To the Graduate Council:

I am submitting herewith a thesis written by Charles Steven Harris entitled "Biostratigraphy and Environmental Distribution of Conodonts from the Lowermost Middle Ordovician in East Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

Thomas W. Broadhead, Major Professor

We have read this thesis
and recommend its acceptance:

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Graduate Studies and Research

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4

BIOSTRATIGRAPHY AND ENVIRONMENTAL DISTRIBUTION OF CONODONTS FROM THE LOWERMOST MIDDLE ORDOVICIAN IN EAST TENNESSEE

A Thesis

Presented for the

Master of Science

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Charles Steven Harris

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ABSTRACT

The stratigraphic sequence of east Tennessee Middle Ordovician late Llanvirn-Llandeilo carbonate facies at Cedar Springs (Copper Creek Allochthon), Silver City and Douglas Lake (Bays Mountain Synclinorium) provides a unique lithologic framework for the study of conodont faunas, their biostratigraphy and paleoecology. These three sections correlate with previously published sections primarily on the first appearance of Phragmodus sp. A and Polyplacognathus friendsvillensis.

During pre-Phragmodus sp. A time, portions of the Knox Group were subareally exposed with considerable topographic relief. "Mosheim" and "Blackford" lithologies represent thin patches of carbonate mud which washed into topographic depressions. During Phragmodus sp. A time the northwestern extension of a Knox topographic low (Cedar Springs) was open to the transgressing sea establishing intertidal conditions which opened onto a shallow shelf (Douglas Lake and Silver City) on which argillaceous limestones of the lower main body of the Lenoir Formation were deposited. Polyplacognathus friendsvillensis time marked the shelfward migration of the shelf edge, establishing deeper water conditions in the eastern most part of the study area evidenced by deposition of the Fetzer Facies of the Whitesburg Formation.

The distribution of conodont species in shallow water, carbonate restricted and normal marine facies, inferred from petrologic analysis, suggests that environmental controls were species specific. Salinity and temperature appear to have been the major controlling factors

affecting conodont distribution (i.e. Plectodina ? sp. and P. n. sp. of Carnes (1975), Leptochirognathus semiflorealis and L. quadratus). Species of Phragmodus display differing environmental distributions. P. sp. A is associated with restricted intertidal channels. P. flexuosus specimens are also present in intertidal channels, but peak abundance occurs in subtidal channel facies containing stenotopic shelly fauna. Substrate type appears to control distribution of species such as Plectodina joachimensis in algally laminated tidal channel levee deposits. Finally, the distribution of biostratigraphically important species such as Polyplacognathus friendsvillensis appears to be environmentally controlled, but only excluded from facies deposited in shallow restricted environments. Consequently, conodont biostratigraphy should include consideration of possible ecologic controls affecting species distribution.

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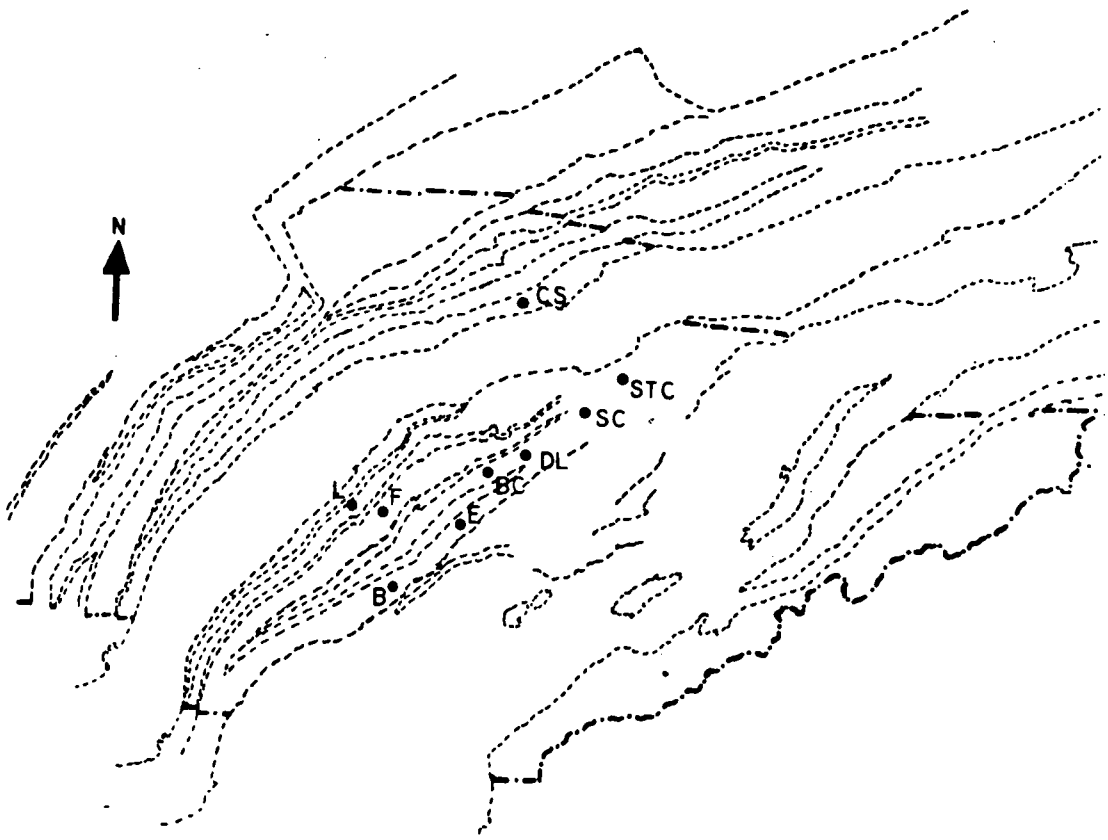
CHAPTER I

INTRODUCTION

Previous conodont biostratigraphic studies in east Tennessee (Berström, 1971a, 1973b; Carnes, 1975; and Bergström and Carnes, 1976), have involved collections from numerous stratigraphic sections and hundreds of meters of Middle Ordovician strata. These workers have adapted and refined the North Atlantic Province Conodont Zonation of Bergström (1971) applicable to Middle Ordovician strata in east Tennessee. Consequently, a considerable data base of conodont biostratigraphic information exists in published and unpublished papers. This information has been used liberally to correlate published stratigraphic sections with late Llavirn-Llandeilo (Ross, et al., 1982) strata studied herein (Figure 1), integrating this study area with a larger portion of east Tennessee.

This investigation attempts a slightly different approach to the study of conodonts. The thickness of section examined at each of three localities studied was small, less than 40 meters. Emphasis was placed on discrete sampling of lithologically homogeneous units, resulting in a variable sample interval (0.1 to 3.7 meters). This sampling technique permits evaluation of environmental information from each lithology. Thin section analysis is utilized in the interpretation of conodont assemblages.

Paleoecology and biostratigraphy are assumed to be interrelated. Bergström and Carnes (1976) studied relations between conodont distribution and environments of deposition of the Lenoir and Holston



SECTIONS

CS - Cedar Springs	St.C.	- St. Clair	Bergström 1973
DL - Douglas Lake	E	- Ellejoy	"
SC - Silver City	B	- Blockhouse	"
	F	- Friendsville	"
	L	- Lenoir City	"
	BC	- Boyd's Creek	Shanmugan 1979

Figure 1. Location of Sections on Palinspastic Map of Roeder and Witherspoon (1978)

formations in eastern Tennessee. They recognized recurrent associations of conodont species (R.S.A.'s) that appeared to be characteristic of certain environments. The Leptochirognathus R.S.A., consisting mostly of hyaline forms, is associated with the calcilutitic tidal flat deposits of the Mosheim Member of the Lenoir Formation. Two recurrent species associations were found characteristic of the Lenoir above the Mosheim Member. The dominantly Midcontinent Province (Sweet et al., 1959) forms of the Belodella-Phragmodus-Polyplacognathus R.S.A. were reported to be in shallow subtidal portions. Deeper, subtidal portions of the Lenoir had characteristic North Atlantic Province (Sweet et al., 1959; and Sweet and Bergström, 1962) forms of the Periodon-Pygodus R.S.A. also present in the basinal Blockhouse shale. Holston strata contained fewer specimens which were similar in composition to the Belodella-Phragmodus-Polyplacognathus R.S.A. The deeper water Periodon-Pygodus R.S.A. of eastern Tennessee was found in intertidal to shallow subtidal deposits in the Baltic Shield area of the North Atlantic Province suggesting somewhat colder temperatures for that region (Bergström and Carnes, 1976). How environmental restrictions affected the rapid evolution of Ordovician conodontophorid apparatuses, and what specific environmental aspects were acting as limiting factors are questions that remained unanswered.

Other paleoecologic studies of conodont distribution and facies relationships are discussed in the chapter on paleoecology. Most of these studies, however, have neglected to approach microenvironmental relationships afforded by detailed petrographic analysis of each sample from which conodonts were recovered. Consequently, important

biostratigraphic events, such as the transition of typical to late forms of Polyplacognathus friendsvillensis cannot definitely be considered free of environmental influences.

In addition to conodont biostratigraphic and paleoecologic studies of Ordovician strata in east Tennessee, much lithostratigraphic work has been completed. Rodgers (1953), B. N. Cooper (1953) and G. A. Cooper (1956) pioneered the early lithostratigraphic and shelly biostratigraphic framework for the Middle and Upper Ordovician. More recent studies are summarized in the chapter on stratigraphy.

The primary purpose of this investigation was to identify conodont biostratigraphic events for intrabasinal correlation in an ecologic framework that identifies environmental controls on conodont distribution. The major aims of this study have been to:

1. Assess the spatial distribution of conodontophorids in terms of the nearshore restricted marine environments of the enclosing Lenoir, Five Oaks and Lincolnshire Formations.
2. Make a detailed analysis of the conodont assemblages in the Mosheim Member of the Lenoir Formation and Five Oaks Formation including the transition zones into the overlying Lenoir and Lincolnshire Formations, respectively.
3. Identify those factors which control conodont distribution in the Middle Ordovician of eastern Tennessee.
4. Identify evolutionary relationships between lower Middle Ordovician species in order to recognize biostratigraphic events which can be used for intrabasinal correlation.
5. Compile previous lithostratigraphic and biostratigraphic data with new information generated from this investigation

to recognize temporally successive facies relationships in the Sevier Basin prior to Pygodus anserinus Zone time.

One of the major purposes of this study is to examine relationships between carbonate depositional environments and conodont faunas. Consequently, field techniques were designed to provide the maximum amount of integrateble biostratigraphic and lithostratigraphic data. Field work for this study involved:

1. Measuring sections of approximately 40 meters of the Chickamauga Group, beginning just below the Knox Group contact at each locality (Figure 1).
2. Collection of 62 samples (5 to 8 kilograms) including oriented specimens for thin sections. The vertical distribution of samples reflects both the succession of discrete lithologies and the discontinuous exposure of strata.
3. Finally, locating each sample precisely within the measured section, as well as numbering each sample with paint on the outcrop for future reference.

Laboratory treatment of samples included conodont recovery and thin section or acetate peel preparation. A variety of acid recovery techniques, modified after Collinson (1963), were used to recover the conodonts. All samples were cleaned prior to crushing to a modal size of 1 cm. Nearly pure limestones were then digested using 8.0 liters of 10% glacial acetic acid. Samples containing appreciable amounts of dolomite were processed using 10% formic acid. No apparent etching effect was observed on conodonts recovered from any of the acids or

concentrations. Rarely, some samples (e.g. 11, 12 and 13 from Douglas Lake) exhibited only minor dissolution after 3 acid baths and exposure to the dispersing agent Calgon.

Heavy residues of dissolved samples were concentrated using a tetrabromoethane heavy-liquid separation. Residues floated at least 3 hours and were stirred every 15 minutes in separatory funnels. The heavy fraction was then poured on and drained through coarse filter paper, cleaned with acetone, and examined for conodonts. Collected specimens were placed on micropaleontology slides, glued with gum tragacanth, and maps of each slide were compiled.

From the remaining portion of selected samples, 23 thin sections, 35 acetate peels, and 59 polished slabs were prepared for petrologic and sedimentologic analysis. This combination of techniques allowed integration of biologic and lithologic information and provided an environmental framework for the evaluation of conodont faunas.

CHAPTER II

STRATIGRAPHY

Cedar Springs

Location. The Cedar Springs section is located in the Copper Creek Allochthon (Figure 1, page 2), defined to the northwest by the Copper Creek Fault and to the southeast by the Saltville Fault. This section crops out in a field on the south side of Cedar Springs Church Road, 4.8 km northeast of Thorn Hill, Grainger County, Tennessee. Petrologic and sedimentologic summary of the entire section is presented by Ruppel (1979). In the present study, only the lower 30 meters of the section, including the Five Oaks Formation and the base of the Lincolnshire Formation, are considered.

Lithostratigraphy. The lowermost rock unit in the Middle Ordovician succession at Cedar Springs is the Blackford Member of the Five Oaks Formation. This unit is 1.5 meters thick and is characterized by greenish gray dismicritic lime mudstone. Lithologically, it is similar to strata located in other strikebelts, identified as the Mosheim Member of the Lenoir Formation.

The lower contact between the Knox Group and the base of the Blackford Member is unconformable and is exposed in the field on the northern side of Cedar Springs Church Road. Approximately 4 meters below the Knox-Five Oaks contact a breccia zone, composed of a chert- and dolomite-cobble conglomerate, is exposed in the parking lot of Cedar Springs Church. The upper contact of the Blackford Member with

the remaining 21.5 meters of Five Oaks Formation is marked by a distinct change in lithology from dismicrite to a pelletal grainstone which occurs as a thin unit at the base of the remaining main body of the Five Oaks Formation. This upper portion of the Five Oaks displays a variety of rock-types including pellet rich, commonly dolomitic, internally laminated mudstone and wackestone with minor occurrences of packstone. The macrofauna of the Five Oaks Formation is characterized by ostracodes, trilobites and gastropods.

The upper contact of the Five Oaks with the overlying Lincolnshire Formation is marked by an abrupt lithologic change from mudstone and pelletal wackestone to skeletal grainstone 23 meters above the post-Knox unconformity. Only the lower 7 meters of Lincolnshire are discussed here. A more diverse macrofauna appears at the base of the Lincolnshire composed of ostracodes, trilobites, gastropods, brachiopods and the red alga Solenopora (Type P. of Moore, 1977). A discussion of the petrology and depositional environments of this section is given in Chapter III.

Conodont biostratigraphy. Sample CS-1 from the Blackford Member of the Five Oaks Formation yielded the smallest conodont collection (about 2 spm/kg), which is comprised of elements of Panderodus sp. cf. P. gracilis and Plectodina joachimensis (Figure 2). Neither of these species is biostratigraphically significant in the context of this study.

Samples CS-2 and CS-3 collected from the lower 0.9 meters of the remaining main body of the Five Oaks Formation have yielded ample collections (up to 298/kg). The prominent constituents of this fauna

Figure 2. Cedar Springs Stratigraphic Distribution of Conodonts

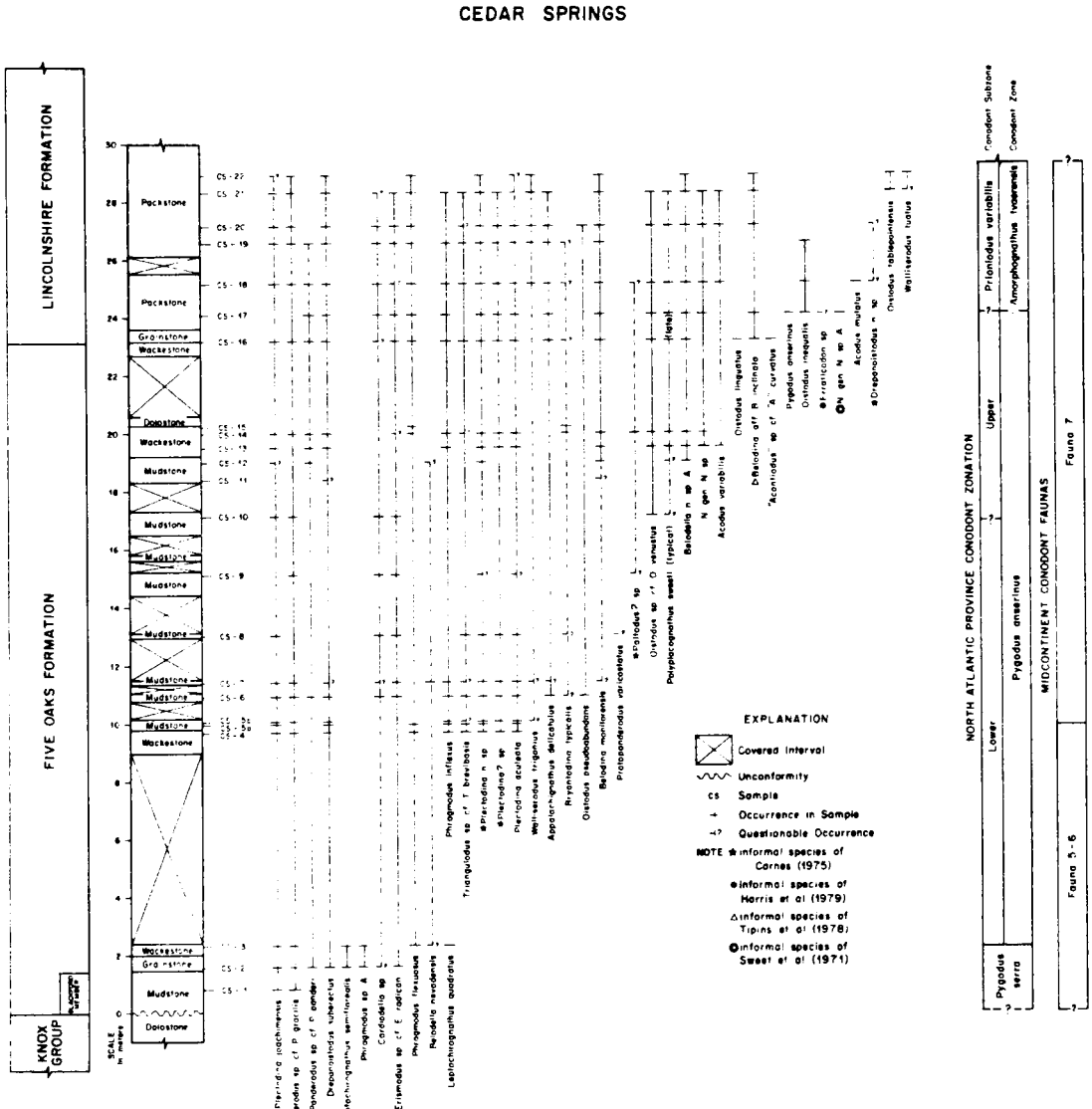

CEDAR SPRINGS
KNOX GROUP
FIVE OAKS FORMATION
LINCOLNSHIRE FORMATION
Packstone
Grainstone
Wackestone
Dolostone
Mudstone
EXPLANATION
Covered Interval
Unconformity
Sample
Occurrence in Sample
Questionable Occurrence
NOTE: informal species of Cornes (1975)
informal species of Harris et al (1979)
informal species of Tipins et al (1978)
informal species of Sweet et al (1971)
NORTH ATLANTIC PROVINCE CONODONT ZONATION
Lower
Upper
Pygodus serra
Pygodus anserinus
Prioniodus variabilis
Amorphognathus tvaerensis
Conodont Subzone
Conodont Zone
MIDCONTINENT CONODONT FAUNAS
Fauna 5-6
Fauna 7

Figure 2

are: Plectodina joachimensis, Leptochirognathus semiflorealis, Panderodus sp. cf. P. gracilis, Phragmodus sp. A and P. flexuosus. The highest occurrence of gothodontiform elements of Phragmodus sp. A occurs in sample CS-3, 2.3 meters above the post-Knox unconformity.

Gothodontiform elements of P. sp. A occur with Polyplacognathus friendsvillensis at Silver City, Tennessee, and Carnes (1975) reported a similar occurrence in the McLish Formation of Oklahoma which suggests a Pygodus serra zone age (Bergström, 1971a). Subcordylodontiform elements which replace gothodontiforms in the Phragmodus flexuosus apparatus are found in the stratigraphic interval assigned to the Pygodus anserinus and Amorphognathus tvaerensis zones (Carnes, 1975). Therefore, at Cedar Springs, the top of the Pygodus serra zone is tentatively drawn at the highest occurrence of Phragmodus sp. A gothodontiform elements, located 2.3 meters above the Knox. This zonal boundary may occur somewhat higher in the overlying 6.5 meters of covered Five Oaks Formation which could not be sampled. A detailed discussion of the transition from P. sp. A to P. flexuosus is presented in the systematics chapter of this report.

Above this interval, a substantial change in the conodont fauna occurs. Species of Leptochirognathus, characteristic of the lower Five Oaks fauna, are absent throughout the rest of the section studied here. Plectodina joachimensis and Phragmodus flexuosus continue through the upper half of the Five Oaks but are only minor constituents of the conodont fauna. Sample CS-4, 9.6 meters above the Knox, has the highest conodont yield (136 spms/kg) of the remainder of samples from the Five Oaks Formation. Three species of Plectodina, P. aculeata, P. n. sp. of Carnes (1975) and Plectodina? sp. of Carnes (1975) first

occur here, along with Triangulodus sp. cf. T. brevibasis, and Phragmodus inflexus. This association of species along with remnants of the lower fauna characterize this central portion (samples CS-4 through CS-7) of the Five Oaks.

