 30789–PC), USNM 442173.

17–18. Lower and upper views, 187 m (USGS colln. 30786–PC), USNM 442174.

23–25. Upper and upper and lower views, 207 m (USGS colln. 30789–PC), USNM 442178–179.

26–27. *Lochriea commutata* (Branson and Mehl), ×50, lower member, 6 m (USGS colln. 30746–PC).

26. Left Pa element, upper view, USNM 442180.

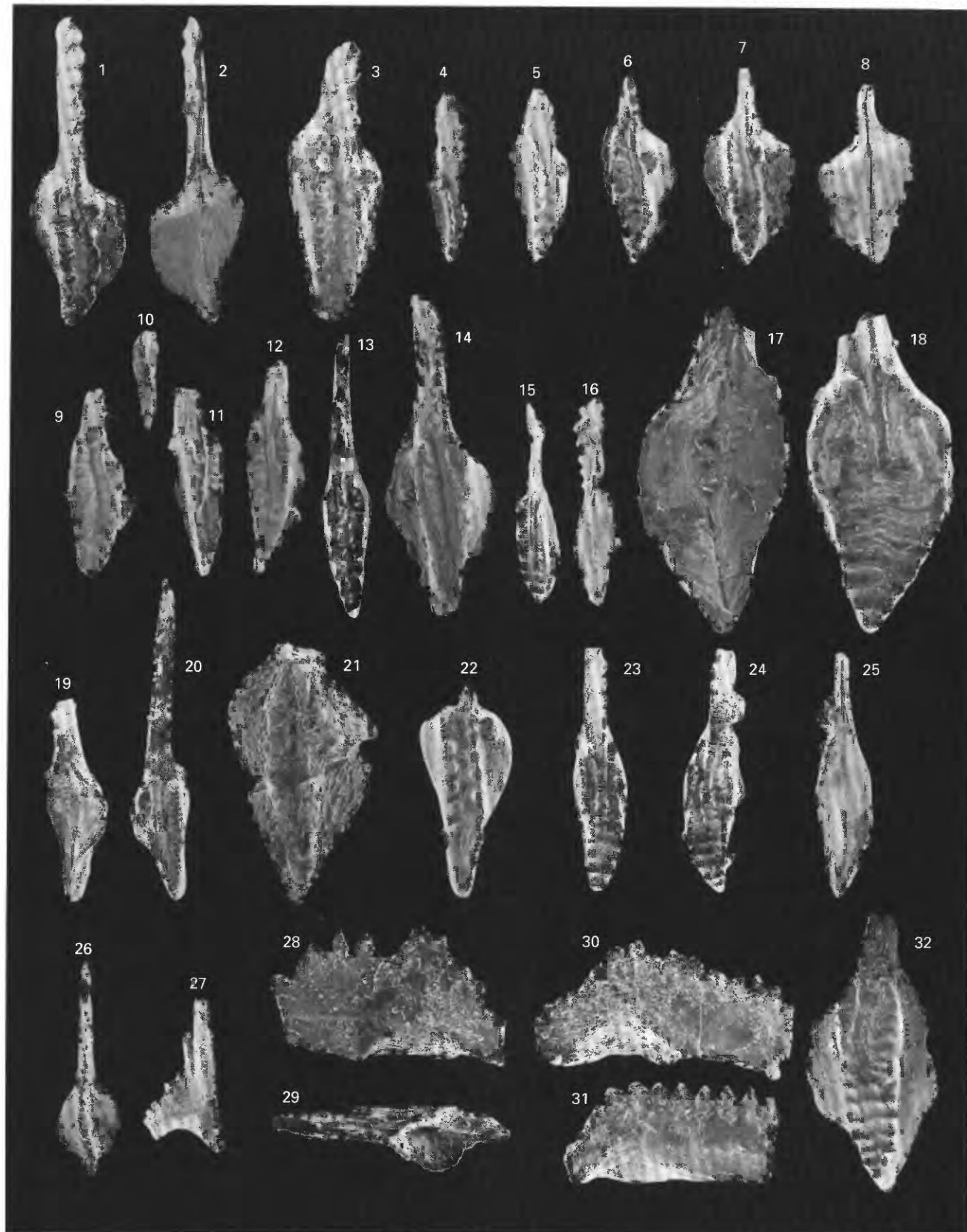
27. M element, lateral view, USNM 442181.