The first appearance of a dichognathiform element of P. inflexus with an anteriorly denticulate cusp occurs in sample CS-5a, 9.9 meters above the post-Knox unconformity. This occurrence marks the influx of species of Midcontinent conodont Fauna 7 of Sweet et al. (1971). As discussed in the systematics section of this report, this boundary appears to be diachronous in eastern Tennessee when compared to the zones of the North Atlantic Province conodont zonation (Bergström, 1973b). Carnes (1975) indicated that the lowest occurrence of the Fauna 7 boundary is in the upper subzone of the Pygodus anserinus zone. It is difficult to discern the upper/lower subzone boundary of the P. anserinus zone in Tennessee. The only indicator, given by Bergström (1971a), is that the upper subzone is characterized by the association of typical forms of Polyplacognathus sweeti and Prioniodus variabilis. Because neither of these species is present at the first occurrence of an anteriorly, denticulate dichognathiform of P. inflexusus the lower boundary of Midcontinent Fauna 7 is interpreted as occurring in the lower subzone of the P. anserinus zone. This marks the lowest occurrence of this boundary reported in eastern Tennessee.

The first specimens of the typical form of Polyplacognathus sweeti appear in sample CS-10, 16.6 meters above the unconformity, and continue through the upper Five Oaks. No specimens of Prioniodus variabilis, which would indicate the upper subzone of the Pygodus

anserinus zone occur. Consequently, the lower-upper subzone boundary is tentatively drawn at the first occurrence of specimens of P. sweeti (typical form), 16.6 meters above the Knox.

The highest sample (CS-15) from the Five Oaks Formation was collected approximately 3 meters below the top. This sample produced only a sparse collection (3 spms/kg) of elements of Bryantodina typicalis and Phragmodus flexuosus. Discussion of this interval and its paleoecologic implications is given in Chapter III.

Sample CS-16 is the lowest sample collected from the Lincolnshire Formation and contains the recurrence of the conodont fauna found in the upper Five Oaks Formation (sample 14). Conodont yields increase in the Lincolnshire to a maximum in sample CS-21 (376 spms/kg). Plectodina joachimensis, Phragmodus flexuosus and P. inflexus, abundant in the lower Five Oaks samples but sparse in samples from the upper portion, reappear to become a significant part of the lower Lincolnshire fauna. Additional species found in this fauna include: Belodina aff. B. inclinata (Branson and Mehl), Walliserodus tuatus (Hamar), Oistodus tablepointensis Stouge, and a single specimen of Pygodus anserinus Lamont and Lindstrom in sample CS-17, 24.1 meters above the post-Knox unconformity. This sample also coincides with the first appearance of Polyplacognathus sweeti (late). Carnes (1975) reported that P. sweeti (late) may extend into the lower part of the Amorphognathus tvaerensis zone. Therefore, Carnes (1975) suggested that the top of the Pygodus anserinus zone should be placed at either the last occurrence of P. anserinus, or P. sweeti (typical form).

For this reason, the top of the Pygodus anserinus zone is placed at sample CS-17, located 24.1 meters above the unconformity.

Summary of biostratigraphic zonation. Based on the conodont occurrences in the section at Cedar Springs described above, the following zonal boundaries have been identified:

1. Top of the Pygodus serra zone, 2.3 meters above the post-Knox unconformity based on the last occurrence of gothodontiform elements of Phragmodus sp. A.
2. Base of Midcontinent Conodont Fauna 7; 9.9 meters above the unconformity based on the first occurrence of a Phragmodus inflexus dichognathiform possessing an anterior denticle on the cusp.
3. Upper-lower subzone boundary of the Pygodus anserinus zone, 16.6 meters above the unconformity based on the first occurrence of typical form Polyplacognathus sweeti.

Chronostratigraphy. Assignment of these rocks to a chronostratigraphic stage is problematic. A brief synopsis of more detailed discussions given in Bergström (1971a, 1973b) and Carnes (1975) is presented here to illustrate the difficulty encountered.

The type Marmor Stage of Cooper (1956) coincides with the top of the Lenoir Formation at Friendsville, Tennessee. Bergström (1971a, 1971b, 1973b) demonstrated that this upper Marmor falls within the Pygodus serra zone. Carnes (1975) has dated the base of the "succeeding" Ashby Stage of Cooper (1956) as younger than the top of the Prioniodus variabilis subzone of the Amorphognathus tvaerensis zone

at its type locality at Lay School, Tennessee. The base of the "succeeding" Porterfield Stage of Cooper (1956) falls within the upper Pygodus anserinus zone at the type locality (Bergström, 1971a) making it older than the base of the Ashby Stage. On this basis, the term Ashby was declared invalid by Carnes (1975). As a result, a post-Marmor, pre-Ashby stratigraphic interval exists which is approximately equivalent to the "Arline" Formation and lower Holston of Bergström (1973b) at Friendsville. This interval includes all southern Appalachian strata corresponding to upper P. serra zone through the P. variabilis subzone of the A. tvaerensis zone that cannot be assigned to any of Cooper's (1956) stages.

Most of the Cedar Springs Middle Ordovician section presented in this report falls within this stratigraphic interval and is tentatively termed post-Marmor or pre-Porterfield of the Whiterockian Series and is equivalent to the Upper Llanvirn-Llandelio British Series (Ross et al., 1932). At the base of the section, however, the presence of Phragmodus sp. A from samples CS-2 and 3, suggests that the lower 2.3 meters of Five Oaks Formation is no younger than Polyplacognathus friendsvillensis age. This interpretation is supported by the occurrence of Phragmodus sp. A with, its absence above, Polyplacognathus friendsvillensis at Douglas Lake and Silver City. This age assignment places lower 2.3 meters of the Five Oaks at Cedar Springs within the top of the Marmor Stage of Cooper (1956) as defined by Bergström, 1973.

Silver City

Location. The section at Silver City is located on the western edge of the Bays Mountain Synclinorium (Figure 1, page 2). Middle Ordovician rocks crop out in a field on the south side of the unmarked, county-maintained road, opposite the post office at Silver City, 2.6 km northeast of Tennessee State Fish Hatchery, Hamble County. This location is approximately 1 km southeast, along strike, from the type section of the Whitesburg Formation (Ulrich, 1930). The section at Silver City is better exposed than the type Whitesburg (Ulrich, 1930) and, consequently, has been chosen as a Whitesburg reference section (Walker and Benedict, 1980).

Lithostratigraphy. The basal unit of the Middle Ordovician sequence at Silver City is the Lenoir Formation. Walker and Benedict (1980) reported striking similarity between the lithologies of the Lenoir Formation at Silver City and those of the Lenoir at Midway Road, Knox County, Tennessee, approximately 60 km to the southwest. The major difference is that the carbonate sequence at Silver City is much thinner than the sequence at Midway Road.

The lowest unit of the Lenoir Formation reported from Silver City (Walker and Benedict, 1980) and the Whitesburg type section (Bergström, 1973b) is the Mosheim Member. Bergström (1973b) stated that the contact between the Mosheim Member and underlying Knox Group dolostone is covered. Walker and Benedict (1980) reported an unconformity between the Mosheim Member and the Knox, but this contact was not clearly seen. The lower 4.3 meters of limestone exposed is

argillaceous, grass covered, weathering to a chippy rubble which obscures the apparent contact interval. This lower lithology of the Mosehim grades into vaguely grayish green dismicrite which constitutes the remaining 7 meters.

Medium-bedded, algal rich, biomicrite overlies the Mosheim and represents the 12 meters thick Asbury Member of the Lenoir in this section. The remaining 17 meters of the Lenoir Formation is predominantly comprised of nodular, algal-poor biomicrite.

Conodont biostratigraphy. Conodont collections from the Lenoir Formation at Silver City (Figure 3) are poor. Examination of Table VI, Appendix A, shows that few multielement taxa are fully represented in any sample except for SC-23 and SC-24, collected from the "Main Body" of the Lenoir.

At the base of the section, samples from the argillaceous portion (lower 5 meters) of the Mosheim Member contain a sparse collection of elements representing species of Leptochirognathus, Triangulodus, Panderodus, Polycaulodus and Oistodus (Figure 3), plus questionable occurrences of Belodella, Prioniodus, Cardiodella and Erraticodon. The sample yielding the most abundant collection of conodonts was SC-3, from the Mosheim Member, which produced 3 spm/kg. Most species of this fauna are restricted to occurrences in the argillaceous portion of the Mosheim.

Samples SC-5 and SC-6, from the lowest, most typical dismicrites of the Mosheim Member of the Lenoir were barren. Specimens of Leptochirognathus quadratus and Belodina monitorensis (sample SC-7 and 8) are the only conodonts recovered from the upper Mosheim.

Figure 3. Silver City Stratigraphic Distribution of Conodonts

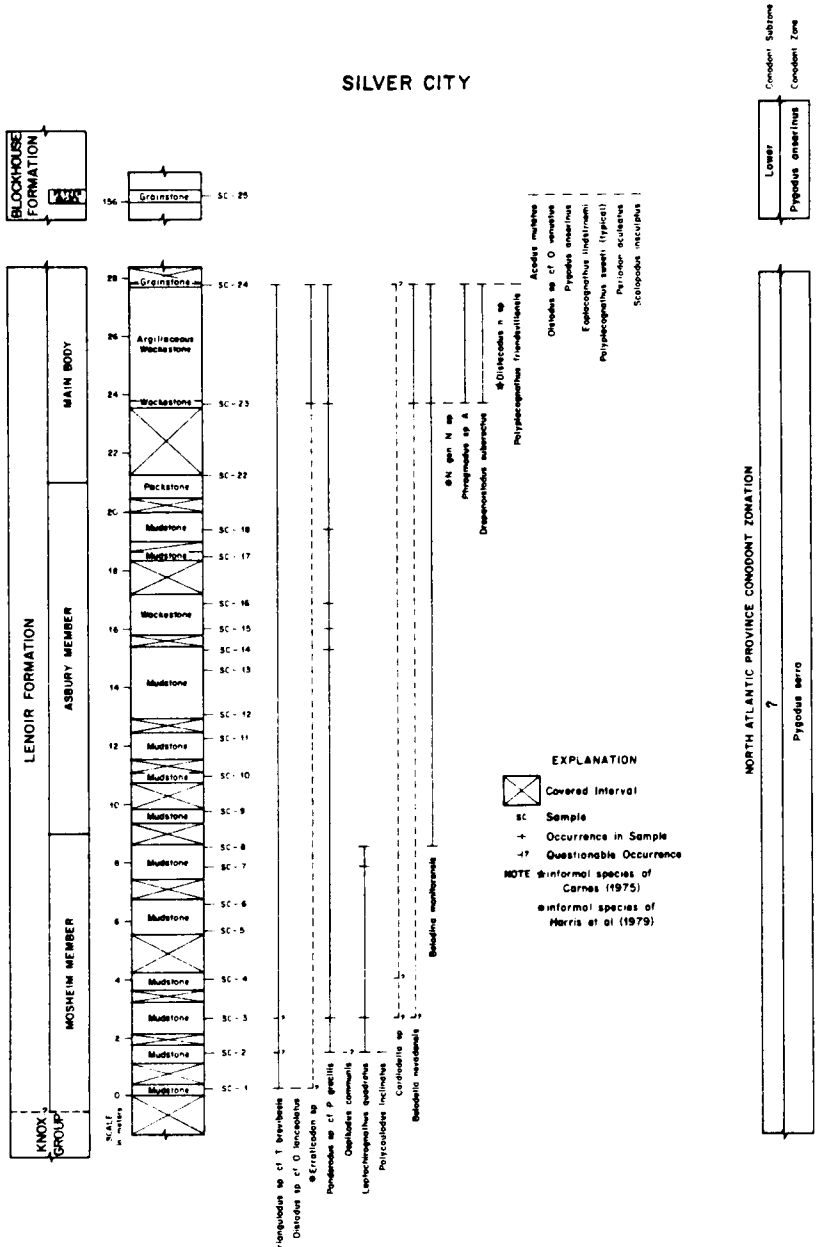

SILVER CITY
BLOCKHOUSE FORMATION
LENOIR FORMATION
KNOX GROUP
MOSHEIM MEMBER
ASBURY MEMBER
MAIN BODY
Grainstone
Argillaceous Wackestone
Wackestone
Packstone
Mudstone
Triangulodus sp. cf. T. brevibasis
Oistodus sp. cf. O. lanceolatus
Erraticodon sp.
Panderodus sp. cf. P. gracilis
Oepikodus communis
Leptochirognathus quadratus
Polyplacognathus inclinatus
Cardiodontia sp.
Belodella novodamensis
Belodina monitorensis
Phragmodus sp. A
Drepanoistodus suberectus
Polyplacognathus trapezoidalis
Acodus mutatus
Oistodus sp. cf. O. venustus
Pygodus anserinus
Eoplacognathus lindstromi
Polyplacognathus sweeti (typical)
Periodon aculeatus
Scolopodus insculptus
EXPLANATION
Covered Interval
Sample
Occurrence in Sample
Questionable Occurrence
NOTE ★informal species of Carnes (1975)
●informal species of Harris et al (1979)
NORTH ATLANTIC PROVINCE CONODONT ZONATION
Pygodus serra
Lower
Pygodus anserinus
Conodont Subzone
Conodont Zone

Figure 3

As does the upper Mosheim, the overlying Asbury Member contains few conodonts. Samples SC-9 through SC-13 collected from an interval representing the lower 6 meters of the Asbury, were barren. The only conodont species recovered from the upper portion of the Asbury is Panderodus sp. cf. P. gracilis which occurs in samples SC-14, 15, 16 and 18. Sample SC-16 contained the most specimens of P. sp. cf. P. gracilis, yielding 4 spm/kg. Samples SC-19 and SC-22, straddling the upper contact of the Asbury Member with the "Main Body" of the Lenoir also were barren.

The next sample that produced a diverse conodont fauna is SC-23, 2.6 meters above the base of the "Main Body." It yielded 13 spm/kg. This fauna included Erraticodon sp., Panderodus sp. cf. P. gracilis and Belodella nevadensis which are recurrent members of the lower Mosheim fauna, and Belodina monitorensis from the upper Mosheim. Included in the "Main Body" fauna are the first appearances of N. gen. n. sp. (of Harris et al., 1979, Pl. 4, Figure 2), Drepanoistodus suberectus and Phragmodus sp. A. Sample SC-24, taken from a thin grainstone bed 6.7 meters above the base of the "Main Body," marks the first appearance of Polyplacognathus friendsvillensis (early) and Distacodus n. sp. of Carnes (1975).

Because of the sparse conodont fauna, biostratigraphic resolution is limited to zonal scale determinations. The occurrence of Phragmodus sp. A and (early) form Polyplacognathus friendsvillensis in samples from the "Main Body" of the Lenoir indicate a Pygodus serra zone age. The underlying Asbury and Mosheim Members are also assigned to the P. serra zone but none of the forms in the lower faunas are

biostratigraphically significant; therefore, assignment is tenative. At the Whitesburg Formation type section, Bergström (1973) extended the P. serra zone into the lower Whitesburg but was unable to locate the top. Based on the primitive nature of the specimens collected, he suggested that the base of the Pygodus anserinus zone should be located in the upper 70 meters of Whitesburg or higher.

Approximately 156 m above the base of the section at Silver City a dark grainstone, interbedded with black shales occurs, about 10 meters above the base of the Blockhouse Formation. Walker and Benedict (1980) described this unit as containing abundant coiled cephalopods, asaphid trilobites, and phosphatic ooids and equated the unit lithologically to the Fetzer of the Whitesburg at other localities. Sample SC-25, collected from this lithology, has yielded an important fauna which includes Pygodus anserinus, Eoplacognathus lindstroemi, Polyplacognathus sweeti (typical form), Periodon aculeatus, Scolopodus insculptus, and Acodus mutatus. The occurrence of the first three species indicates that this interval falls within the lower subzone of the Pygodus anserinus zone.

Summary of biostratigraphic zonation. Based on the conodont occurrences in the section at Silver City described above, the following zonal markers have been identified:

1. Pygodus serra zone, 27.6 m above the base of the section, based on the occurrence of Polyplacognathus friendsvillensis and Phragmodus sp. A.
2. Lower subzone of the Pygodus anserinus zone, 156 m above the base based on the occurrence of Pygodus anserinus,

Eoplacognathus lindstroemi, and typical forms of Polyphacognathus sweeti.

Chronostratigraphy. J.E. Repetski (pers. comm., 1982) reported that samples collected from the upper 10 m of the Knox Group at Silver City contain a fauna of Lower Ordovician Age. Bergström (1973) indicated that Polyplacognathus friendsvillensis from the upper portion of the Lenoir occurs at Friendsville, Tennessee, in the type section of Cooper's (1956) Marmor Stage. Considering the high first occurrence of P. friendsvillensis (early) (Figure 3) and the slow accumulation rate of this lithology (Shanmugan and Walker, 1980), it seems reasonable to assume that most of the Marmor Stage is represented in the Lenoir. The Fetzer-like lithology, in the lower Blockhouse Formation, is of Pygodus anserinus zone age, placing it in the post-Marmor pre-Porterfield stratigraphic interval of the Whiterockian Series equivalent to the upper Llanvirn-Llandeilo British Series (Ross et al., 1982). For a discussion of this time interval, see the discussion of chronostratigraphy at Cedar Springs.

Douglas Lake

Location. The Douglas Lake Section is also located on the western edge of the Bays Mountain Synclinorium (Figure 1, page 2), southwest of Silver City. This section is exposed on the northeast side of the public boat dock, located at the foot of the U.S. Highway 25/70 bridge, on the eastern side of Douglas Lake, approximately 2 km east of Dandridge, Tennessee.

Lithostratigraphy. The lowermost 25.1 meters of Middle Ordovician strata exposed at Douglas Lake are assigned to the Lenoir Formation. Stratigraphically, the Lenoir consists of the Lower Douglas Lake Member and the overlying unnamed "Main Body." The Mosheim and Asbury members, prominent at Silver City, are absent.

The contact between the Douglas Lake Member and the underlying Knox Group is sharply unconformable. A rubble breccia forms a laterally discontinuous unit at the Knox-Lenoir contact. Above the unconformity, 2.1 meters of quartz sandstone comprise the Douglas Lake Member. The upper contact of the Douglas Lake with the overlying "Main Body" is abrupt.

The "Main Body" of the Lenoir Formation is 22.1 meters thick and consists of argillaceous, nodular wackestone and mudstone. The lower 12.6 meters has a fairly diverse megafauna including bryozoans, sponges, trilobites, cephalopods and brachiopods. Above this, the "Main Body" is characterized by thin bedded, argillaceous nodular mudstone containing bryozoans, trilobites, sponges and soft sediment deformation features.

A thin 0.7 meter bed of fissile black shale overlies the top of the Lenoir, 24.4 meters above the unconformity. This unit contains little carbonate and probably represents a tongue of the Blockhouse Formation.

Walker and Benedict (1980) noted that the "Fetzer facies" is a characteristic lithology that has a variable stratigraphic position in the Middle Ordovician sequence in eastern Tennessee. At Douglas Lake, the Fetzer is 8.35 meters thick, overlies the tongue of the

Blockhouse Formation above the Lenoir, and underlies the Whitesburg Formation. The lower 2.8 meters is composed of packstone (biomicrite). Fossiliferous grainstone of the upper 5.3 meters of Fetzer contains chamosite ooids, suggesting moderate water depths (Benedict and Walker, 1978).

Conodont biostratigraphy. The stratigraphic distribution of conodonts at Douglas Lake is shown in Figure 4. The lowest stratum of the section DL-1, 0.3 m below the unconformity, produced no conodonts from a 2 kg sample of upper Knox Group dolostone. No attempt was made to process samples from the Douglas Lake Member. Furthermore, Bergström (1973b) reported barren samples from the Douglas Lake Member at Ellejoy, Tennessee.

Stratigraphically, the lowest occurrence of conodonts was a meager collection (8 spm/kg) of elements from sample DL-2, 2.5 meters above the post-Knox unconformity, in the lower "Main Body" of the Lenoir. This sparse fauna includes: Drepanoistodus suberectus, Belodina monitorensis, Panderodus sp. cf. P. gracilis, Leptochirognathus elements and a questionable occurrence of Plectodina n. sp. (of Carnes, 1975). Species diversity and specimen abundance increases in the lower 3 meters of the "Main Body" to include 13 species in sample DL-5, 5 meters above the unconformity. The highest yield from this lowermost interval is 59 spm/kg from sample DL-4, 4.7 meters above the unconformity.

Phragmodus sp. A first appears in sample DL-4, and ranges through sample DL-13, 20 meters above the unconformity. Gothodontiform

Figure 4. Douglas Lake Stratigraphic Distribution of Conodonts

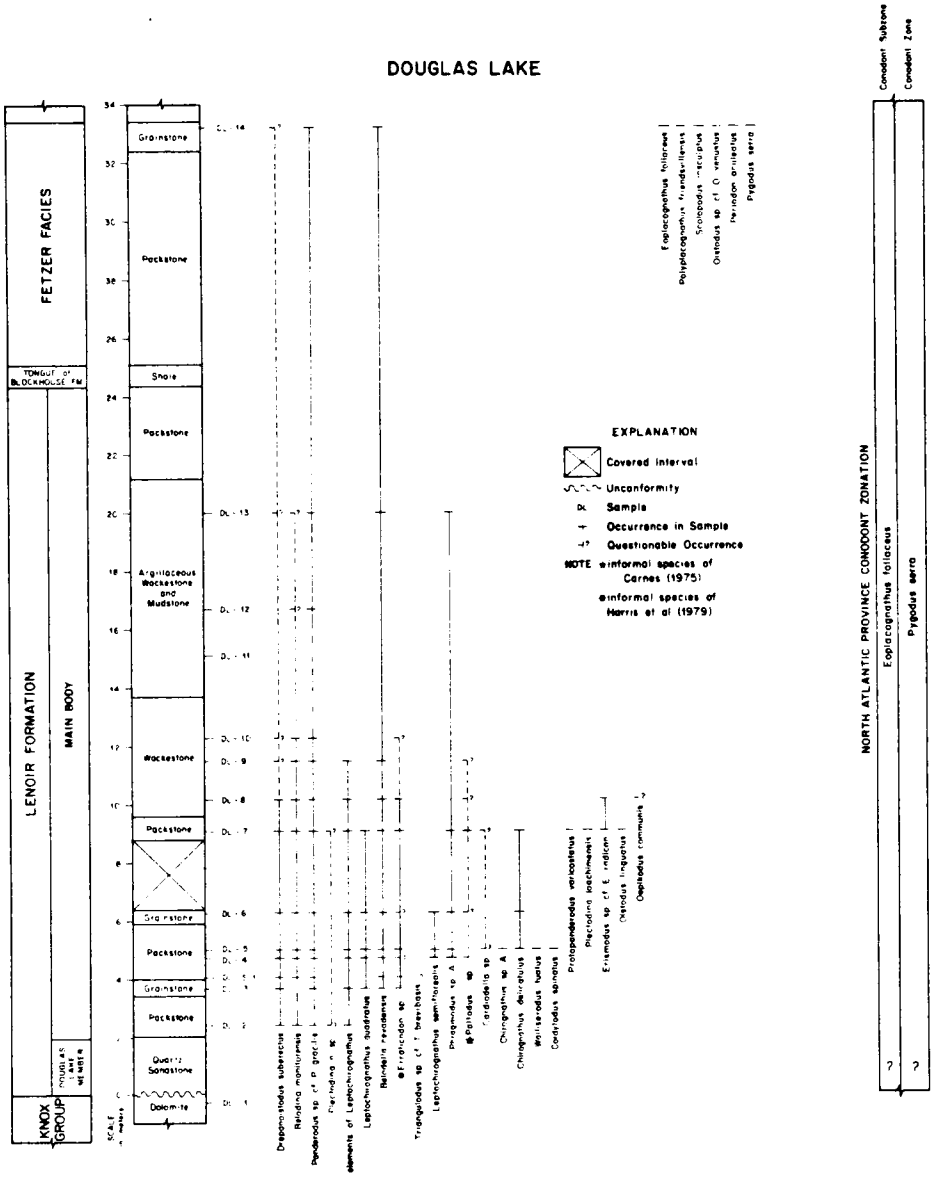

DOUGLAS LAKE
FETZER FACIES
LENOIR FORMATION
KNOX GROUP
MAIN BODY
TONGUE OF BLOCKHOUSE FM
Grainstone
Packstone
Shale
Argillaceous Wackestone and Mudstone
Quartz Sandstone
Dolomite
EXPLANATION
Covered interval
Unconformity
Sample
Occurrence in Sample
Questionable Occurrence
NOTE: informal species of Carnes (1975)
informal species of Harris et al (1979)
NORTH ATLANTIC PROVINCE CONODONT ZONATION
Conodont Subzone
Conodont Zone
Epicoregnathus folaceus
Pygodus serra

Figure 4

elements of P. sp. A represent an evolutionary stage comparable to that of elements of the same species in the "Main Body" of the upper Lenoir Formation at Silver City. Three of the 13 species represented in sample DL-5 are restricted in occurrence to that sample: Chirognathus sp. A., Walliserodus tuatus, and Cordylodus spinatus.

Sample DL-7, 9.1 meters above the unconformity, contains the most prolific collection of conodonts from the Lenoir (77 spm/kg) with 17 species represented. This fauna consists predominantly of species which occur in lower samples (DL-2-4). Four additional species first appear in DL-7: Erismodus sp. cf. E. radicans (Hinde), Oistodus sp. cf. O. linguatus, Lindstrom; Protopanderodus insculptus Branson & Mehl and Plectodina joachimensis (Andrews).

Above DL-7, the conodont fauna of the Lenoir is greatly reduced with only one questionable addition, Oepikodus communis (Ethington and Clark) in DL-8. At 12.3 meters above the unconformity, the fauna is reduced to 4 species, 2 of which are questionable identifications, and samples yielded only 4 spm/kg. Above sample 10, the "Main Body" becomes argillaceous and nodular. The only barren sample (DL-11) from the "Main Body" falls within this interval. Other samples, DL-12 and 13 produced few specimens and included no additional taxa. Only three species range through this zone of the Main Body: Drepanoistodus suberectus, Panderodus sp. cf. P. gracilis and Belodella nevadensis. Samples processed from this interval were difficult to dissolve and produced large insoluble residues. It is impossible to determine if the reduction of the lower "Main Body" conodont fauna is actual or an artifact of the recovery process.

The uppermost sample collected at Douglas Lake is DL-14 from 0.2 m below the top of the Fetzer facies. In addition to the three species which range upward from the "Main Body", the Fetzer fauna includes Scolopodus insculptus, Periodon aculeatus, Oistodus venustus, and three biostratigraphically important species, Pygodus serra, Polyplacognathus friendsvillensis, and Eoplacognathus foliaceus. The cocurrences of the last three taxa indicate that this interval may be assigned to the Eoplacognathus foliaceus subzone of the Pygodus serra zone (Bergström, 1971a). The presence of Polyplacognathus friendsvillensis suggests that this interval may lie in the upper half of that subzone, according to the range of P. friendsvillensis, indicated by Bergström and Carnes (1976).

Summary of biostratigraphic zonation. Based on the conodont occurrences in the Douglas Lake section described above, the following zonal reference has been identified: Eoplacognathus foliaceus subzone, 33.4 m above the post-Knox unconformity, based on the occurrence of E. foliaceus and Pygodus serra.

Chronostratigraphy. Bergström (1971a, 1973b) and Carnes (1975) indicated that the lower Pygodus serra zone is represented at the Friendsville type section of Cooper's (1956) Marmor Stage. Consequently, the Middle Ordovician strata from Douglas Lake, examined in this study, fall within the Marmor interval or lower in the Whiterockian Series equivalent to the upper Llanvirn-Llandeilo British Series (Ross et al., 1982).

Application of Conodont Biostratigraphy to Basin Analysis

High resolution biostratigraphic correlation, afforded by conodonts, has direct applications to determining facies relationships, analyzing paleobathymetry, and estimating rates of sedimentation and subsidence. In fact, the validity of intrabasinal analyses depends on the accuracy of recognizable datums which establish the paleogeographic relationship of facies and basin morphology.

Biostratigraphic information generated from this study provides a new conodont-based time-datum in the Pygodus serra zone. This datum is based on the first occurrence of Phragmodus sp. A and can be used to correlate lower Middle Ordovician strata both east and west of the Saltville fault, allowing more accurate analysis of facies relationships during P. serra time. In the absence of a biostratigraphic means, the validity of this datum is independently evaluated by absolute time calculations involving published rates of lithologic accumulation. Using biostratigraphic, lithostratigraphic and paleobathymetric data in conjunction with new evidence, three Middle Ordovician paleogeographic, facies maps prior to the beginning of Pygodus anserinus time may be generated.

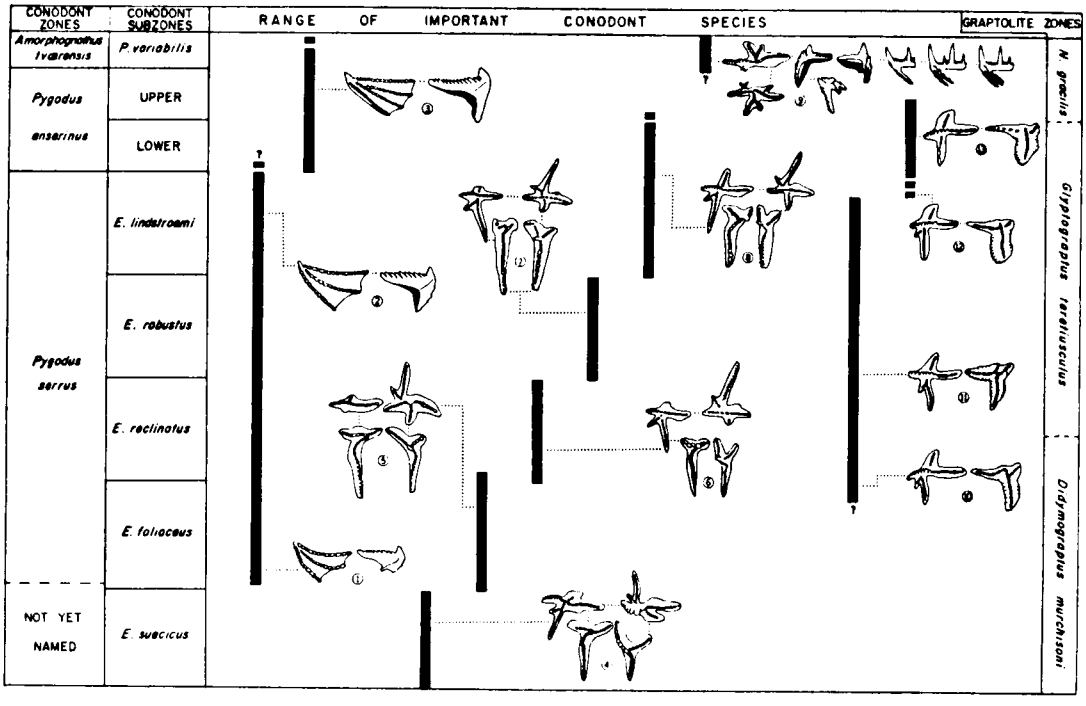
The work presented here represents a small addition to the overall concept of the evolution of the Middle Ordovician Sevier Basin. Consequently, a synopsis of previous work which developed the present concepts of this basin is essential. Coarse scale studies of the entire Middle and Upper Ordovician strata in the area were pioneered by Rodgers (1953), B.N. Copper (1953) and G.A. Cooper (1956). The importance of these early works is underscored in most of the papers

discussed here. The scope of the subsequent discussion is limited to consideration of several more recent papers dating from 1973.

McLaughlin (1973) recognized the provincial nature of Middle Ordovician megafaunas and lithotypes in eastern Tennessee and designated two provinces, Chickamaugan (western thrust belts) and Blountian (eastern thrust belts). At that time, evidence of a physical division between provinces was lacking, but the rocks then thought to be completely concealed by the Saltville thrust were recognized as containing this underdetermined paleobiogeographic boundary. In his discussion of the Blountian subphase, McLaughlin (1973) also emphasized the importance of the variable topography of the Knox surface. McLaughlin's scenario of Middle Ordovician depoisition emphasized a westward shift of faunas and environments coeval with transgression such that strata became progressively younger from east to west.

Extensive use of conodonts in determining Middle Ordovician biostratigraphic relations of the Southern Appalachians was first applied by Bergström (1971a, 1973b). Bergström was able to relate a detailed conodont zonation, based on Middle Ordovician sections in southern and central Sweden to coeval strata in easternmost Tennessee (Figure 5). These zonal and subzonal units are based on the stratigraphic range of related forms representing successive evolutionary stages of rapidly evolving lineages (Bergström, 1973b). Hence, many of these zones are lineage-zones or phylozones in the sense of Hedberg (1972). Bergström (1973b) recognized four biostratigraphic events he interpreted as independent of ecologic conditions:

1. The first appearance of a primitive type of Polyplacognathus friendsvillensis.



(1) Pygodus serra (Hadding) early form
(2) same, late form
(3) P. anserinus Lamont and Lindstrom
(4) Eoplacognathus suecicus Bergstrom
(5) E. foliaceus (Fahraeus)
(6) E. reclinatus (Fahraeus)
(7) E. robustus Bergström
(8) E. lindstroemi (Hamar)
(9) Amorphognathus tvaerensis Bergström
(10) Polyplacognathus friendsvillensis Bergström, early form
(11) same, more advanced form
(12) P. friendsvillensis-P. sweeti Bergström transition
(13) P. sweeti, typical form

Figure 5. North Atlantic Province Conodont Zones from Bergström (1973b)

2. The first appearance of a more advanced type of the same species.
3. The first appearance of a primitive type of Pygodus serra.
4. The level of the Pygodus serra-P. anserinus transition.

Bergström used these biostratigraphic datums to correlate across the Bays Mountain Synclinorium. These correlations supported previous inferences by Walker and Ferrigno (1973) that higher relative rates of carbonate sedimentation occurred to the northwest than to the southeast of the present Bays Mountain Synclinorium during Pygodus serra zone time. Because the thin limestone sequence at the base of the section to the southeast indicated shallow depositional conditions, Walker and Ferrogno (1973) and Bergström (1973) eliminated water depth as an explanation for sedimentation rates. Above the Pygodus serra zone, clastic sequences in the east are much thicker than western carbonates. To explain this, Walker and Ferrigno (1973) proposed a rapid subsidence event in the east that did not necessarily result in deeper water conditions. Bergström also indicated that the onset of shale deposition was progressively earlier to the southeast.

Walker and Ferrigno (1973a, 1973b) presented a scenario of Middle Ordovician facies relationships based primarily on sedimentary petrology. These authors suggested that the Holston Formation of the Friendsville and Lenoir City Belts formed a reef tract. Southwestward and southeastward the Athens and Blockhouse shales respectively were deposited under deep basinal conditions. Westward or shelfward of the Holston reef tract, back-reef shelf lagoon and tidal flat deposits formed the Lenoir Formation. Later, patch reefs developed northwestward

of the previous Holstone deposits and backreef deposits of the Lenoir migrated westward. Shallow water clastic deposits (Ottossee and Chapman Ridge) were deposited over the older basinal shales and shelf edge reefs. A more detailed discussion of this same array of facies was presented by Walker (1974).

Bergström and Carnes (1976) applied conodont biostratigraphic time datums to the scenario presented by Walker and Ferrigno (1973a, 1973b) and Walker (1974). Using conodont data from sections east and west of the Saltville Fault, they proposed a transgressive pattern of Middle Ordovician deposition from east to west similar to that of McLaughlin (1973). They reported that the sea did not transgress farther than the palinspastic location of Lenoir City and Friendsville Belt deposits until after Pygodus anserinus zone time.

Paleobathymetric analysis by Benedict and Walker (1978) produced paleobathymetric maps of four time intervals during the Middle Ordovician, illustrating basin evolution (Figure 6). The earliest time-datum of these maps was generated by extrapolating conodont data from two sections to others based on lithologic evidence, i.e. tongues of the Athens and Blockhouse formations. Important paleobathymetric indicators used in that study are presented in Table 1. Benedict and Walker (1978) suggested that a major initial subsidence of the Sevier Basin occurred prior to the arrival of sediments from bordering source areas producing a short-lived starved basin. This basin acted as a sediment sink allowing carbonate build-up to continue on the shelf.

Subsidence and sedimentation rates of the Sevier Basin were further analyzed by Shanmugan and Walker (1980). Depths for basinal

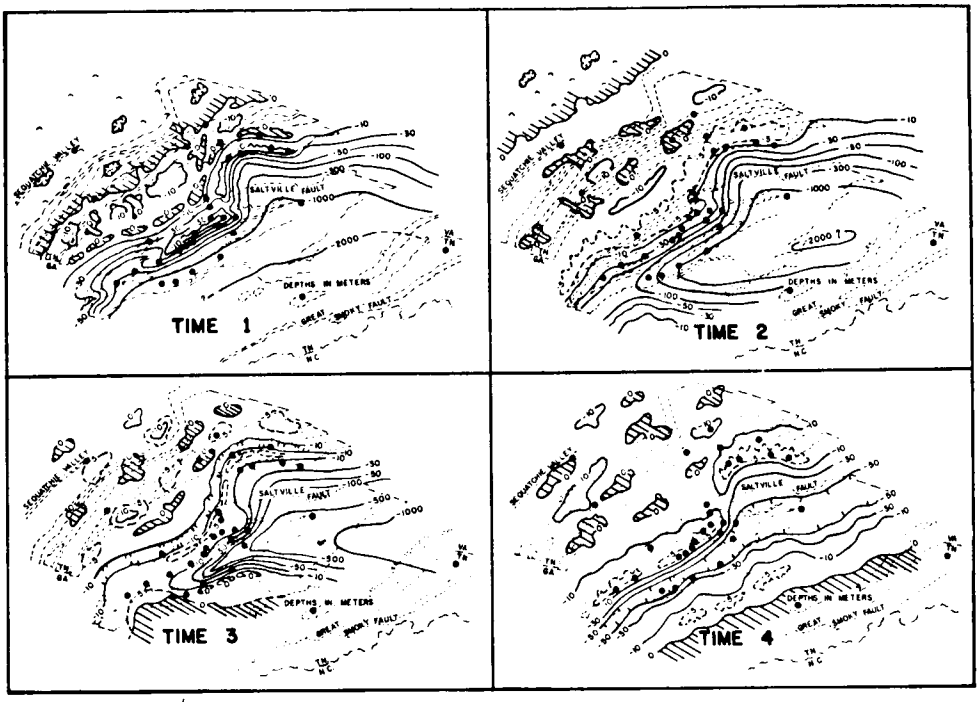
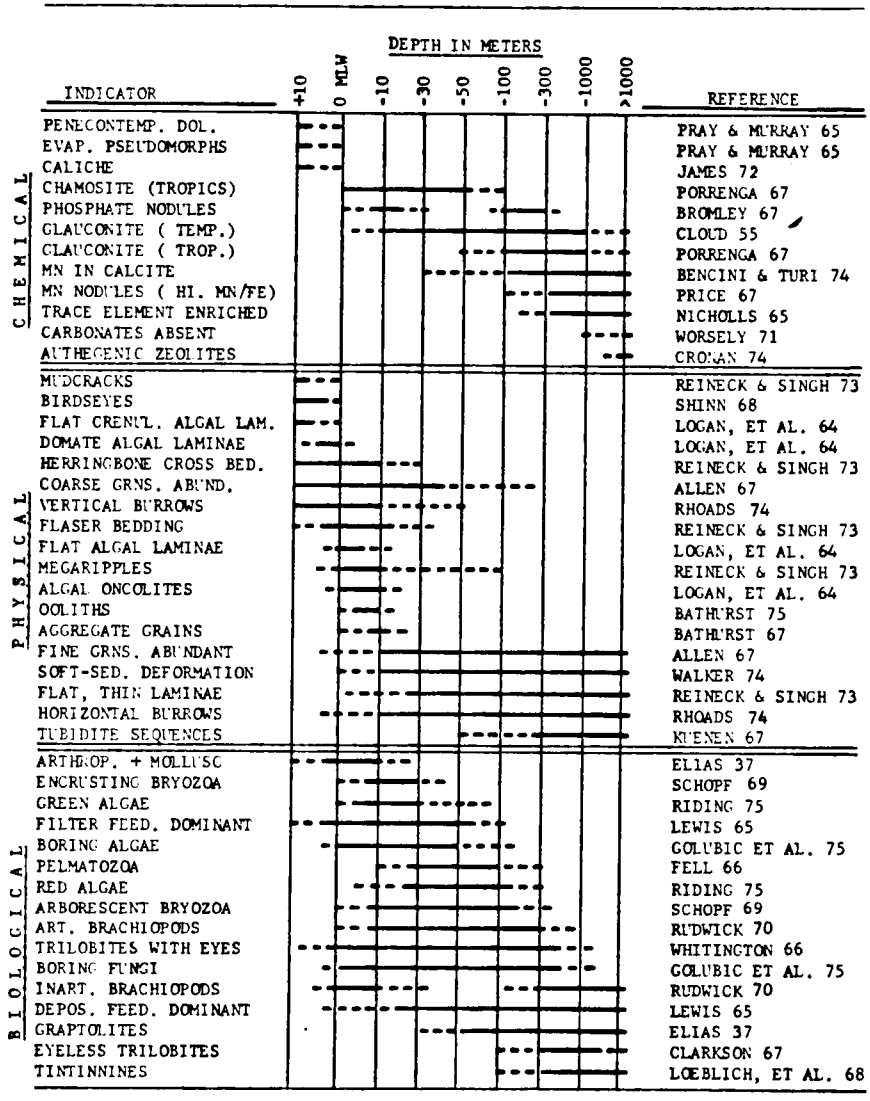


Figure 6. Paleobathymetric Maps of Four Times During the Middle Ordovician, from Benedict and Walker (1978)

TABLE I

Bathymetric Indicators From Benedict and Walker (1978)



deposits were trigonometrically calculated by measuring the shortest palinspastic distance between coeval shelf and basin deposits, estimating a moderate angle of 2.5° for the slope (based on modern analogues) and solving for the depth of the basin (Shanmugan and Walker, 1980, pp. 485-486).

Subsidence in the basin area was characterized by three phases: (1) first 1 to 2 m.y. - tectonic subsidence and sedimentation loading rates were coequal at 3 to 4 cm/1,000 years; (2) second phase, about 1 m.y. - subsidence rate was 60 to 65 cm/1,000 years and mainly tectonic; (3) final phase lasting 10 to 13 m.y. - subsidence was mainly caused by sediment loading at a rate of 4 to 15 cm/1,000 years. Estimates of sedimentation rates were based on modern analogues and are presented in Table II (Shanmugan and Walker, 1980).

Previous studies have emphasized facies relationships younger than late Pygodus serra zone time. At most sections east of the Chestuee and Dumplin Valley faults, the end of carbonate deposition occurred during late Pygodus serra zone time. How early Pygodus serra zone limestones in the east relate to similar facies west of the Saltville fault, such as the Five Oaks Formation (including the Blackford Member), has not been well determined in previous studies. A similar problem applies to the post-Knox unconformity. In contrast, the emphasis of this study at Cedar Springs, Douglas Lake and Silver City has been placed on the lower Middle Ordovician limestones in an attempt to provide better means of biostratigraphic correlation.

A new biostratigraphic time-relevant datum is proposed based on the first appearance of specimens of Phragmodus sp. A. The first

TABLE II

Accumulation Rates for Middle Ordovician Lithologies
from Shanmugan and Walker (1980)

Types of sedimentary deposits and their accumulation rates

Formation	Deposit	Rate in cm/1000 yrs (modified from original source) of modern analogous deposits	Original source of analogue information
Sevier	Turbidite	10-35 (compacted)	Kuenen, 1968; Huang & Stanley, 1972
Blockhouse	Pelagite	1-3 (compacted)	Revelle and others, 1955; Kuenen, 1968; Stanley and others, 1972
Whitesburg	Slope	5-20 (Alboran Sea)	Huang and Stanley, 1972
Lenoir (main body)	Back reef lagoon	30-40 (Area in between Florida bay and reef tract is the modern analogue of Lenoir)	Milliman, 1974
Lenoir (Mosheim Member)	Tidal flat	1-2 (world wide average)	Kukal, 1971

appearance of P. sp. A occurs stratigraphically below Pygodus serra at Silver City and below Eoplacognathus foliaceus at Douglas Lake. Its highest stratigraphic occurrence is considered to be limited at or below the top of the P. serra zone. A detailed discussion of the evolutionary transition from Phragmodus sp. A to Phragmodus flexuosus is presented in the systematics section of this report.