28–31. *Vogelgnathus postcampbelli* (Austin and Husri), Pa elements, lower member.

28–29. Lateral and lower oblique views, 13.2 m (USGS colln. 30748–PC), USNM 442182.

30. Lateral view, 53 m (USGS colln. 30757–PC), USNM 442183.

31. Lateral view, 55.3 m (USGS colln. 31836–PC, app. 1, loc. 1B1g), USNM 483407. From Mississippian-Pennsylvanian boundary section 1 km west of study section. Sample from 2.8 m above the first appearance of *Declinognathodus noduliferus japonicus* in the eastern Sadlerochit Mountains.



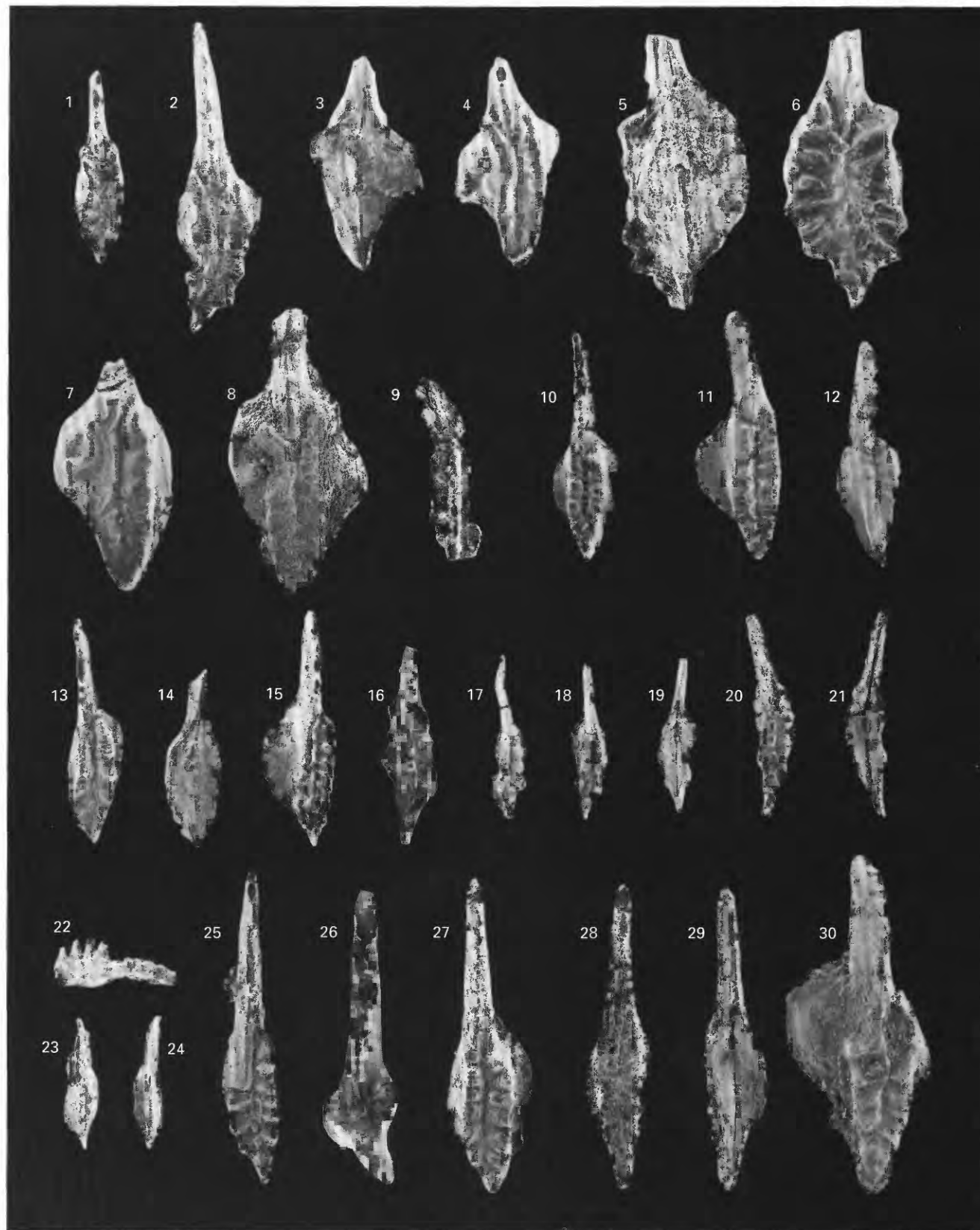
DECLINOGNATHODUS, IDIOGNATHODUS, LOCHRIEA, AND VOGELGNATHUS

PLATE 4

Conodonts from the Wahoo Limestone, eastern Sadlerochit Mountains,
northeast Brooks Range, Alaska, except figure 26 from Pogopuk Creek section,
Franklin Mountains (see text-fig. 2).

[Scanning electron microscope photomicrographs of specimens coated
with carbon and gold. Meters shown are above base of formation]

- Figures 1–9. *Rhachistognathus minutus declinatus* Baesemann and Lane, Pa elements, ×50, upper member.
1. Right element, upper view, 107 m (USGS colln. 30774–PC), USNM 442185.
 2. Right element, upper view, 177 m (USGS colln. 30785–PC), USNM 442186.
 - 3–4. Right element, lower and upper views, with node on anterior part of inner lobe, 187 m (USGS colln. 30786–PC), USNM 442187.
 - 5–6. Left element, lower and upper views, 187 m (USGS colln. 30786–PC), USNM 442188.
 7. Right element, upper view, with transverse ridge connecting node on inner lobe to parapet, 191.5 m (USGS colln. 30787–PC), USNM 442189.
 8. Right element, upper view with node on inner lobe, 232 m (USGS colln. 30793–PC), USNM 442190.
 9. Right element, upper view, 85 m (USGS colln. 30768–PC), USNM 442191.
- 10–12. *Rhachistognathus minutus havlenai* Baesemann and Lane, Pa elements, ×50, upper views, upper member.