Lithostratigraphic and conodont biostratigraphic data from previous studies are combined with data generated from this report to construct two cross-sections (Figures 8 and 9). Figure 7 illustrates the location of each cross-section. Three time-datums are used to correlate the sections in each figure:

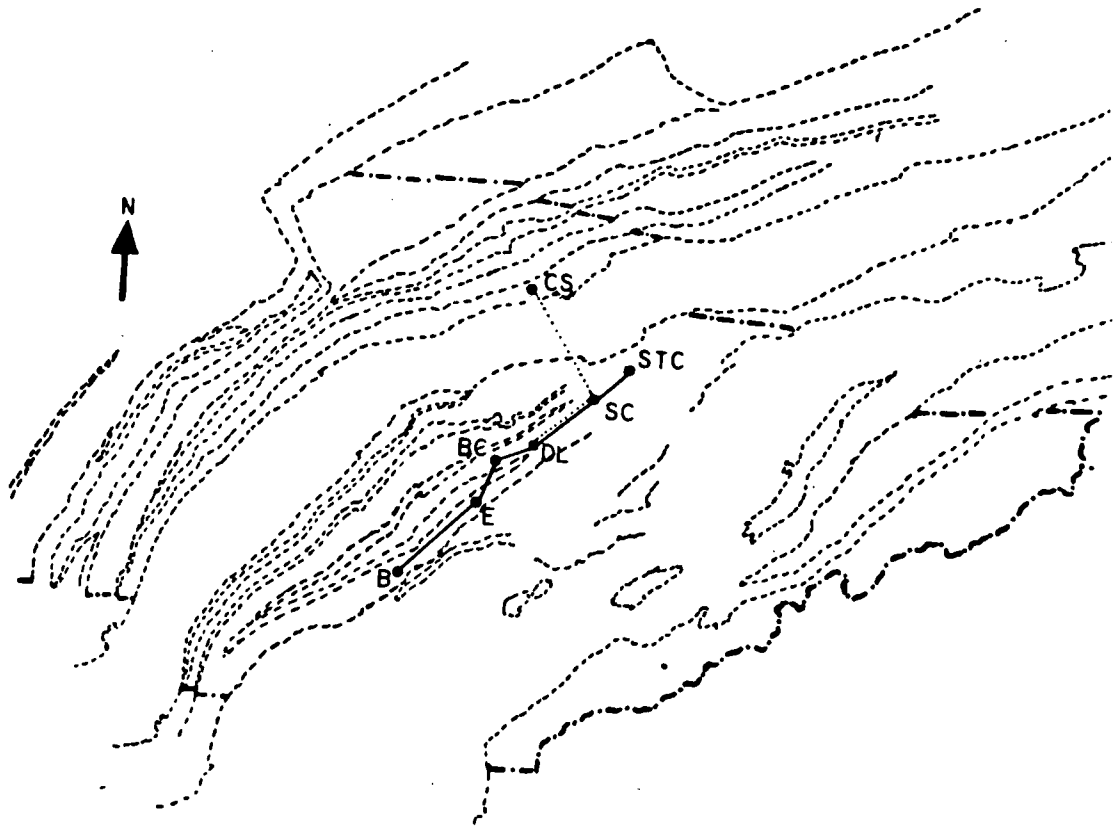
A - The first appearance of Phragmodus sp. A, pl. 2, figure 6, Appendix B.

B - The first appearance of a primitive type of Polyphacognathus friendsvillensis, pl. 1, figure 15, Appendix B (Bergstrom, 1971).

C - The first appearance of Pygodus anserinus, pl. 1, Figure 13, Appendix B.

Dashed lines represent projections of time-lines into a section where the key species was not reported or collected. These projections are based on lithostratigraphic relationships and consideration of other conodonts.

In Figure 8 the P. friendsvillensis time-line is projected into Cedar Springs, 2.2 meters above the post-Knox unconformity. This projection is placed at the top of the Pygodus serra zone boundary based on the last occurrence of Phragmodus sp. A gothodontiform



····· Line of section for figure 9 from Cedar Springs to Douglas Lake

—— Line of section for figure 8 from St. Clair to Blockhouse

Figure 7. Location Map for Cross-section Lines

Figure 8. Correlation of Cedar Springs, Silver City and Douglas Lake

CORRELATION OF CEDAR SPRINGS, DOUGLAS LAKE, AND SILVER CITY

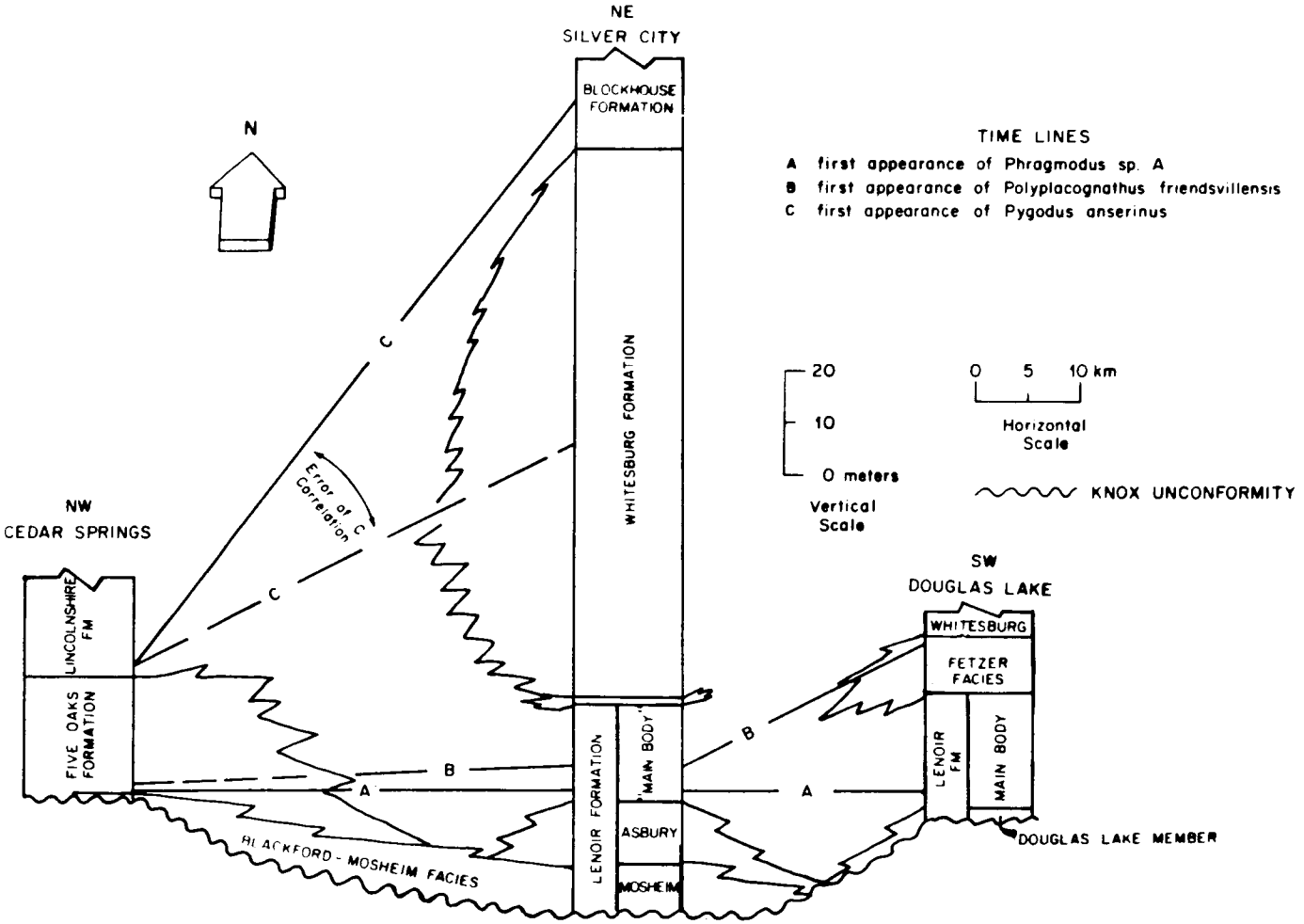


Figure 8

Figure 9. Correlation of Middle Ordovician Sections along Strike Tellico-Sevier Belt to Bays Mountain Synclinorium

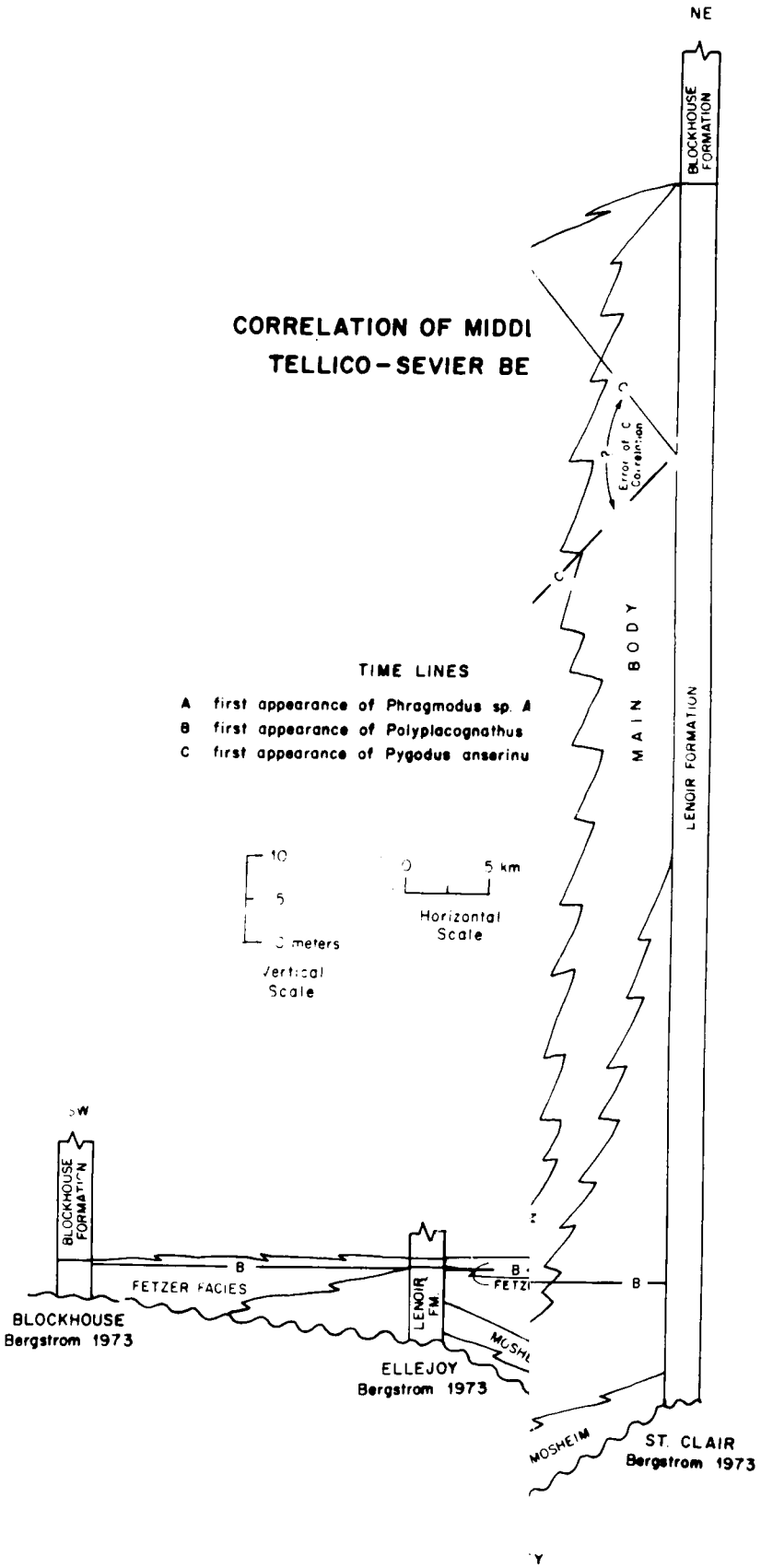

NE
BLOCKHOUSE FORMATION
CORRELATION OF MIDDI
TELLICO-SEVIER BE
Error of C Correlation
C
MAIN BODY
LENOIR FORMATION
TIME LINES
A first appearance of Phragmodus sp. A
B first appearance of Polyplacognathus
C first appearance of Pygodus anserinu
10
5
meters
Vertical Scale
0
5 km
Horizontal Scale
SW
BLOCKHOUSE FORMATION
B
FETZER FACIES
LENOIR FM.
B
FETZI
B
BLOCKHOUSE
Bergstrom 1973
ELLEJOY
Bergstrom 1973
MOSHEIM
ST. CLAIR
Bergstrom 1973
Y

Figure 9

elements (Figure 2, page 9). The first occurrence of P. sp. A is less than a meter below. Since P. friendsvillensis first appears after Phragmodus sp. A but before the transition to Phragmodus flexuosus, the projection of the P. friendsvillensis time-line B into Cedar Springs is accurate to within one meter. Unfortunately, the projection of the Phragmodus sp. A time-line A into sections south of Douglas Lake in Figure 9, is not as reliable. These projections are based on general lithofacies relationships and consideration of the evolutionary stage of specimens of Polyplacognathus friendsvillensis found higher in the section. The absence of Phragmodus sp. A from these sections may have been environmentally controlled, as discussed in the paleoecology section of this paper (Chapter III).

Because the Phragmodus sp. A time-datum has not been recognized prior to this report, an attempt should be made to further assess its validity. No other stratigraphically diagnostic species occurs with P. sp. A precluding a biostratigraphic test. It is possible, however, to test this time-line using published rates of sediment accumulation.

The stratigraphic interval between time-lines A and C (Figure 8) at Cedar Springs and Douglas Lake, indicates a distinct contrast in relative rates of rock accumulation. At Cedar Springs, 22.6 meters of tidal flat and tidal channel deposits accumulated during the time interval defined by lines A and C. At Silver City, 132.3 meters of strata resulted from deposition during the same interval and can be divided into three parts: 17 meters of lagoonal "Main Body" of the Lenoir Formation, 105 meters of slope deposits of the Whitesburg (including 1 m of Fetzer facies) and 10 meters of basinal Blockhouse

Formation (including 0.5 m of Fetzer facies). Using the median value of sedimentary rates for these formations (Table 2, page 482, Shanmugam and Walker, 1980) and the number of measured meters of section, the amount of time represented between time-lines A and C can be computed independently at each section by the unit factor method. The following calculations are rounded to the nearest 1000 years.

Cedar Springs Section A-C time calculation is:

Sediment thickness		Sediment. Rate	Time represented by A-C interval
2,260 cm	x	$\frac{1{,}000 \text{ yr.}}{1.5 \text{ cm}}$	= 1,507,000 yrs.

Silver City A-C time calculations are:

Sediment thickness		Sediment. Rate	Time represented by A-C interval
1,700 cm	x	$\frac{1{,}000 \text{ yr.}}{35 \text{ cm}}$	= 49,000 yrs.
10,500 cm	x	$\frac{1{,}000 \text{ yr.}}{12.5 \text{ cm}}$	= 850,000 yrs.
1,000 cm	x	$\frac{1{,}000 \text{ yr.}}{2 \text{ cm}}$	= 500,000 yrs.
			1,399,000 yrs. Total

1,507,000 yrs. A-C time at Cedar Springs

1,399,000 yrs. A-C time at Silver City

The calculation of error is:

$$\frac{\text{difference between values}}{\text{mean of value}} \times 100 = \text{Error}$$

$$\frac{108{,}000}{1{,}453{,}000} \times 100 = 7\%$$

The average value of time represented between the first appearance of Phragmodus sp. A and Pygodus anserinus is 1,453,000 years. The error between independent computations at Cedar Springs and Silver City is 7%. Part of this error is a result of including the Fetzer facies in the Whitesburg and Blockhouse Formations. K.R. Walker (

pers. comm., 1982) has suggested that this lithosome probably represents a greater amount of time because of an extremely slow accumulation rate. Still, this amount of error seems reasonable considering the sources of error inherent to sediment accumulation calculations as discussed by Benedict and Walker (1978) and Shanmugan and Walker (1980). These values are not presented here as absolute measurements. Rather, they represent congruent lines of evidence that support both the accuracy of sediment accumulation rates, estimated by Shanmugan and Walker (1980), and the validity of the Phragmodus sp. A time-datum.

The cross-sections in Figures 8 and 9, pages 40 and 42 respectively, are used in conjunction with published sections from previous works to construct three paleogeographic facies maps. (Figures 10a, 10b, and 10c). These maps illustrate facies relationships and environmental conditions during three time periods prior to the beginning of Pygodus anserinus time: 10a - pre-Phragmodus sp. A time, 10b - Phragmodus sp. A time, and 10c - Polyplacognathus friendsvillensis time.

At pre-Phragmodus sp. A time (Figure 10a), portions of the Knox Group were subaerially exposed. However, as McLaughlin (1973) suggested, considerable topographic relief existed. Large topographic lows formed sediment traps on the Knox surface. Carbonate mud and cherty residuum washed into these topographic depressions forming localized, thin patches of restricted micrite deposits which characterize "Mosheim" and "Blackford" type lithologies. Later, with increased circulation in the transgressing sea, these depressions developed into intertidal areas or collected subtidal "Main Body" Lenoir deposits.

Figure 10. Paleoenvironmental Maps Showing Relationships During: 10a - Pre-*Phragmodus* sp. A Time, 10b - *Phragmodus* sp. A Time, 10c - *Polyplacognathus friendsvillensis* (early) Time

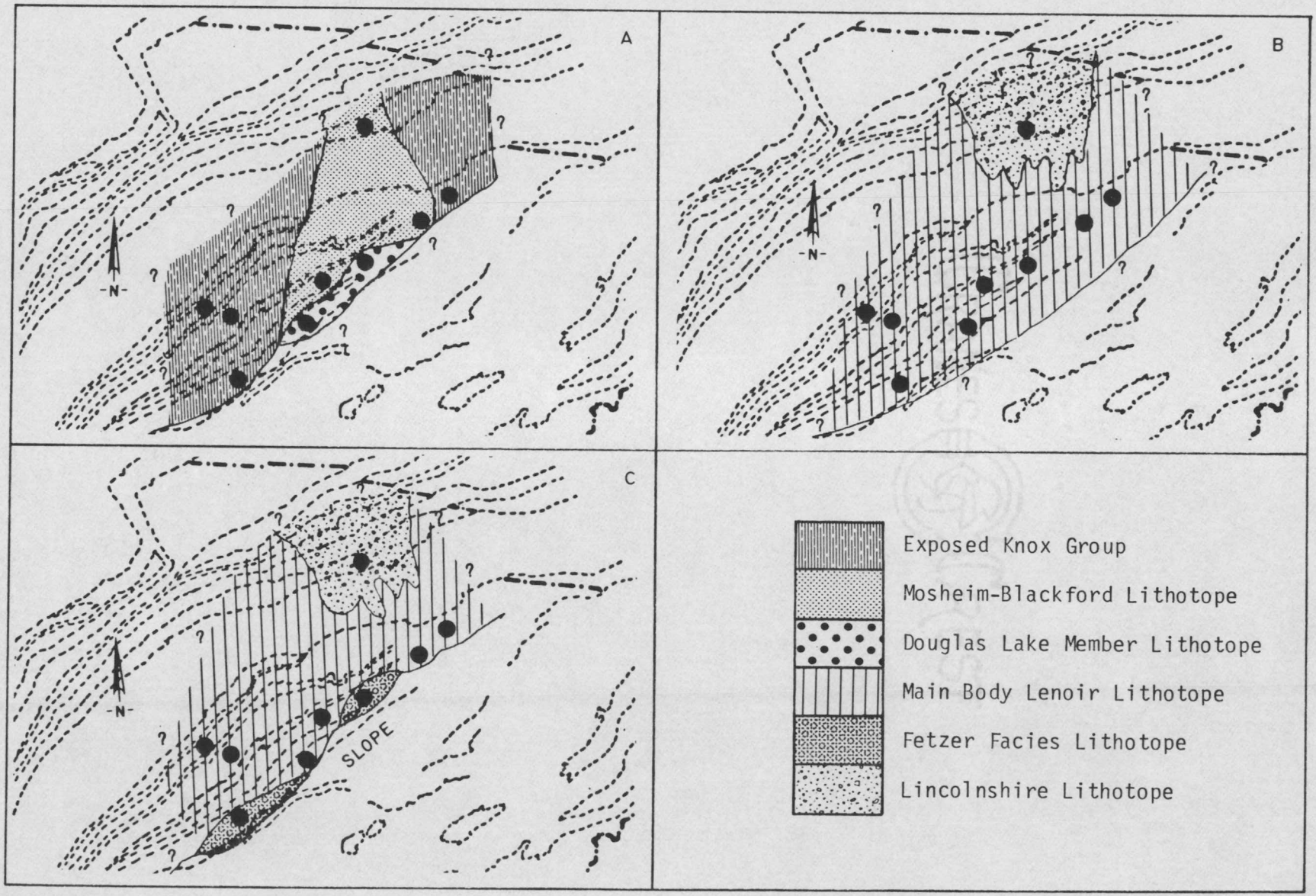

A
B
C
-N-
-N-
-N-
SLOPE
Exposed Knox Group
Mosheim-Blackford Lithotope
Douglas Lake Member Lithotope
Main Body Lenoir Lithotope
Fetzer Facies Lithotope
Lincolnshire Lithotope

Figure 10

During Phragmodus sp. A time (Figure 10b) the northwestern extension of a topographic low which collected carbonate mud at Cedar Springs was opened to the transgressing sea, establishing intertidal conditions there. This increase in circulation is further evidenced by the development of the Asbury facies, rich in oncolites at Silver City and Midway Road sections just prior to P. sp. A time (Figure 8, page 40). Tidal channels opened onto a shallow shelf on which argillaceous limestones of the lower "Main Body" of the Lenoir accumulated. Phragmodus sp. A occurred in the tidal channels near Cedar Springs. Sparse occurrences of abraded elements of P. sp. A at Silver City and Douglas Lake may represent elements transported onto the shelf from these environments.

The lithofacies and environmental array during Polyplacognathus friendsvillensis time (Figure 10c) are similar to those of Phragmodus sp. A time. The major difference is the shelfward migration of the slope (Ruppel, 1979) indicated by the presence of the Fetzer facies at Blockhouse (Bergström, 1973) and Douglas Lake. Deposition of the Fetzer facies there began shortly after P. friendsvillensis time (Figure 9, page 42). The arrival of slope conditions at Boyd's Creek occurred shortly after the P. friendsvillensis time datum, discussed herein. This is evidenced by a collection of conodonts from the lower Whitesburg which suggest Eoplacognathus foliaceus subzone time (Shanmungan, 1978).

The P. friendsvillensis time-datum falls within or less than a meter below the Fetzer facies in the three southwestern sections (Figure 9, page 42). To the northeast, the Fetzer facies is correlated

to strata of the "Main Body" of the Lenoir Formation. The Fetzer facies at Douglas Lake is a pelmatozoan grainstone containing chamosite ooids. Using the paleobathymetric indicators from Benedict and Walker (1978) Table I, page 35, this deposit can be interpreted as representing water depths of 30 to 50 meters. The argillaceous mudstone deposits of the "Main Body" Lenoir at Silver City are similar to those at Midway Road, estimated by Benedict and Walker (1978) to represent water depths of 30 to 40 m. Using mean water depth values and a palinspastic distance of 33.3 km, the minimum paleoslope between Silver City Lenoir and the Fetzer facies at Douglas Lake is calculated as 0.15 m/km. Since the Fetzer facies is directly overlain by slope or basin deposits, the line of section (Figure 9, page 42) probably represents the shelf edge just prior to subsidence or the toe of slope just after subsidence.

This scenario for pre-Pygodus anserinus deposition conforms with the sequence of subsidence events proposed by Shanmugan and Walker (1980). Pre-Phragmodus sp. A and P. sp. A times correspond to early and late periods of the first phase of 1 to 2 m.y. when the subsidence rate was 3 to 4 cm/1,000 yr. and tectonic and sediment loading subsidence were coequal, during Whiterockian, early Marmorian time (Ross et al., 1982). The onset of the second phase is marked by Polyplacognathus friendsvillensis time which lasted about 1 m.y., and subsidence was mainly tectonic at a rate of 60 to 67 cm/1,000 yrs. during late Whiterockian time (Ross et al., 1982).

CHAPTER III

CONODONT PALEOECOLOGY

Conodont Provincialism

Realization that the spatial distribution of most conodonts is controlled by environmental factors has resulted from detailed stratigraphic and paleoecologic studies by numerous workers, e.g., Sweet, Bergström, Barnes, Rhodes, and others. The existence of two major conodont provinces for the Ordovician was first distinguished, in a general way, by Sweet et al. (1959). They suggested one province based on the North American Midcontinent fauna and the other on Anglo-Scandinavian and Appalachian faunas. Sweet et al. (1971), reported that of the 80 conodont form genera recognized at the time, nearly 80 percent were represented in both European and American faunas. Similarities at the specific level, however, were less evident. About one third of approximately 400 form species were recorded from European localities or American strata yielding only European conodonts.

Bergström (1971b) observed a widespread, but rarely common occurrence of conodonts related to hyaline forms. These forms included: Chirognathus alternans, and other species of Chirognathus, and Cordylodus. Inspection of Middle Ordovician conodonts from central Australia revealed that these forms were dominant with several species occurring in both North American and Australian faunas. Because this fauna was so different from other Ordovician conodonts, Bergström described a third major conodont province in Australia especially

significant during the early Middle Ordovician. Later studies (e.g. Barnes et al., 1973; and Barnes and Fåhreaus, 1975) have not supported this interpretation; and have included the Australian forms in the North American Midcontinent fauna. Presently, the interpretation of Ordovician conodonts suggests two major conodont faunas: (1) the North Atlantic Province equivalent to Sweet's (1971) Anglo-Scandinavian-Appalachian faunas and (2) the North American Midcontinent Province.

Early definition implied that the North American Midcontinent Province was coextensive with the cratonic interior of North America. The Midcontinent Province was defined on the basis of the areal distribution of successions of distinctive Middle Ordovician conodont faunas (Sweet et al., 1959; Bergström, 1973a; Bergström, 1973b; Sweet and Bergström, 1974). The Midcontinent Province was described by these workers as having a paleogeographic location that extended through the stable shelf region of North America, terminating near the outer edge of the Ordovician continental shelf. Presently, the province is represented in strata that is bounded to the west by the Cordilleran region, to the east by the Appalachians, to the south by the Ouachita-Marathon system, and to the north by the area north of the Canadian Arctic Archipelago. Elsewhere, this provincial fauna is well known from Siberian and Australia plate localities.

The paleogeography and environment of the North American Midcontinent Province has been interpreted by Barnes and Fåhraeus (1975), who stated (p. 145):

> We regard the equatorial position, vast areal extent, shallowness, and proximity to areas of active evaporite deposition of the Ordovician epeiric seas as good evidence that raised salinity and temperature was characteristic of the Midcontinent Province.

The North-Atlantic Province conodonts are presently best known from eastern North America, the British Isles and Baltoscandia. Other occurrences of North Atlantic Province faunas include: southern, western, and northern North America (including Arctic Canada), Germany, Poland, Austria, Italy, Spain, Turkey, Spitsbergen, Australia, Tasmania, New Zealand and Argentina (Bergström, 1973a). North Atlantic faunas were widely dispersed longitudinally as well as latitudinally. This is in marked contrast to the Midcontinent faunas which were apparently restricted to occurrence in a fairly narrow equatorial belt.

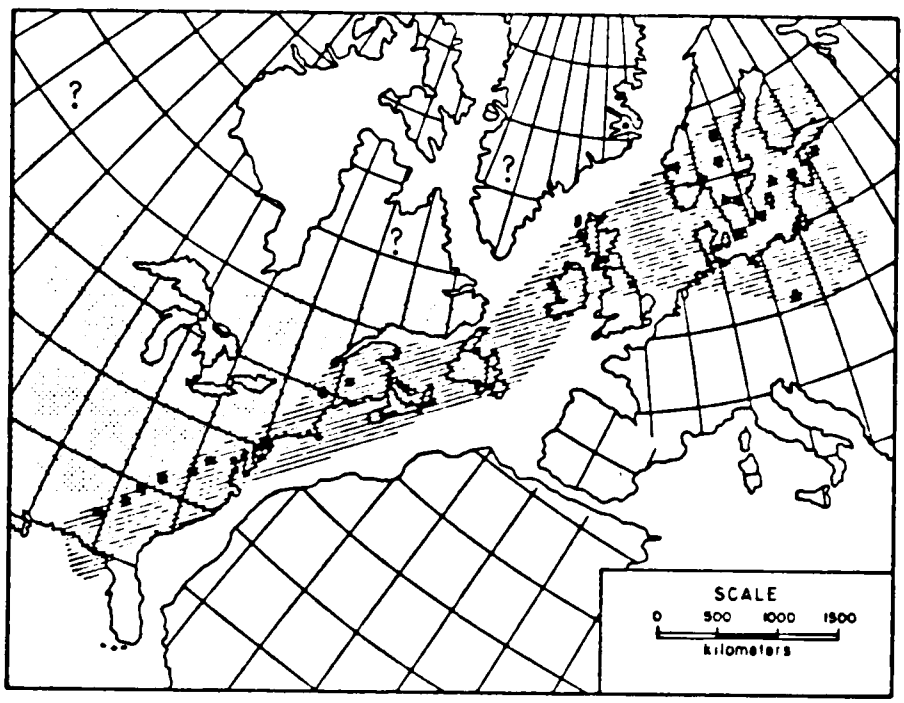
The tectonic setting for the North Atlantic Province is interpreted as representing either continental margin areas or marginal cratonic basins. Either of these settings allows for free circulation of oceanic waters with lower (i.e., normal marine) salinities and milder temperatures establishing a paleoenvironment fundamentally different from the Midcontinent Province (Barnes and Fåhraeus, 1975; Bergström, 1973a).

The boundary between the North Atlantic Province and the North American, Midcontinent Province was mapped by Bergström (1971a), based on conodont collections from the Appalachians. Bergström found that the eastern Appalachian region fauna was mostly characteristic of the North Atlantic Province whereas the western Appalachian region contained a fauna common to the Midcontinent Province. More precisely, the provincial boundary closely approximates the Helena overthrust in the Cahaba Valley of Alabama, and northward follows the Saltville fault through Tennessee and southern Virginia, the North Mountain fault in

northern Virginia. The boundary further extends northward to the Taconic front in the Champlain Valley with an extension into the St. Lawrence Valley as shown in Figure 11 (Bergström, 1971a). Generally, this boundary coincides with the division of western limestone lithologies with continental interior faunas from eastern more shaley lithologies with brachiopods, graptolites, and other biota of European affinity.

Attempts to arrive at an explanation for the segregation of conodonts into the currently recognized provinces have been made by Bergström (1971a), Barnes and Fåhraeus (1975), Lindström (1964), Fåhraeus (1976) and Dzik (1978). These studies suggested that temperature, salinity, regional climate, paleogeographical position, and tectonic evolution were the dominant controlling factors of provincialism.

Bergström (1971a) proposed that local ecological factors alone were not sufficient to explain the provincial division of conodonts, and suggested considerable post-Middle Ordovician change in the relative distance between North America and Europe as an important factor. Barnes and Fåhraeus (1975) suggested that faunal adaptation to raised temperatures and salinities in the epeiric sea of the North American midcontinent led to the segregation of conodont distribution in the Ordovician. This interpretation is supported by the fact that migration of Atlantic Province fauna into the Midcontinent Province is limited to transgressions where reduction of otherwise high salinity and temperature was possible and are consistent with interpretation of physical characteristics of those rocks.



Stippled area marks Midcontinent Province.
Lined area marks North Atlantic Province.

Figure 11. Distribution of North Atlantic and Midcontinent Provinces During the Middle Ordovician After Bergström (1971a)

Paleogeographic reconstruction of the Ordovician by Lindström (1964) illustrates that although the North Atlantic Province extended to near the equator, these cooler water faunas could have been contained in a body of cold water protected by continental barriers and maintained by current circulation. Dzik (1978) pointed out that the interpretation of the segregation of the conodonts based on paleogeographic position is in conformity with the distribution of populations in relation to hydrographic conditions observed in recent pelagic organisms.

The role played by tectonic evolution may not be restricted to resulting changes in paleogeography. Fåhraeus (1976) argued that major alterations of continental margins induced marked increases in taxonomic turnover. He proposed that Ordovician provincialism was established during the Cambrian to early Ordovician evolutionary burst induced by the concurrent destruction and transformation of continental margins.

Precisely what controls most affected conodont distribution segregating the biota into the North Atlantic and Midcontinent Province is uncertain. Many of the factors presented above are congruent with each other and a combination of some or all of these probably best explains Ordovician conodont distribution.

Mode of Life

Seddon and Sweet (1971) proposed an ecologic model for conodonts using depth-stratified, planktonic chaetognaths as a modern analogue. This model was applied to Devonian and Ordovician examples where conodont distributional data were available. Conodont faunas from the

Middle and Upper Ordovician rocks from the Cincinnati Region were divided into three components: (1) indigenous fauna - Phragmodus undatus, Plectodina aculeata and P. furcata; (2) European fauna - Amorphognathus, Icriodella, Periodon and Rhodesognathus; and (3) interior fauna - Panderodus, and Belodina. Distributional data indicated that some species within each fauna were ubiquitous while others were restricted, generally to deeper water facies.

Application of the depth stratified model to the indigenous fauna identified Phragmodus as the principal component at deeper-water depositional sites and Plectodina as the principal contributor in shallow-water lithotopes. Amorphognathus was considered the deep-water form and Icriodella the shallow-water member of the immigrant European fauna, with some overlap of depth ranges. Assignment of depth relationships for the interior fauna was tentative. Panderodus was suggested as the shallow water form and Belodina as the deeper water form. Both were considered to occur at much shallower depths than the lower depth limit of indigenous fauna.

Seddon and Sweet (1971) also suggested a relationship between ecologic habit and evolution. Shallow water species, or inhabitants of the upper photic zone were regarded as "generalized" having departed least from the ancestral stock. Inhabitants of the deeper zone were considered "more specialized" having evolved farther from the ancestral stock.

Chamberlain and Clark (1973) integrated trace fossil and conodont distributional data from Pennsylvanian and Early Permian strata of the Oquirrh Basin of central Utah. Bathymetric interpretations, based

primarily on the succession of trace-fossil assemblages and sediment types, coincided with conodont distributions predicted by the Seddon and Sweet (1971) depth-stratification model.

Druce (1973) also interpreted the distribution of Upper Devonian and Lower Carboniferous conodont faunas with an adaptation of the depth-stratification model of Seddon and Sweet (1971). In addition to a vertical segregation of faunas, Druce implied a relationship between distance from shore and absence of shallow-water fauna. This scenario suggests shallow water forms reach greatest abundance near shore, explaining their absence from some samples which contained only deep-water forms. Three biofacies were recognized within the depth-stratification model. Biofacies I was the shallowest and contained the greatest density of individuals nearest shore. Biofacies II was intermediate in depth and the density of individuals remained high farther from the shoreline. Biozone III represents the deepest zone where the density of individuals was evenly distributed throughout the zone.

Heckel and Baesemann (1975) described a cyclic pattern of conodont distribution in lower Upper Pennsylvanian (Missourian) mega-cyclothems of eastern Kansas. The complex vertical pattern of conodont distribution found in those strata conformed to the Seddon and Sweet (1971) model of planktonic depth zonation. These authors state:

> The general order of progressive appearance of genera with increasing depth of water in each megacyclothem appears to be: Adetognathus-Ozarkodina minuta-Aethotaxis-Idiognathodus-Idioprioniodus-Gondolella-an unassigned O, element.

(Heckel and Baesemann, 1975, p. 507). Deeper water conodonts displayed a progressively more restricted stratigraphic occurrence centered around

the deeper water, dark shale member of each megacyclothem. Shallower water genera were identified as those that were found in both deep facies and shallow deposits. Uncertain of the actual controlling factors over this depth zonation, Heckel and Baesemann (1975) proposed that a slightly different mix of environmental conditions may lead to a somewhat different depth zonation in other basins.

Chatterton (1976) discussed the distribution of conodont faunas in Middle Devonian strata from the Mackenzie District of western and northwestern Canada. Four distinct conodont associations were recognized. These "biofacies" were considered to be similar to those recognized by Druce (1973). Chatterton recognized both a pelagic form, Polygnathus parawebbi and benthic or nektobenthic forms, Icriodus expansus, I. n. sp. A (of Chatterton) and species of Pelekysgnathus. Much of the strata discussed by Chatterton, were deposited under restricted or semi-restricted conditions. Consequently, temperature and salinity were regarded as the major controlling factors of pelagic form distribution in a scenario similar to that presented by Druce (1973). Other studies which describe similar distributional patterns to the modified depth-stratification model of Seddon and Sweet (1971) include Sandberg (1976), Upper Devonian; Schumacher (1976), lower and middle Devonian; Austin (1976), lower Carboniferous; and Clark and Rosser (1976) Early Triassic.

An alternative model to depth stratification, proposed by Barnes, Rexroad, and Miller (1973) and refined by Barnes and Fåhreaus (1975), favored a strong component of lateral segregation of most Ordovician conodonts as a result of a benthic or nektobenthic mode of life. They

conclude: "Thus, collections taken from different contemporaneous lithofacies representing nearshore to progressively offshore environments will show distinct changes in faunal composition" (Barnes and Fåhraeus, 1975, p. 135). Included in this latter model were a minority of taxa that showed wide tolerance of lithofacies and wide distribution which were regarded as pelagic, such as Panderodus and Drepanoistodus. Conodont "communities", in the sense of Valentine (1968), were recognized within the Midcontinent (Figure 12a) and North Atlantic (Figure 12b) Provinces. In general, those species considered to live farthest from shore corresponded to the deeper water fauna of Seddon and Sweet (1971), which includes Phragmodus and Amorphognathus. The major difference between the two models lies in the interpretation of "mode of life", whether pelagic or nektobenthic.

Barnes and Fåhraeus (1975) in also suggesting relationships between conodont paleoecology and evolution state: "It appears possible to correlate evolutionary changes in the conodont apparatus with changes in the preferred habitat" (Barnes and Fåhraeus, 1975, p. 133). Three such relationships were identified: 1) neurodont or hyaline conodonts, adapted to higher salinities, are generally more robust; 2) conodonts evolving from a pelagic to a benthic or nektobenthic habit acquired an apparatus characterized by a symmetry transition series and added ramiform elements; and 3) deep-water forms migrating shoreward modified platform elements in North Atlantic forms such as the Prioniodus-Eoplacognathus (deep to shallow water), and modified blades in Midcontinent forms Eoplacognathus-Polyplacoganthus (North Atlantic to Midcontinent).

ENVIRONMENT / SERIES		LITTORAL		INCREASING DEPTH →
CINCINNATIAN		*Rhipidognathus*	*Belodina* *Oulodus* *Plectodina* *Pristognathus*	*Phragmodus*
CHAMPLAINIAN	Trentonian	*Cardiodella* *Chirognathus* **Erismodus* *Polycaulodus*	**Belodina* *Bryantodina* *Oulodus* **Plectodina* **Polyplacognathus*	**Phragmodus*
	Blackriveran			
	Chazyan	*Coleodus* **Leptochirognathus*	*Histiodella* Hyaline prioniodids *Multioistodus*	**Belodella* *Oulodus* **Phragmodus*
	Whiterockian			
CANADIAN			*Drepanodus* *Loxodus* *Scolopodus* *Ulrichodina*	

12a

ENVIRONMENT / SERIES	LITTORAL		INCREASING DEPTH →		
ASHGILLIAN	?	*Amorphognathus* *Baltoniodus* *Belodina* *Plectodina*	*Belodella*	?	?
CARADOCIAN	NEURODONTS	*Amorphognathus* *Baltoniodus* *Eoplacognathus* *Icriodella* *Rhodesognathus*	*Belodella* *Cordylodus*	*Periodon*	?
LLANDEILIAN	NEURODONTS	*Amorphognathus* *Baltoniodus* **Eoplacognathus* *Icriodella*	**Belodella* *Cordylodus*	**Periodon*	?
LLANVIRNIAN	NEURODONTS HYALINE PRIONIODIDS	*Baltoniodus* **Eoplacognathus*	**Belodella* *Cordylodus*	*Amorphognathus* **Oistodus* **Periodon*	?
ARENIGIAN	NEURODONTS HYALINE PRIONIODIDS	?	*Belodella* *Cordylodus*	*Amorphognathus* *Baltoniodus* *Microzarkodina* *Oistodus* *Periodon*	*Prioniodus*
TREMADOCIAN	?	?	*Cordylodus*	?	?

12b

* Indicates genera recovered in the present study.

Figure 12. Nektobenthic Conodont Communities after Barnes and Fåhraeus (1975): 12a Midcontinent Province, 12b North Atlantic Province

Titus and Cameron (1976) defined six paleocommunities distributed perpendicular to the paleoshore within the lower Trenton Group (Middle Ordovician) of central and northwestern New York State. Their community analysis included conodont distributions obtained from Schopf (1966). Four of the six paleocommunities were analogous to shelly megafaunal assemblages recognized by Ziegler, Cocks and Bambach (1968) which included the following paleocommunities: lagoonal Triplesia, offshore shoal Liospira, and two level bottom shelf communities dominated by Encrinurus and Trematis respectively. Two additional shelf to basin transitional facies communities were identified as: the outer shelf-bank margin Geisonoceras and the bank-slope Triarthrus communities.

Conodont distributions within these communities closely paralleled those of presumed nektobenthic nautiloids. Conodont diversity was greatest in the shoal Liospira and deep water Geisonoceras and Trematis communities. Fewer taxa were associated with the lagoonal Triplesia and shallow shelf Encrinurus communities. Some species, such as Plectodina furcata, were confined to time transgressive shallow water facies. These distributions were cited as evidence for the benthic or nektobenthic conodont model of Barnes and Fåhraeus (1975) as opposed to the planktonic model of Seddon and Sweet (1971). Other studies which support the benthic or nektobenthic model of Barnes and Fåhraeus (1975) include: Kozur (1976) for the Triassic, and Le Fevre et al. (1976) for the Ordovician-Silurian.

The pelagic depth stratification model and the benthic model of lateral segregation are perhaps the most popular explanations of

conodont distribution. There are, however, several studies which describe faunal distributions and characteristics that are not accounted for by these models alone. Aldridge (1976) described Silurian faunas that did not conform to either model, pelagic or benthic. Water energy was suggested as the major controlling factor. Bultynck (1976) also reported that the pelagic and benthic models insufficiently explained his middle Devonian faunas and suggested that provincialism was the dominant controlling factor. Merrill and Martin (1976) also rejected the pelagic and benthic models warning that these models are too simplistic because they rely upon single environmental factors to explain complex distributional patterns of conodonts.

"Recurrent species associations", identified by Bergström and Carnes (1976) in Middle Ordovician faunas of Tennessee, do not conveniently fit into either model. These groups of conodonts appeared to be associated with certain environments. The Leptochirognathus R.S.A. was associated with tidal flat deposits of the Mosheim Member of the lower Lenoir Formation. Two recurrent species associations were found in the upper Lenoir. The Belodella-Phragmodus-Polyplacognathus R.S.A. occupied shallow subtidal environments. Deeper, subtidal facies of the Lenoir contain the Periodon-Pygodus R.S.A. A further synopsis of the Bergström and Carnes (1976) study is presented in the introduction of this report.