- 10–11. Right elements, 107 m (USGS colln. 30774–PC), USNM 442192–93.
 12. Left element, 162 m (USGS colln. 30782–PC), USNM 442194.
- 13–15. *Rhachistognathus minutus minutus* (Higgins and Bouckaert), Pa elements, ×50, upper member.
- 13–14. Right elements, upper and lower views, 85 m (USGS colln. 30768–PC), USNM 442195–96.
 15. Left? element, upper view, 107 m (USGS colln. 30774–PC), USNM 442197.
16. *Rhachistognathus muricatus* (Dunn) transitional to *R. websteri* Baesemann and Lane, ×50, upper view, lower member, 6 m (USGS colln. 30746–PC), USNM 442198.
- 17–21. *Rhachistognathus websteri* Baesemann and Lane, Pa elements, ×50, upper member.
- 17–19. Upper, lower, and upper views, 91 m (USGS colln. 30770–PC), USNM 442199–200.
 - 20–21. Upper and lower views, 122 m (USGS colln. 30777–PC), USNM 442201.
- 22–24. *Rhachistognathus* spp. indet., Pa elements, juveniles, lateral, upper, and lower views, upper member, 260.5 m (USGS colln. 30799–PC), USNM 442202–203.
25. *Rhachistognathus muricatus* (Dunn) transitional to *R. primus* Dunn, Pa element, ×50, upper view, upper member, 95 m (USGS colln. 30771–PC), USNM 442204.
26. *Gnathodus defectus* Dunn, Pa element, ×50, upper view, lower member, 154.5 m below base of overlying Echooka Formation (USGS colln. 31860–PC, app. 1, loc. 5D), USNM 442205. In this collection, *G. defectus* occurs with three species of *Rhachistognathus*, including *R. minutus*, indicating the lower *minutus* Fauna.
- 27–30. *Rhachistognathus muricatus* (Dunn), Pa elements, lower member.
27. Upper view, ×50, 56 m (USGS colln. 30758–PC), USNM 442206.
 - 28–29. Upper and lower views, ×50, 7 m (USGS colln. 30747–PC), USNM 442207.
 30. Upper view, ×40, 69 m (USGS colln. 30762–PC), USNM 442208.