Jaanusson and Bergström (1980) compared the distributional differentiation of Baltoscandian Middle Ordovician faunas to counterparts in the southern and central Appalachians. Shelly fauna, graptolite and conodont distributions were compared, and three

confacies belts were described. The ecological factors responsible for segregation of confacies were not identified; however, water depth was considered to be important for second-order differentiation within a confacies belt. Distribution patterns of shelly, graptolite, and conodont faunas did not always coincide. Consequently, ecological factors affecting distribution were considered to be specific for each fauna.

Many of the previous studies cited herein are discussed in a review of conodont ecology, by Klapper and Barrick (1978). Similar to the views of Merrill and Martin (1976), these authors regard distributional data alone as insufficient for the analysis of the mode of life of conodonts. Stressing hydrographic factors, a neritic or nektobenthic model was proposed for conodonts. Variations in salinity and temperature were considered responsible for the lateral segregation of faunas reported by proponents of the Barnes and Fåhraeus (1975) model.

Approach to Conodont Paleoecology

Most ecologic studies, discussed previously, were based on groups (e.g. biofacies or communities) of conodonts that shared similar distributional relationships. These "biofacies" were placed in a sedimentologic setting in which formations or lithosomes were considered to represent paleodepositional environments. In most cases, however, the depositional environments of these lithosomes have been interpreted in an extremely simplistic way without detailed petrologic study of the sediments. Attempts were made to recognize community reorganizations which reflected large scale changes in environments,

such as the transition from carbonate to silici clastic deposition. A similar but refined approach is taken here.

At each locality, lithologically homogeneous units within formations were sampled in an attempt to recognize biotic responses to subtle environmental changes. Thin section and acetate peel analyses were employed to compile environmental information. High and low subdivision of supratidal, intertidal and subtidal environments were recognized using criteria established by Purdy (1963), Laporte (1971) and Walker (1973). Facies relationships, discussed in the chapter on biostratigraphy, were used to integrate environmental information from Cedar Springs, Silver City, and Douglas Lake, providing a three-dimensional perspective of environmental relationships, as suggested by Merrill and Martin (1976). Biostratigraphic events, used in intrabasinal correlation, such as the first appearance of Polyplacognathus friendsvillensis, are examined within this environmental framework in order to test their ecologic independence.

Petrology and Depositional Environments

Depositional environments were inferred from petrographic examination of 23 thin sections, 35 acetate peels and more than 50 polished slabs. Terminology for lithologic descriptions in this chapter is as follows: bedding thickness-McKee and Weir (1953), modified by Ingram (1954); grain size-Wentworth (1922); roundness-Powers (1953); and sorting Folk (1974). Carbonate rock classifications follow Dunham (1962). Facies with corresponding inferences of depositional environments are described in ascending stratigraphic order in each situation.

Cedar Springs. Generalized depositional interpretations for the Five Oaks and Lincolnshire Formations at Cedar Springs have been presented by Ruppel (1979). Referring to the heterogeneous nature of these formations, Ruppel (1979, p. 61) stated that ". . . each is a complex admixture of intergradational microfacies." Figure 13 illustrates the stratigraphic occurrence of these lithologies (units 1-7), and the characteristic constituents of each.

The Five Oaks Formation is divided into 7 units, representing successive microfacies. At the base of the formation, unit one unconformably overlies the Knox Group and corresponds to the Blackford Member. This unit consists of a light green to gray dismicrite, containing vertical burrows, irregular birdseyes, and rare lithoclasts of tan to brown dolostone and chert, probably derived from the Knox. Pelloids and intraclasts, if present, are difficult to discern in the near homogeneous micrite composing this rock. The biotic components of unit 1 comprise only a few small fragmentary fossil allochems including trilobites, gastropods, ostracode valves, and rare pelmatozoan debris. Vertical burrows suggest that the lithotope was regularly submerged and nonlithified. This unit is interpreted as representing carbonate mud which accumulated in a restricted pond on the eroding Knox surface in a low supratidal tidal flat environment. Analogous supratidal ponds in the Bahamas have been described by Shinn, Lloyd and Ginsburg (1969). Mud was probably derived from offshore environments and deposited during storms in a process similar to that described by Ball et al. (1967) and Perkins and Enos (1968). This depositional process also accounts for the presence of pelmatozoan

Figure 13. Stratigraphic Distribution of Conodont Species, Petrologic Data and Inferred Depositional Environments at Cedar Springs

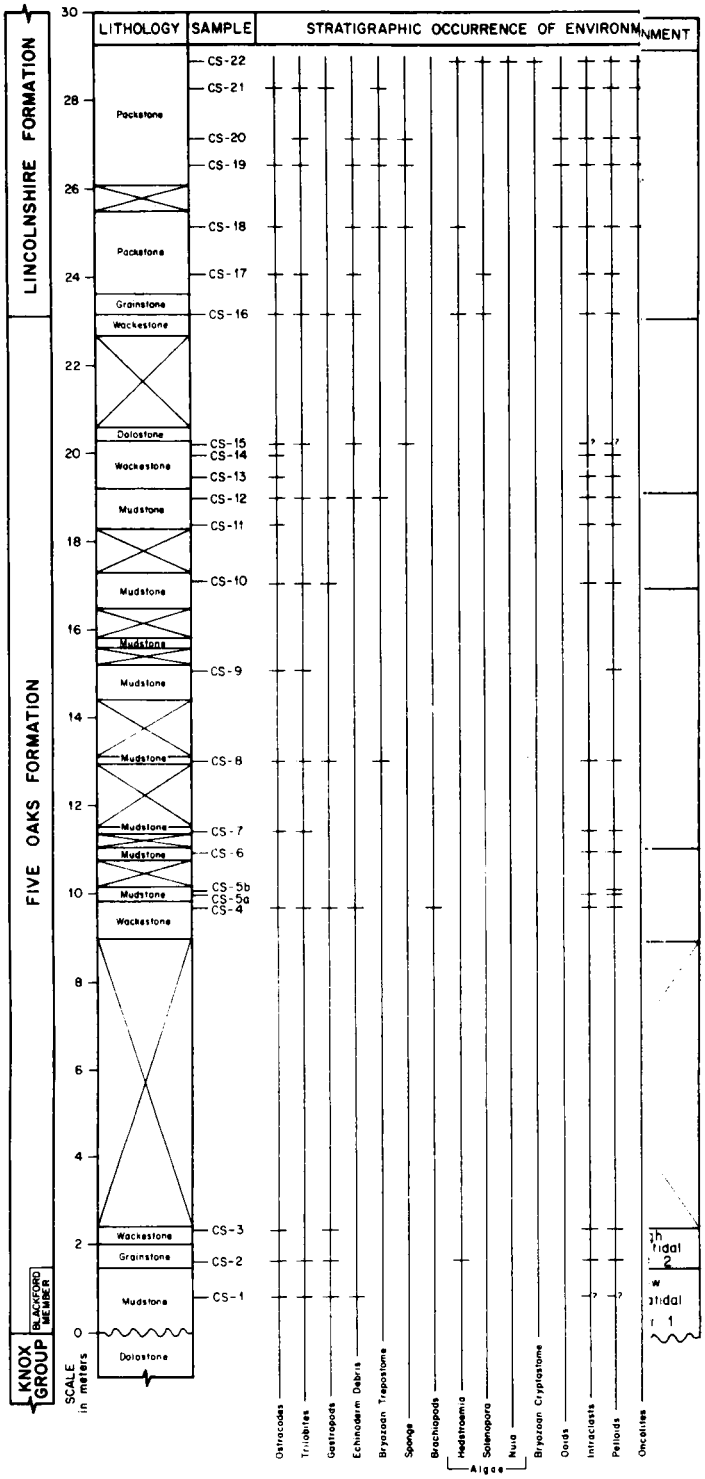

LINCOLNSHIRE FORMATION
FIVE OAKS FORMATION
KNOX GROUP
BLACKFORD MEMBER
LITHOLOGY
SAMPLE
STRATIGRAPHIC OCCURRENCE OF ENVIRONMENT
SCALE in meters
Packstone
Packstone
Grainstone
Wackestone
Dolostone
Wackestone
Mudstone
Mudstone
Mudstone
Mudstone
Mudstone
Mudstone
Mudstone
Wackestone
Wackestone
Grainstone
Mudstone
Dolostone
CS-22
CS-21
CS-20
CS-19
CS-18
CS-17
CS-16
CS-15
CS-14
CS-13
CS-12
CS-11
CS-10
CS-9
CS-8
CS-7
CS-6
CS-5b
CS-5a
CS-4
CS-3
CS-2
CS-1
Ostracodes
Trilobites
Gastropods
Echinoderm Debris
Bryozoan Trepostome
Sponge
Brachiopods
Hedstroemia
Solenopora
Nuia
Algae
Bryozoan Cryptostome
Oolids
Intraclasts
Pelloids
Oncolites

Figure 13

debris not commonly found in restricted environments (Laporte, 1967, 1971; Walker and Laporte, 1970; and Walker, 1972).

Medium gray grainstone and wackestone of unit 2 are lithologically and environmentally distinct from unit 1; intraclasts and pelloids are significant components. Fossil allochems include ostracodes, trilobites, gastropods and fragments of the alga Hedstroemia. Grainstone comprising the lower portion of this unit contains detrital dolomite rhombs and vertical burrows. Desiccated laminations, characteristic of algal activity, result in a well developed interlaminar fenestral fabric. Generally, these laminations are preserved in environments such as inland algal flats, which lack burrowing organisms (Davies, 1970 and Logan et al., 1974). The presence of burrowed laminations in the upper portion of unit 2 suggests a high intertidal environment where burrowers are not totally excluded, such as tidal channel, bank or levee.

Unit 3 is characterized by mudstone which contains large, elongate intraclasts oriented parallel to bedding. Two types of intraclast occur. Laminated intraclasts, composed of micrite and dolomite rhombs, are devoid of fossils. Non-laminated micrite intraclasts are less abundant and contain gastropods, ostracodes, trilobite fragments and burrows. Geopetal structures indicate that burrows within these intraclasts were vertical. Fossil allochems, other than those contained in intraclasts, are absent. Dolomite rhombs and rare micrite comprise a laminated matrix lithologically similar to the first intraclast type. Similar fabrics have been described from desiccating, algally laminated sediments by Shinn et al. (1969) and

Logan et al. (1974). Unit 3 is interpreted as representing a low supratidal environment. Laminated intraclasts suggest local desiccation of algal mats. Rare, fossiliferous, and vertically burrowed intraclasts suggest deposition of sediment derived from deeper water environments probably during storms. Skeletal sand which includes abraded brachiopods and echinoderm ossicles occurs in a nonlaminated bed within the unit (Sample CS-4). This sample is interpreted as a thin deposit of storm debris which washed exotic skeletal material onto the supratidal algal mats.

Unit 4 is a light gray, relatively homogeneous, mudstone that differs from unit 3 by a conspicuous absence of large intraclasts and dolomite rhombs. Nonlaminated micrite comprises most of this rock. Small, rare, micrite intraclasts devoid of either fossils or laminations, are distinguished from the matrix by their darker color. Ostracodes, trilobites and gastropods comprise the biota. Rare vertical burrows suggest a minor amount of additional biogenic activity. Based on the restricted fauna (Laporte, 1971; Walker and Laporte, 1970; and Walker, 1972), presence of vertical burrows, and stratigraphic proximity to a supratidal facies, this unit is interpreted to represent a high intertidal environment.

Bioturbated mudstone is characteristic of unit 5. This lithology displays a dismicrite fabric, similar to that of the Blackford Member (unit 1). Ostracodes are the sole biotic constituent of the lower portion of this unit. The upper part is characterized by the occurrence of intraclasts and abundant fossil fragments including trilobites, gastropods and trepostome bryozoan as well as echinoderm debris. The dismicritic fabric and near absence of fauna in the lower portion of

unit 5 are characteristic of a supratidal environment which would nearly exclude biota and promote desiccation. The disarticulated and fragmentary nature of echinoderms and other fossil allochems in the upper portion of this unit are characteristic of exotic constituents transported into this environment, probably by storm activity.

Wackestone, with a well developed fenestral fabric, characterizes unit 6. Algal laminations are bioturbated and show evidence of desiccation. Intraclast composition is nearly identical to the laminated wackestone suggesting proximity of source. With the exception of abraded gastropods and trepostome bryozoans (sample CS-15), ostracodes are the only biotic constituent observed in thin section. In addition to its greater biotic diversity, sample 15 (see Figure 13) is also distinguished from the general lithology of unit 6 by the conspicuous absence of a well developed fenestral fabric. The environmental interpretation of unit 6 is based not only on its lithologic composition but also on its stratigraphic proximity to channel deposits of unit 7. The fenestral wackestone is interpreted as an intertidal levee deposit, similar to those at the top of unit 2. The fragmentary exotic biotic composition and lack of laminations and fenestral fabric in sample 15 probably represents a thin bed of storm detritus, or perhaps channel lag within unit 6.

The base of unit 7 coincides with the lower boundary of the Lincolnshire Formation. This unit is characterized by poorly sorted grainstone and wackestone. Well-rounded, poorly-sorted, lithic allochems include intraclasts, and pelloids. Superficial ooids are large (2-5 mm in diameter) with a small cortex to nucleus ratio, and a

small number of concentric laminations. Biotic constituents include: ostracodes, trilobites, gastropods, trepostome and cryptostome bryozoans, sponge spicules, brachiopods and fragments of the algae Hedstroemia, Solenopora, and Nuia. Further evidence of possible algal activity includes the presence of oncolites and micritic rinds which coat nearly all fossil allochems. Vertical burrows are absent, but abundant horizontal burrows occur in the upper portion of this unit. Bi-directional cross bedding, recognizable in thin section, is characteristic of the central third of the unit.

The increase in faunal abundance and diversity and the presence of stenotopic organisms such as pelmatozoans, brachiopods, and cryptostome bryozoans suggest a normal marine environment. Additionally, superficial ooids, algally-coated grains and cross bedding common to this lithology, are characteristic constituents in modern carbonate tidal channels described by Loreau and Purser (1973). Consequently, this unit probably represents a distal subtidal channel where conditions of temperature and salinity were stable enough to support a fairly stenotopic fauna. Strong tidal currents which could winnow mud and agitate grains acted on the sediment-water interface. Gradual deepening within this environment is suggested by the presence of horizontal burrows in the upper 2 meters of unit 7.

Douglas Lake. The petrologic investigation of the Douglas Lake section incorporated analysis of thin sections and acetate peels. Petrologic analysis included the upper 8 meters of the Knox group and the Douglas Lake Member and 22.8 m of the main body of the Lenoir

Formation. Petrologic, lithologic and biologic data are summarized with inferred environmental units (Figure 14).

The upper 8 meters of Knox Group dolostone comprise unit 1. These rocks are characterized by cryptalgally laminated, dolomitic mudstones evidenced by: (1) wavy laminae and, (2) antigravitational sediment accumulation. Desiccation features include mudcracks, poorly developed irregular fenestrae (0.10 mm to 0.30 mm thick). Rare vertical burrows are filled with blocky spar cement. The fauna is present in this lithology in a low abundance and consists of ostracodes, gastropods and sponges. The ostracodes occur as randomly oriented, rarely articulated valves. Other allochems present include laminated, micritic interclasts and homogeneous pelloids.

The greatest lithologic variation within the upper Knox Group is the occurrence of a pelletal mudstone with a grumeleuse fabric approximately 4.0 meters below the unconformity. This rock commonly contains abundant dolomite rhombs and small chert grains. Allizarin red stain for calcite indicates that algal laminations have a lower abundance of dolomite than the interbedded muds.

Logan et al. (1974) stated that irregular fenestral fabric is commonly formed by algal mats in the upper and middle intertidal zones. Gastropods and ostracodes are euryhaline groups of animals with representatives able to survive variable salinities characteristic of intertidal environments. Furthermore, exclusion of stenohaline fauna from the Upper Knox Group is an additional indication that sediment comprising these rocks was deposited in the intertidal zone.

Figure 14. Stratigraphic Distribution of Conodont Species, Petrologic Data and Inferred Depositional Environments at Douglas Lake

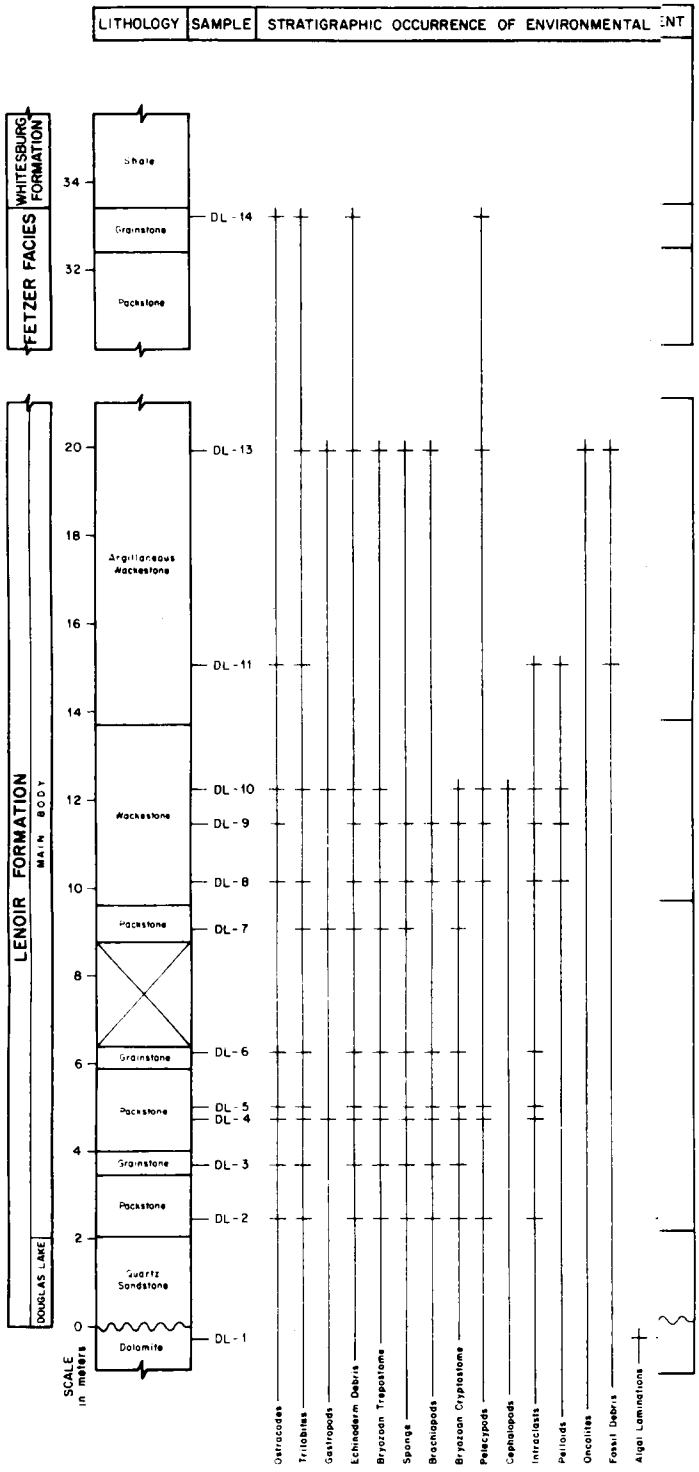

LITHOLOGY
SAMPLE
STRATIGRAPHIC OCCURRENCE OF ENVIRONMENTAL
WHITESBURG FORMATION
FETZER FACIES
LENOIR FORMATION
MAIN BODY
DOUGLAS LAKE
Shale
Grainstone
Packstone
Argillaceous Mackestone
Wackestone
Packstone
Grainstone
Packstone
Grainstone
Packstone
Quartz Sandstone
Dolomite
DL-14
DL-13
DL-11
DL-10
DL-9
DL-8
DL-7
DL-6
DL-5
DL-4
DL-3
DL-2
DL-1
34
32
20
18
16
14
12
10
8
6
4
2
0
SCALE in meters
Ostracodes
Trilobites
Gastropods
Echinoderm Debris
Bryozoan Trepostome
Sponge
Brachiopods
Bryozoan Cryptostome
Pelecypods
Cephalopods
Intraclasts
Pelloids
Oncolites
Fossil Debris
Algal Laminations

Figure 14

The post-Knox unconformity is well exposed at Douglas Lake forming the boundary between the Upper Knox Group and the Douglas Lake Member of the overlying Lenoir Formation. Rubble breccia, situated on the Knox erosional surface, forms a laterally discontinuous unit. Above the unconformity, the Lenoir Formation measures approximately 25.1 meters thick and comprises the Douglas Lake Member (unit 2) and the overlying "main body" (units 3-5).

The quartz sandstone comprising the Douglas Lake Member of the Lenoir Formation (unit 2) contains a variety of terrigenous clastic material including chert and metamorphic quartz. These constituents are generally fine grained, rounded, and well sorted. The matrix contains dolomite rhombs and terrigenous silt cemented by dolomite and blocky calcite.

Paleoenvironmental interpretation of this unit must be based on its stratigraphic position and terrigenous character. Two possible environmental settings are proposed. First, these sands could have been deposited in a high energy shoaling or beach environment associated with a topographic high on the eroding Knox surface. Detrital, terrigenous sand was probably derived from the Knox. A second possibility is that these sands represent fine grained peritidal channel deposits.

The lowermost "main body" Lenoir (unit 3) is 7.6 meters thick and comprised of fossiliferous packstone. The fauna present in this lithology consists of trepostome and cryptostome bryozoans, brachiopods, ostracodes, echinoderm debris, trilobites and sponge spicules. These grains are surrounded by a matrix of micrite with unidentifiable

fossil fragments. Minor occurrences of micrite intraclasts represent the only other allochems. A few dolomite rhombs occur at the bottom of this unit (sample 2) and styolites are common.

The change from deposition of the Douglas Lake Member sandstone to unit 3 carbonates indicates a decrease in water energy associated with deepening conditions. This is evidenced by the presence of abundant mud and an apparently indigenous fauna. These lithologies are interpreted to represent subtidal conditions near effective wave base where currents of removal occasionally acted to abrade fossil allochems and produce relatively thin beds of grainstone. Within these grainstones diverse fauna includes: cryptostome and trepostome bryozoans, echinoderm fragments (in abundance), brachiopods, sponges, ostracodes, and trilobites; grains characteristically have micrite envelopes. Other allochems are restricted to a minor occurrence of micrite intraclasts. Intergranular pore space is filled by blocky spar cement with many of the echinoderm plates possessing syntaxial overgrowths.

The obvious decrease in the abundance of micrite indicates the onset of currents of removal at the sediment-water interface. Regardless of this decrease in mud, fossil diversity is nearly identical to that observed for packstone lithologies. Thus, these grainstones could be explained in two ways. A lateral shift of environments could have resulted in bringing these sediments well within the zone of effective wave agitation allowing for the removal of mud without a significant change in faunal diversity. Or, the increase in echinoderm debris could have resulted from build up of an adjacent pelmatozoan

dominated bioherm supplying abundant debris and consequently raising the sediment water interface into winnowing currents.

Unit 4 is 4.1 meters thick and is characterized by wackestone and the presence of abundant micrite. The fauna present in this unit includes echinoderms (debris), ostracodes, gastropods, brachiopods, bryozoans (encrusting, trepostome and cryptosome) trilobites, sponges, cephalopods and pelecypods. Large intraclasts are also common and their similarity to the wackestone suggests little transportation. Many fossil grains have well developed micrite envelopes. Abundant horsetail stylolites are common in this unit and often bound terrigenous silt and clay drapes. Rare, vertical burrows are filled by a blocky calcite spar cement. The presence of abundant terrigenous and carbonate mud indicates a lowering of current activity at the sediment-water interface, probably associated with increasing water depth. The relative abundance of brachiopods and several types of bryozoans suggest the development of stable, normal marine conditions. This unit is interpreted as representing lower subtidal deposition, below wave base.

Unit 5 is 7.5 meters thick and is composed of shaly, fissile, nodular wackestone containing ostracodes, sponges, bryozoans, and trilobites. Sample 13 contains the highest diversity of fossil allochems in the unit with a matrix of micrite and highly abraded skeletal debris. Pelloids and intraclasts composed of micrite also occur. The abundance of mud and highly abraded ostracode valves is interpreted as representing the distal finer fraction of a tidal delta channel deposit.

The Fetzer facies of the Whitesburg Formation is a characteristic lithology that has a variable stratigraphic position in the Middle Ordovician sequence in eastern Tennessee. At Douglas Lake, the Fetzer facies has a stratigraphic position above a thin tongue of Blockhouse Shale and below the main body of the Whitesburg with a total thickness of 8.35 meters. The Fetzer can be divided into the following two lithologies: unit 6, a basal 7.35 meter thick fossiliferous packstone and unit 7, 1 meter of fossiliferous grainstone. Unit 6 is characterized by abundant fossil allochems similar in composition to the upper portion of the Lenoir (units 4 and 5).

The occurrence of oncolites in the lower part of unit 6 suggest a water depth of about 10 meters (Benedict and Walker, 1978). A fairly diverse fauna, however, indicates normal marine conditions. Consequently, the lower part of unit 6 was probably deposited under upper subtidal conditions. The presence of mud suggests that these deposits were not subject to strong currents of removal. Near the top of unit 6 oncolites are absent, suggesting an increase in water depth to a lower subtidal environment.

Unit 7 is characterized by echinoderm grainstones containing chamosite ooids. Most grains in this lithology have thin micritic rinds. The presence of chamosite ooids suggests moderate water depth conditions of 30-40 meters (Benedict and Walker, 1978). Currents of removal probably were active at the sediment-water interface as evidenced by the absence of micrite. The abundance of echinoderm debris in sample 14 suggests that these rocks represent an echinoderm mound or sand flat which possessed a sediment surface extending above

the normally muddy bottom. Similarly, the deposits may also represent the accumulation of debris from an adjacent reef, forming a reef debris slope deposit in moderately active currents subject to winnowing conditions. The stratigraphic superposition of shelf, slope deposits of the Whitesburg Formation further suggests that the Fetzer facies represents a transitional shelf to slope or shelf edge environment.

Silver City. Depositional environments for the Lenoir Formation at Silver City are based on petrologic analysis of acetate peels. Four lithologic units are recognized with the stratigraphic distribution of lithic and biologic constituents shown in Figure 15.

The Mosheim Member of the Lenoir is separated from the Knox Group by a small covered interval approximately 2.5 meters thick. Unit 1 comprises the lower 4.3 meters of Mosheim which is argillaceous and weathers to a chippy rubble. Micrite, nonlaminated intraclasts devoid of fossils, and thin shale drapes (0.5-1.5 cm thick) characterize this rock. Small dolomite rhombs and argillaceous material become less abundant near the top of unit 1 grading into relatively pure dismicrites of the upper Mosheim. Gastropods, ostracodes and trilobites, absent in samples SC-1 and 2, are rare constituents near the top of unit 1. This upper part also contains a few spar filled vertical burrows. The fabric imparted by clay drapes and intraclasts in sample SC-1 resembles flaser bedding and suggests tidal current activity. The abundance of dolomite rhombs and near absence of a biota in the lower part indicates proximity to a supratidal environment. Gastropods, trilobites and ostracodes are generally eurytopic groups of

Figure 15. Stratigraphic Distribution of Conodont Species, Petrologic Data and Inferred Depositional Environments at Silver City

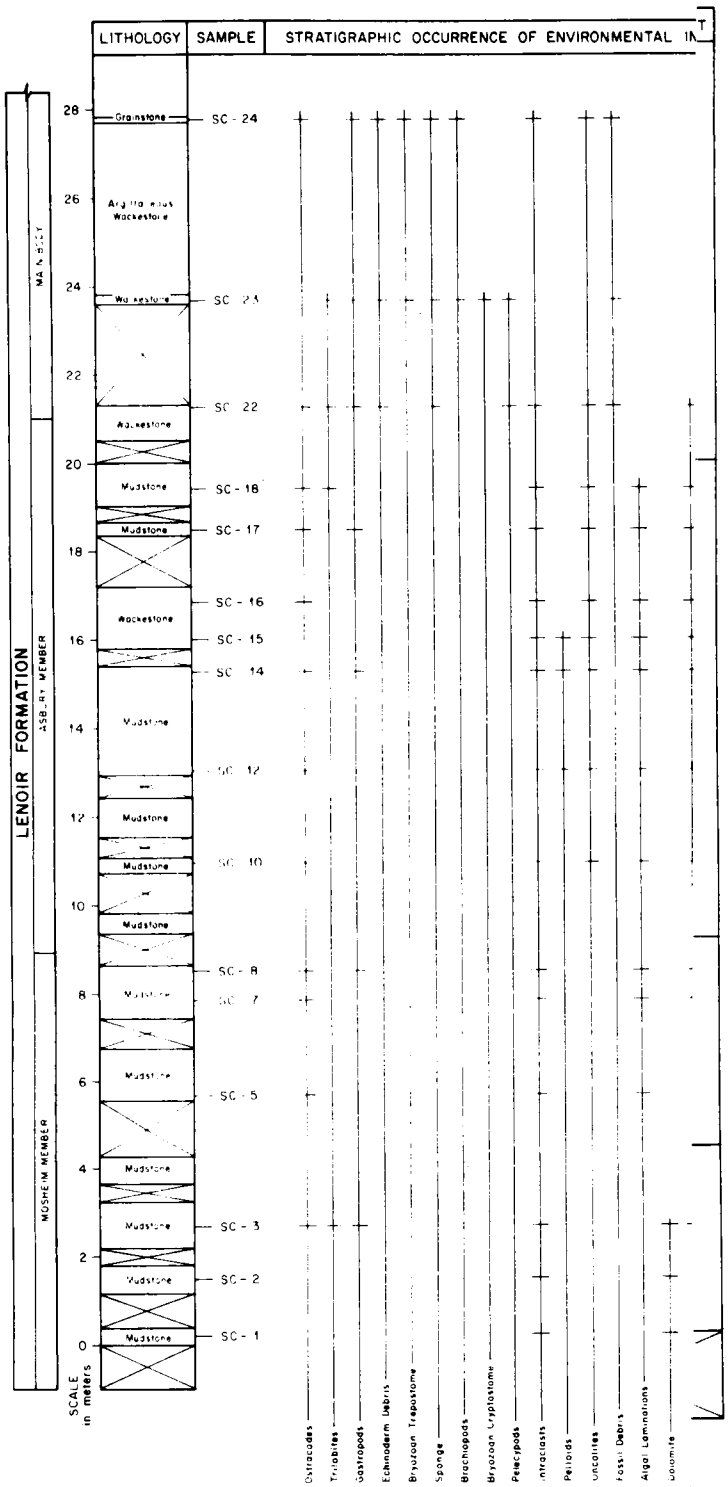

LITHOLOGY
SAMPLE
STRATIGRAPHIC OCCURRENCE OF ENVIRONMENTAL IN
LENOIR FORMATION
MOSHEIM MEMBER
ASBURY MEMBER
MARBLEY
SCALE in meters
Grainstone
Argillaceous Wackestone
Wackestone
Packstone
Mudstone
Wackestone
SC - 24
SC - 23
SC - 22
SC - 18
SC - 17
SC - 16
SC - 15
SC - 14
SC - 12
SC - 10
SC - 8
SC - 7
SC - 5
SC - 3
SC - 2
SC - 1
Ostracodes
Trilobites
Gastropods
Echinoderm Debris
Bryozoan Trepostome
Sponge
Brachiopods
Bryozoan Cryptostome
Pelecypods
Foraminifera
Peloids
Oncolites
Fossil Debris
Algal Laminations
Dolomite

Figure 15

organisms associated with restricted conditions characteristic of a high intertidal environment.

The upper 4.7 meters of the Mosheim comprises unit 2, and is characterized by fenestral dismicrite. Spar-filled cracks and birdseyes are often abundant and appear wavy. This fabric is a common feature of desiccated algal laminations. Rare, dismicrite intraclasts occur suggesting short transportation. The biota is restricted to eurytopic groups of organisms which include gastropods and trilobites. Other biotic activity is evidenced by vertical burrows which indicate that the algal mats were regularly submerged and unlithified. The restricted fauna and vertical burrows further suggest that intertidal conditions were present. Abundant mud and the near absence of coarse grained allochems or intraclasts indicate relatively low energy conditions, possibly in a tidal pond or lagoon.

Unit 3 corresponds to the stratigraphic interval assigned to the Asbury Member of the Lenoir (Walker and Benedict, 1980). Compositionally, this unit is similar to the dismicrite of unit 2. Bridseyes and spar filling are commonly arranged laterally in wavy laminations suggesting algal activity. Gastropods and ostracodes comprise the restricted fauna. Spar-filled vertical burrows indicate a soft substrate within the tidal zone. The distinctive feature of this unit is the abundance of intraclasts and oncolites. Intraclasts range from fine to coarse grained and are composed of dismicrite. Larger grains have a laminated fabric and suggest a desiccating, algally matted source. Nearly all oncolites have a fine to medium grained dismicrite intraclast as the nucleus. Algal coatings about

the nucleus usually are thin (approximately 2 mm). Both intraclasts and oncolites appear to be evenly distributed and incorporated in the general laminated fabric of the rock. Based on the restricted fauna and laminated fabric of the lithology, unit 3 appears characteristic of an intertidal environment. The abundance of algally laminated intraclasts and oncolites suggest periodic agitation of grains. Furthermore, water depth conditions are limited to about 10 meters based on the presence of oncolites (Benedict and Walker, 1978). Analogous algally dominated environments were described from Shark Bay, Australia by Logan (1961). He reported algal-laminated sediments and structures were confined to the hypersaline bay-head environments. Associated biota was specifically restricted to a few euryhaline marine species.

Unit 4 comprises the lower 7 meters of the unnamed "Main Body" Lenoir. Abundant argillaceous material produces a nodular wackestone, distinct from the dismicrites of the Asbury Member. Intraclasts and oncolites continue to occur in these rocks, however, their abundance is greatly reduced. Biotic diversity and abundance increases from the base of the unit to include: ostracodes, trilobites, gastropods, trepostome and cryptostome bryozoans, sponge spicules, brachiopods, pelecypods and echinoderm debris. Micrite, pelloids and fine grained skeletal debris form the matrix. Within this wackestone lithology thin beds of grainstone occur. These grainstone beds contain a biota similar to that of the wackestone suggesting a periodic increase in current activity at the sediment-water interface without a major change in environment. The abundance of stenotopic organisms indicates

unrestricted, subtidal conditions. Abundant mud suggests deposition below the zone of effective wave agitation with occasional shifts in wave base producing grainstones. Thus, this unit probably represents deposition in normal marine conditions of a shallow subtidal shelf.

Environmental Distribution of Conodonts

The paleoecologic interpretations presented are based on the stratigraphic distribution of conodont species and petrologic data which include: (1) composition of lithic and biologic constituents; (2) relative abundance of carbonate mud; and (3) texture or fabric of the lithology. These data are presented for Cedar Springs (Figure 13, page 67), Silver City (Figure 15), and Douglas Lake (Figure 14, page 74). The stratigraphic occurrence of each conodont species is recorded as the number of elements assigned to that species per sample. Conodont abundance is defined here as the number of elements per kilogram of dissolved sample.

A high abundance of conodont elements in a sample can be interpreted two ways, depending on the nature of the assemblage. High abundance in a thanatocoenosis indicates the mortality of a large number of individuals and may represent a sudden change in environmental conditions. A high abundance of conodont elements of a biocoenosis however, may indicate the favorable nature of the environment or a slow rate of deposition. The presence of exotic megafauna is an indication of a typical taphocoenosis produced by storms in a tidal flat environment.

The complex sequence of microfacies in the Five Oaks and Lincolnshire formations at Cedar Springs contains the most abundant and diverse conodont fauna of the three sections investigated. Consequently, discussion of conodont paleoecology is centered around occurrences at this section. Seventeen species representing 10 genera (Figure 13, page 67) were selected from the Cedar Springs fauna for paleoecologic study along with selected species at Douglas Lake and Silver City.

Panderodus sp. cf. P. gracilis occupies the lowest stratigraphic position of the sampled interval at Cedar Springs. This species was recovered from strata representing supratidal lagoonal or pond sediments of unit 1 in a meager collection of 1.9 spms/kg (sample CS-1).

The dominant depositional process of modern tidal flat environments is storms which import sediment from seaward environments (Ball et al., 1967; and Perkins and Enos, 1968). The occurrence of stenotopic fauna such as echinoderms suggests that constituents from unrestricted environments off-shore were imported into the supratidal environment of unit 1. Consequently, it is reasonable that the conodonts present in these environments might be exotic, and may have been introduced from adjacent seaward environments.

Panderodus cf. P. panderi commonly is absent in the supratidal and high intertidal environments of Cedar Springs units 3-6. Its peak abundance occurs in sample CS-18 (56.5 spms/kg) in subtidal, channel deposits of unit 7. In general, this abundance of this species at Cedar Springs appears to increase with: (1) an increase in average water depth in the intertidal environments; and (2) an increase in

circulation indicated by the presence of a stenotopic fauna recognized by Laporte (1971), and Walker (1972).

The stratigraphic distribution of Panderodus sp. cf. P. gracilis at Cedar Springs also shows a general increase in abundance which parallels an increase in water depth and circulation. This trend is not as distinct as that of Panderodus sp. cf. P. panderi. In fact, the peak abundance of P. cf. P. gracilis occurs in sample CS-7 at 65.6 spms/kg. The corresponding lithology is interpreted as representing a high intertidal zone and does not contain biota exotic to this environment.

Panderodus sp. cf. P. gracilis also occurs in high and low subtidal, shallow shelf and tidal channel delta deposits at Douglas Lake (Figure 14, page 74). At Silver City, this species occurs in high and low intertidal and low subtidal environments (Figure 15, page 81). Consequently, a ubiquitous, pelagic life mode for this species coincides well with distribution data.

Previous investigations (Barnes and Fåhraeus, 1975) have described the genus Panderodus as ubiquitous and therefore, probably pelagic during the Middle Ordovician. The occurrence of these Panderodus species does not contradict this interpretation altogether. However, the distribution of these two species suggest that there may have been a difference in habitat between them.

Specimens of P. sp. cf. P. panderi are absent at Douglas Lake and Silver City. These latter sections are older than the portion of Cedar Springs where this species occurs in abundance. At an

equivalent stratigraphic level to Douglas Lake, this species is only sparsely represented by 10 specimens at Cedar Springs.

Plectodina joachimensis first occurs in sample CS-1 and reaches a peak abundance at Cedar Springs of 64.8 spms/kg in the algally laminated, levee deposits of an intertidal channel, sample CS-3 in unit 2. A relative, high abundance of this species was also found in: storm deposits (sample CS-4), subtidal channel deposits (samples CS-18-20), and other intertidal levee deposits (sample CS-14). This distribution suggests that Plectodina joachimensis probably inhabited tidal channels and could have been associated with algally laminated levee substrate. Such an interpretation is supported by the absence of this species in coeval deeper water subtidal facies at Silver City and the occurrence of only one element of P. joachimensis in subtidal facies at Douglas Lake.

Three other species of Plectodina are also represented at Cedar Springs. Plectodina ? sp. and P. n. sp. are informal multielement species recognized by Carnes (1975) and first occur together with P. aculeata in sample CS-4. In general, all three of these later species of Plectodina show greatest abundance in low supratidal unit 3, high intertidal unit 4 and subtidal channels of unit 7. The only other occurrence of these later Plectodina species is at Douglas Lake. Two elements of P. n. sp. occur in the high subtidal facies of unit 3 (Figure 14, page 74). No specimens of Plectodina were recovered at Silver City.

Drepanoistodus suberectus is also considered to have had a ubiquitous distribution and therefore a pelagic mode of life (Barnes

and Fåhraeus, 1975). At Cedar Springs this species has a distribution somewhat similar to Panderodus sp. cf. P. panderi and P. sp. cf. P. gracilis. Highest abundance occurs in subtidal channels containing unrestricted faunas (unit 7). Restricted tidal channels and levees in high intertidal environments contain few specimens of D. suberectus. A pelagic model for this species should include salinity restrictions on its habitat which favor open marine conditions. The distribution of D. suberectus at Silver City and Douglas Lake where it occurs in subtidal environments supports this interpretation.

Three species of Phragmodus occur at Cedar Springs: P. sp. A, P. flexuosus and P. inflexus. P. sp. A is found in the high intertidal facies of unit 2, lower Five Oaks Formation. Considerable variation of P. sp. A abundance occurs within this unit. Tidal channel deposits contained 88.8 spms/kg whereas levee microfacies yielded only 7.2 spms/kg. P. sp. A is the only species of Phragmodus also found at Douglas Lake and Silver City. This occurrence in both high and low subtidal facies of the Lenoir might represent specimens transported onto the shelf from tidal channels. Interpreting these subtidal occurrences as exotic, transported specimens accounts for their abraded nature and the lack of a complete apparatus in any one sample.

Phragmodus sp. A evolved into P. flexuosus with the replacement of gothodontiform elements by subcodylodontiform elements (see Chapter V for discussion). Distribution data for P. flexuosus suggest a similar ecologic habitat to P. sp. A. The lowest stratigraphic occurrence of P. flexuosus at Cedar Springs is in the levee microfacies

of unit 2 where its range overlaps the upper occurrence of P. sp. A. Only sparse occurrences of P. flexuosus are found in the low supratidal and high intertidal (non-channel) facies of units 3-6. The most abundant occurrence of this species is in the subtidal channel deposits of unit 7. Here the peak abundance is 67.8 spms/kg. In the subtidal, shallow shelf facies of Douglas Lake and Silver City, the absence of P. flexuosus probably reflects a difference in age of these strata.

P. inflexus first occurs in storm deposits of unit 3 at Cedar Springs. Its stratigraphic distribution is similar to that of P. flexuosus but is generally much less abundant. The peak abundance of this species occurs in subtidal channels of unit 7 at 10.6 spms/kg.

Barnes and Fåhraeus (1975) suggested that species of Phragmodus occupied deeper water environments farthest from shore in the Midcontinent Province. The abundant occurrence of the three species of Phragmodus studied herein suggests a general association with nearshore or shoreface channel deposits. Tolerance of variation in salinity and temperature appears to be species specific. P. sp. A appears to favor semi-restricted shallow tidal channels, and is nearly absent from shallow offshore shelf environments. It may be possible that these intertidal environments adjacent to the deep water of the Sevier Basin possessed similar temperatures and salinities to the deeper environments of the Midcontinent Province. P. flexuosus and P. inflexus are present in intertidal environments but reach maximum abundance in subtidal channel deposits.

Two species of Leptochirognathus occur at Cedar Springs in the high intertidal facies of unit 2. The number of elements assigned to these species (Figures 13, 14 and 15, pages 67, 74 and 81 respectively) include only P and S elements. The distribution of other vicarious elements is illustrated in Appendix A. At Cedar Springs, L. semiflorealis is nearly equally represented in both tidal channel and levee microfacies. Only two specimens of L. quadratus were recovered at Cedar Springs, occurring in the levee microfacies. At Douglas Lake these species occur in the high subtidal facies of unit 3. Here, L. quadratus has a longer stratigraphic range and is slightly more abundant than L. semiflorealis. Only L. quadratus occurs in the high intertidal facies of unit 1 at Silver City. This unit is interpreted as a restricted tidal flat environment which probably received storm transported material from seaward environments. The distribution of these species at Cedar Springs and Douglas Lake suggests that L. semiflorealis may have been more eurytopic than L. quadratus, reaching its peak abundance in restricted tidal channels. L. quadratus appears to be better represented in shallow shelf subtidal environments. The occurrence of L. quadratus in restricted facies of unit 1 at Silver City probably represent specimens-transported into this environment along with specimens of Panderodus sp. cf. P. gracilis and Triangulodus sp. cf. T. brevibasis.