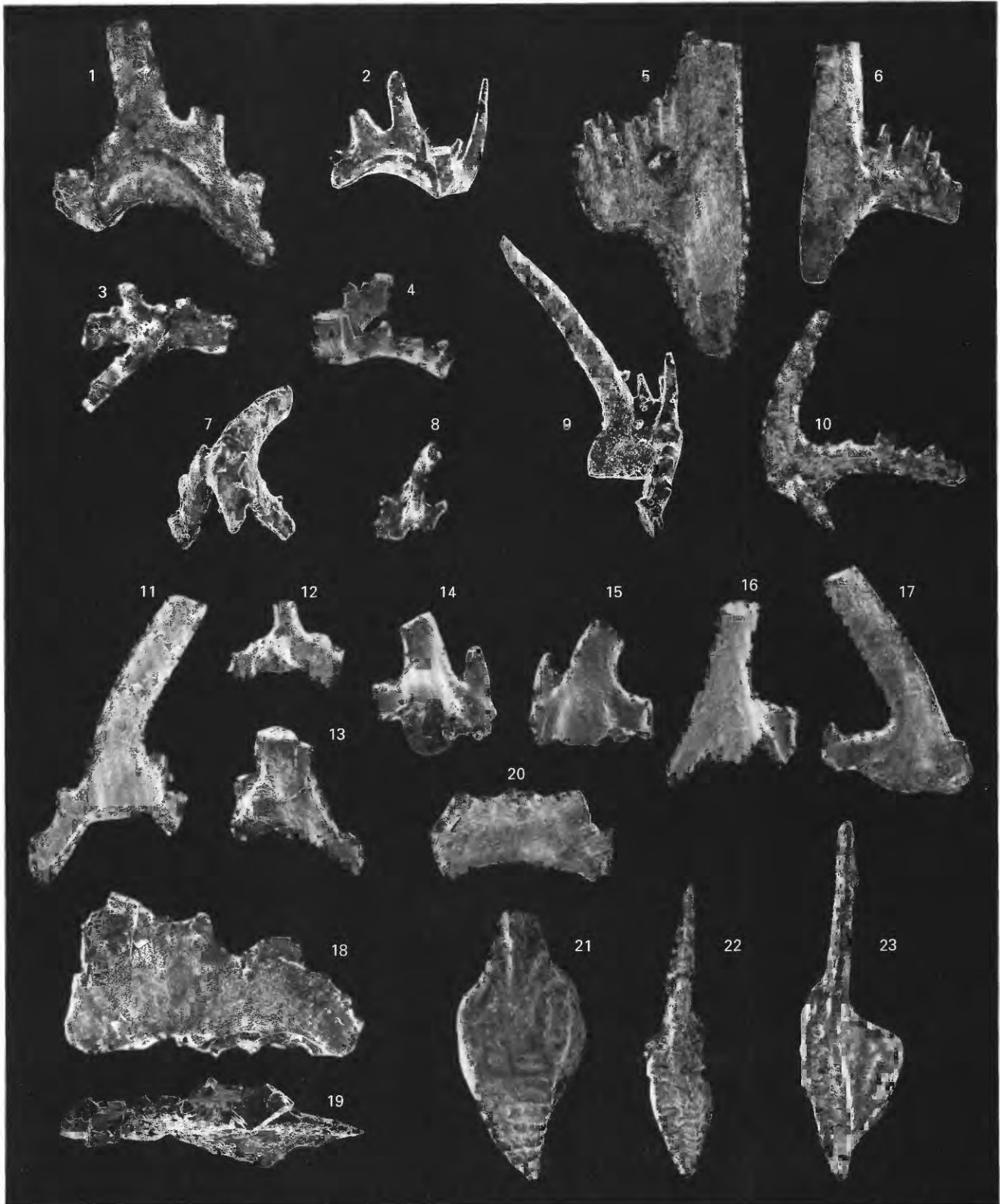
RHACHISTOGNATHUS AND GNATHODUS

PLATE 5

Conodonts from the Wahoo Limestone, eastern Sadlerochit Mountains, northeast Brooks Range, Alaska.

[Scanning electron microscope photomicrographs of specimens coated
with carbon and gold. Meters shown are above base of formation]

- Figures 1–10. *Kladognathus* spp. indet., lower member.
1. P element, ×50, lateral view, 0.4 m (USGS colln. 30745–PC), USNM 442209.
 2. P element, ×50, lateral view, 6 m (USGS colln. 30746–PC), USNM 442210.
 3. P element, ×50, oblique view, 0.4 m (USGS colln. 30745–PC), USNM 442215.
 4. P element, ×50, oblique view, 42 m (USGS colln. 30754–PC), USNM 442216.
 5. M element, ×45, lateral view, 7 m (USGS colln. 30747–PC), USNM 442211.
 6. M element, ×30, lateral view, 6 m (USGS colln. 30746–PC), USNM 442212.
 7. Sa element, ×50, anterolateral view, 0.4 m (USGS colln. 30745–PC), USNM 442213.
 8. Sa element, ×50, posterior view, 37 m (USGS colln. 30753–PC), USNM 442214.
 9. Sc element, ×50, lateral view, 6 m (USGS colln. 30746–PC), USNM 442217.
 10. Sb element, ×50, lateral view, 0.4 m (USGS colln. 30745–PC), USNM 442218.
- 11, 14–17. *Idioprioniodus conjunctus* (Gunnell)?, ×50.
11. Pb element, lateral view, upper member, 162 m (USGS colln. 30782–PC), USNM 442219.
 - 14–15. Sb? element, inner and outer lateral views, upper member, 207 m (USGS colln. 30789–PC), USNM 442222.
 - 16–17. M and Sc elements, lateral view, lower member, 53 m (USGS colln. 30757–PC), USNM 442223–24.
12. *Idioprioniodus* sp. indet., Pb element, ×50, lateral view, lower member, 53 m (USGS colln. 30757–PC), USNM 442220.
 13. *Idioprioniodus* cf. *I. healdi* (Roundy)?, Pb? element, ×50, lateral view, upper member, 207 m (USGS colln. 30789–PC), USNM 442221.
- 18–19. *Diplognathodus? ellesmerensis* Bender?, Pa element, ×50, lateral and upper views, upper member, 203 m (USGS colln. 31710–PC), USNM 442227.
20. *Cavusgnathus? tythus* Brown and Rexroad, Pb element, ×50, inner lateral view, lower member, 54.9 m (USGS colln. 31698–PC), USNM 484526.
 21. *Idiognathodus incurvus* Dunn?, Pa element, ×40, upper view, upper member, 250 m (USGS colln. 30796–PC), USNM 442225.
 22. *Idiognathoides sinuatus* Harris and Hollingsworth, Pa element, ×40, upper view, upper member, 217.5 m (USGS colln. 30790–PC), USNM 442226.
 23. *Gnathodus bilineatus bilineatus* (Roundy), juvenile right Pa element, ×90, upper view, lower member, 69 m (USGS colln. 30762–PC), USNM 483408. This specimen is possibly redeposited because it occurs 13 m above the base of the Pennsylvanian and all other representatives of the species are restricted to the Mississippian part of the Wahoo Limestone in the study section (table 1).



CAVUSGNATHUS?, *DIPLOGNATHODUS?*, *GNATHODUS*, *IDIOGNATHODUS*, *IDIOGNATHOIDES*,
IDIOPRIONIODUS, AND *KLADOGNATHUS*