Triangulodus sp. cf. T. brevibasis first occurs at Cedar Springs in a storm deposit within the lower supratidal facies of unit 3. This sample also marks the peak abundance of this species at 6.9 spms/kg. Fossiliferous intraclasts imported into this unit may contribute an

exotic conodont fauna. T. sp. cf. T. brevibasis is the only species which ranges through the Five Oaks and does not show a general increase in abundance in the lower Lincolnshire unit 7. This species is absent at Douglas Lake but occurs at Silver City in restricted facies of Unit 1 and subtidal deposits of unit 3 (Figure 15, page 81). Only four specimens represent these occurrences, suggesting that these T. sp. cf. T. brevibasis elements might have been transported into deeper subtidal environments.

Appalachignathus delicatulus first occurs in lower supratidal facies of unit 3, and high intertidal deposits of lower unit 4 at Cedar Springs. This species does not recur through the remainder of the Five Oaks but reappears at the base of the Lincolnshire in subtidal channel facies. Consequently, elements from unit 3 may have been imported from seaward environments in intraclasts. Only sparse collections of this species were recovered from most samples. This species is absent from the sampled facies at Douglas Lake and Silver City. Its exclusion from these sections, however, may be related to age relationships rather than environmental conditions.

Belodina monitorensis first occurs in sample CS-7 at Cedar Springs; however, only one element occurs in this intertidal facies. In general the abundance of this species increases in samples from levee to storm to subtidal channel deposits. The peak abundance of this species occurs in sample CS-20 at 11.9 spms/kg. Specimens of B. monitorensis also occur at Douglas Lake and Silver City. At Douglas Lake this species is most abundant in sample 7 from the top of unit 3 near the high-low subtidal boundary. Occurrence of this species

at Silver City is restricted to the upper part of unit 1 supratidal facies and unit 3, subtidal deposits. Barnes and Fåhraeus (1975) suggested a deep water nektobenthic habit for species of Belodina in the Midcontinent Province during the Middle Ordovician, with a distal position from shore. This interpretation coincides with the distributional data presented here. B. monitorensis however, may have extended further into low intertidal environments at Cedar Springs.

Polyplacognathus sweeti first occurs at Cedar Springs in sample CS-10 at the high intertidal-low intertidal facies boundary of units 5 and 6. With the exception of a storm deposit sample CS-12, no specimens of this species occur in environments shallower than high intertidal. The highest abundance of this species at Cedar Springs occurs in subtidal channel facies of unit 7.

P. sweeti was not found at Douglas Lake. This exclusion is not environmentally induced however, evidenced by the presence of specimens of P. friendsvillensis which preceded P. sweeti phylogenetically. Specimens of P. friendsvillensis occur in the Fetzer facies, unit 7 at Douglas Lake, which represents shelf-edge deposits of normal marine conditions and probable water depths of 30 to 40 meters. P. friendsvillensis also occurs in the "Main Body" Lenoir at Silver City in subtidal facies of unit 3.

Both P. sweeti and P. friendsvillensis are interpreted as being stenotopic. P. friendsvillensis, however appears to have been much more restricted to normal salinities than P. sweeti. Thus, the absence of P. friendsvillensis at Cedar Springs probably reflects the absence of suitable habitat at the time of Five Oaks deposition.

Belodella n. sp. of Carnes (1975) also is restricted in occurrence at Cedar Springs to environments no shallower than high intertidal except in sample CS-12. This lithology is, however, interpreted as representing storm debris and so the 2 elements of B. n. sp. recovered probably were exotic. This species was absent from collections from Douglas Lake and Silver City where this genus was represented by B. nevadensis. This relationship probably represents an age difference between sections rather than environmental restrictions. The distribution of specimens of Polyplacognathus demonstrates that the upper section of Cedar Springs in which B. n. sp. occurs is not represented in the interval studied at the other two sections, but occurs at both places high in the stratigraphic sequence.

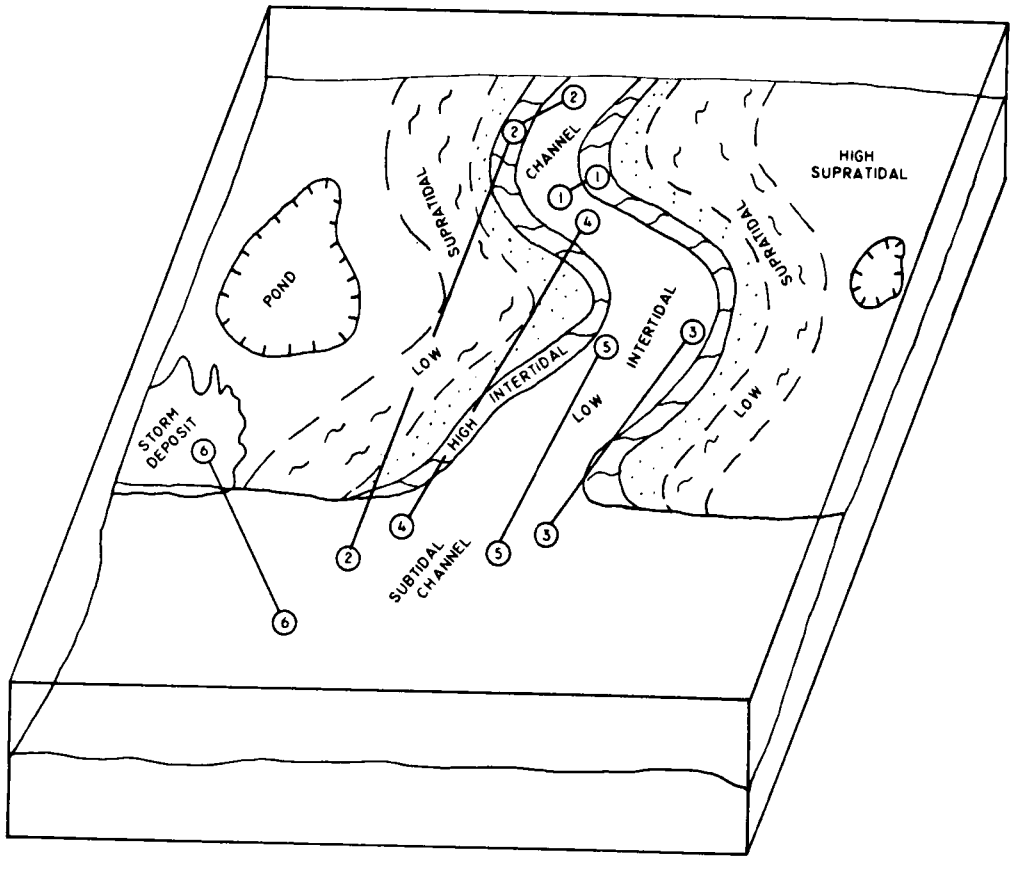
Belodella nevadensis is restricted to the high intertidal facies of unit 1 and lower subtidal deposits of unit 4 at Silver City. At Douglas Lake specimens of this species occur in high and low subtidal facies of units 3-5. Barnes and Fåhraeus (1975) suggested Belodella occupied a deeper water, offshore habitat in the Midcontinent Province. This interpretation is compatible with the distributional data present here.

Two North Atlantic forms occur at Douglas Lake: Periodon aculeatus and Eoplacognathus foliaceus occur together with Pygodus serra and Polyplacognathus friendsvillensis in the Fetzer facies of the Whitesburg Formation. Chamosite ooids within the deposit suggest water depths of 30 to 40 meters (Benedict and Walker, 1978). The stratigraphic position of this facies between a tongue of the Blockhouse

and the Whitesburg also suggests that this facies may represent shelf edge deposits or material transported down onto the basinal slope. This interpretation might explain the occurrence of shallower Eoplacognathus with deeper water Periodon (Barnes and Fåhraeus, 1975).

The distribution of most conodonts at the three sections studied is described better with a nektobenthic rather than a depth-stratified model. The dorsal-caudal fin of the conodontophorid described by Al Dredge and others at ECOS III (Lund, 1982; T. W. Broadhead, oral communication) further supports the nektobenthic model. Still, the generalized nektobenthic models presented for Ordovician conodonts by Barnes and Fåhraeus (1975) do not sufficiently describe the detailed distribution of conodonts in intertidal environments which appear to be largely influenced by changes in salinity and possibly temperature.

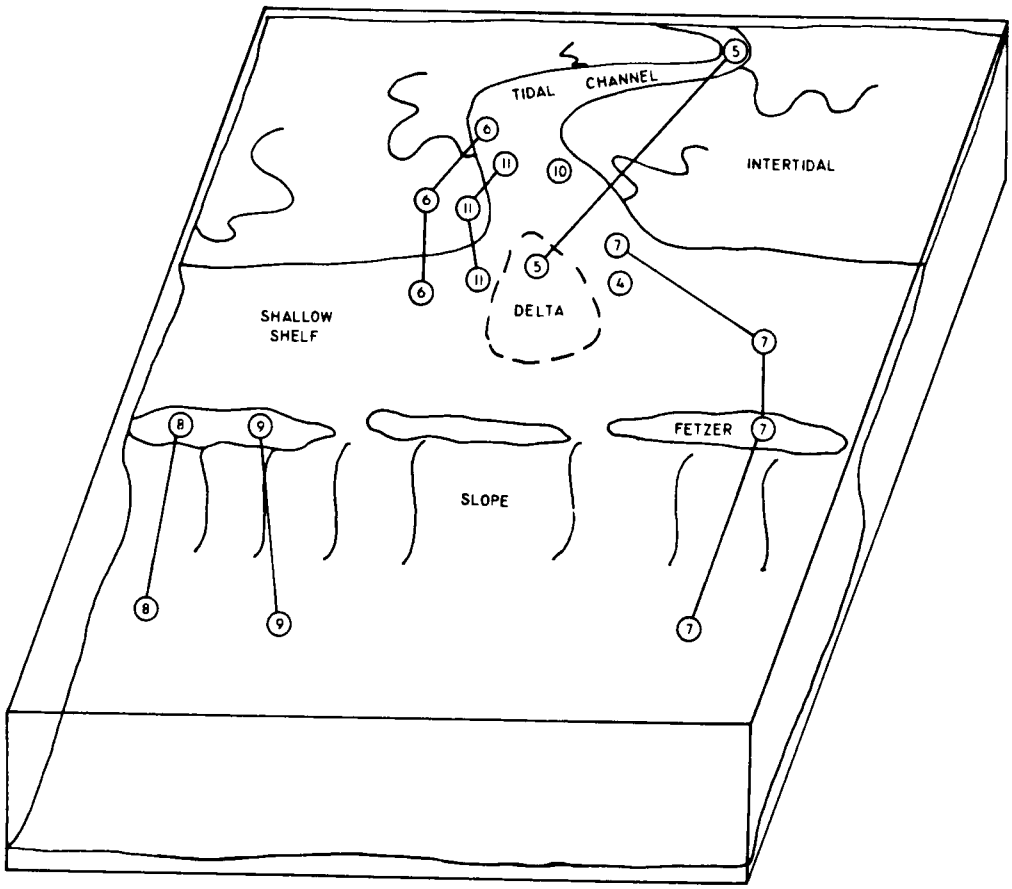
The inferred paleoenvironmental distribution for some of the species investigated is summarized in two time averaged diagrams (Figures 16 and 17). These diagrams indicate conodont distributions for the biostratigraphic interval approximately between the lower Pygodus serra zone and the upper boundary of the lower Pygodus anserinus subzone. Species indigenous in different environments are connected by solid tie lines.



KEY

1. Leptochirognathus semiflorealis
2. Plectodina joachimensis
3. Phragmodus flexuosus
4. Phragmodus inflexus
5. Phragmodus sp. A
6. Panderodus sp. cf. P. gracilis

Figure 16. Tive Averaged Paleoenvironmental Reconstruction with Conodont Distribution from the High Supratidal to the High Subtidal Zone



KEY

4. Phragmodus inflexus
5. Phragmodus sp. A
6. Panderodus sp. cf. P. gracilis
7. Polyplacognathus sweeti
8. Eoplacognathus foliaceous
9. Periodon aculeatus
10. Plectodina n. sp., Plectodina? and P. aculeata
11. Panderodus sp. cf. P. panderi

Figure 17. Time Averaged Paleoenvironmental Reconstruction with Conodont Distribution in the High Subtidal Channel and Open Marine Shelf and Basin

CHAPTER IV

SUMMARY AND CONCLUSIONS

1. Conodont collections from lower Middle Ordovician strata at Cedar Springs, Silver City and Douglas Lake provide biostratigraphic means for correlation of rocks across the Saltville Fault and along strike. The occurrence of biostratigraphically important species at Cedar Springs includes specimens of Polyplacognathus sweeti. The transition from typical to late form occurs in a stratigraphic interval less than one meter thick in the lower Lincolnshire Formation.

Correlations with previously published sections, based primarily on the first appearance of Phragmodus sp. A and Polyplacognathus friendsvillensis, allow recognition of facies relationships during three time periods prior to Pygodus anserinus time. During Pre-Phragmodus sp. A time portions of the Knox Group were subaerially exposed with considerable topographic relief on the erosional surface. Carbonate mud washed into topographic depressions forming localized, thin patches of restricted micrite deposits which characterize "Mosheim" and "Blackford" type lithologies. During Phragmodus sp. A time the northwestern extension of a topographic low which collected carbonate mud at Cedar Springs was opened to the transgressing sea, establishing intertidal conditions there. Tidal channels opened onto a shallow shelf at Douglas Lake and Silver City on which argillaceous limestones of the lower "Main Body" of the Lenoir were deposited. A similar environmental array existed during Polyplacognathus friendsvillensis time. The shelfward migration of the shelf edge slope,

however, established deeper water conditions in the eastern part of the study area evidenced by deposition of the Fetzer facies of the Whitesburg Formation.

2. Facies relationships observed correspond to the early stages in the sequence of subsidence events proposed by Shanmugan and Walker (1980). Pre-Phragmodus sp. A and P. sp. A times correspond to early and late periods of the first phase when the subsidence rate was 3 to 4 cm/1,000 yr. and tectonic and sediment loading subsidence were coequal (Whiterockian, early Marmorian time).

Polyplacognathus friendsvillensis time marked the beginning of phase 2 dominated by tectonic subsidence in the basin at a rate of 60 to 67 cm/1,000 yrs (late Marmorian time).

3. The abundance of Panderodus sp. cf. P. gracilis and P. sp. cf. P. panderi at Cedar Springs appears to increase with: (1) an increase in average water depth; and (2) an increase in circulation indicated by the presence of stenotopic fauna as recognized by Laporte (1971), and Walker (1972). Specimens recovered from restricted supratidal facies occur with fragments of stenotopic organisms and are probably exotic elements transported into these environments during storms. Belodina monitorensis and Drepanoistodus suberectus have similar distributions.

Plectodina joachimensis reaches a peak abundance in algally laminated, levee deposits of an intertidal channel. A relative, high abundance of this species was also found in storm deposits and subtidal channel deposits, suggesting that P. joachimensis probably inhabited tidal channels and could have been associated with algally laminated

levee substrate. Three other species of Plectodina: P. aculeata and Plectodina ? sp. and P. n. sp. both of Carnes (1975) show greatest abundance in low supratidal and high intertidal facies and subtidal channels.

The three species of Phragmodus display considerable variation in their environmental distribution. P. sp. A reaches its peak abundance in intertidal channels, but associated levee facies contain few specimens. P. flexuosus is also present in intertidal channels; peak abundance is found in subtidal channels containing a stenotopic fauna. P. inflexus has a stratigraphic distribution similar to P. flexuosus with a peak abundance in subtidal channels, but this species is generally much less abundant.

At Cedar Springs, Leptochirognathus semiflorealis is nearly equally represented in both tidal channel and levee microfacies. Only two elements of L. quadrata were recovered in these deposits. At Douglas Lake both species occur in high subtidal facies. Here L. quadrata has a longer stratigraphic range and is more abundant than L. semiflorealis.

Triangulodus sp. cf. T. breviabsis is the only species which ranges through the supratidal and intertidal facies of the Five Oaks at Cedar Springs and does not show a general increase in abundance in the normal marine subtidal facies of the Lincolnshire Formation. This distribution suggests a possible association with restricted intertidal environments.

Polyplacognathus sweeti reaches a peak abundance in normal marine, subtidal channel deposits at Cedar Springs. With the exception

of storm deposits, no specimens of this species occur in environments shallower than high intertidal. Both P. sweeti and P. friendsvillensis are interpreted as being stenotpic. P. friendsvillensis, however, appears to have been much more restricted to normal salinities and open marine conditions. Consequently, its absence at Cedar Springs may reflect the absence of an adequate habitat at the time of Five Oaks deposition.

4. The evolutionary transition from P. sp. A to P. flexuosus occurs by the replacement of gothodontiform elements by subcordylodontiform elements in the apparatus with a corresponding decrease in size and robust form of all elements. The composite range of P. sp. A from the three sections begins below Eoplacognathus foliceus, occurs with early forms of Polyplacognathus friendsvillensis and ends prior to the first occurrence of Polyplacognathus sweeti, probably below the top of the Pygodus serra zone. P, M, and S elements within these species display considerable intraspecific variation and vicarious relationships.

5. Conodonts of the genus Leptochirognathus occurring in the Five Oaks Formation at Cedar Springs and Lenoir Formation at Silver City and Douglas Lake comprise two multielement species which contain vicarious M elements. Diagnostic, type S elements distinguish between the multielement species L. quadrata and L. semiflorealis.

CHAPTER V

SYSTEMATIC PALEONTOLOGY

All conodont elements collected during this study are retained in the paleontological collections of the Department of Geological Sciences at The University of Tennessee, Knoxville. Figured specimens are gold- or carbon-coated and mounted in single hole specimen slides with water-soluble glue.

With the exception of the two species discussed herein, all other conodont elements collected in this study conform to published descriptions and illustrations of Carnes (1975), Harris et al. (1979), Tipnis et al. (1978), Bergström (1971a), Sweet et al. (1971), Repetski (1973), and Ziegler (1974). Appendix A lists the numbers of elements assigned to species from each sample at Cedar Springs, Silver City, and Douglas Lake sections.

Skeletal apparatus classification and element-descriptive terminology follows Sweet (in, Clark et al., 1981). Apparatus reconstructions were based on: (1) similarity of stratigraphic ranges of elements and (2) similarity or identity of size, denticulation, character of basal cavity, distribution or absence of white matter, and other morphologic features. Statistical evaluations were not attempted for the small number of elements recovered.

Genus LEPTOCHIROGNATHUS Branson and Mehl, 1943

Leptochirognathus Branson and Mehl, 1943, p. 377

Type species: Leptochirognathus quadrata Branson and Mehl, 1943

Remarks: Barnes et al. (1979, p. 149) suggested an apparatus for Leptochirognathus which contained a transition series of S elements (trichonodelliform), an M element (crytoniodontiform/falodontiform) and a P element (prioniodiniform). The type species L. quadratus was considered to be part of the S element transition series, but subsequent detailed multielement analysis has not been attempted. Thus, the present status of the Leptochirognathus apparatus is uncertain (Barnes et al., 1979, p. 149). The limited number of Leptochirognathus specimens recovered in this study precludes definite apparatus reconstruction. However, examination of the stratigraphic distribution of these specimens and consideration of possible homologous relationships permits a discussion of tentative multielement relationships.

Six form species described by Branson and Mehl (1943) are considered as possible members of two multielement Leptochirognathus species. The form species are: L. quadratus, L. prima, L. semiflorealis, L. tridactyla, L. erecta and L. gracilis.

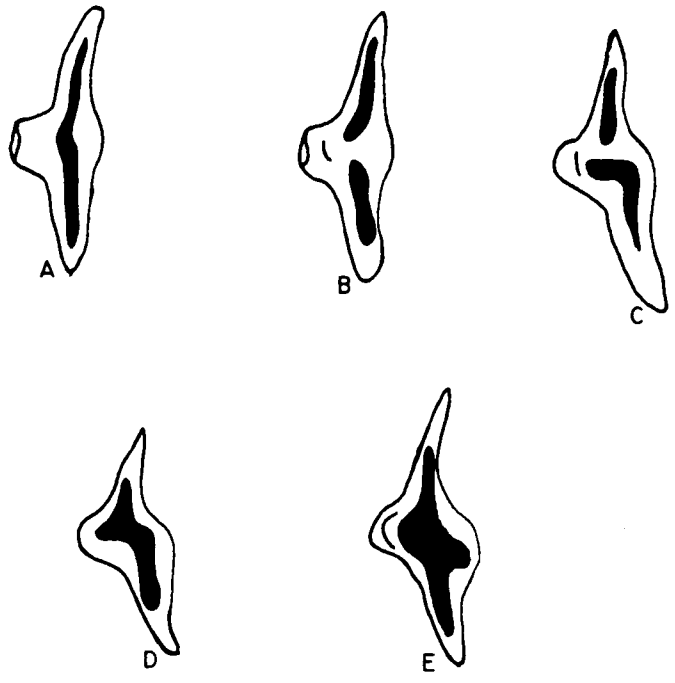
Several form species have similar morphologies that differ primarily in number of denticles. L. semiflorealis and L. quadratus are morphologically similar possessing a morphologic transition expressed in the disposition of the basal groove and a laterally compressed, partly convolute row of denticles. L. semiflorealis elements, however, possess five denticles distinguishing from elements of L. quadratus which possess four. The three denticle element

L. tridactyla is similar to L. erecta but is distinguished by the addition of a fourth denticle in the latter.

The assumption that these elements display positional homeomorphy in related species is the basis for the tentative reconstruction of two multielement species. Consequently, L. quadratus (S) and L. tridactyla (P?) elements are interpreted as members of a multielement species related by positional homeomorphy to L. semiflorealis (S) and L. erecta (P?) elements in the second multielement species. Similar examples of positional homeomorphy in related species which evolved at the same time are discussed by Clark (1981).

Specimens of L. semiflorealis (S elements) collected for this study display a transition series expressed in the disposition of narrow groovelike extensions of the basal pit under adenticulate subdued inner and outer processes. These grooves range through a morphologic transition best described by the shape classification of basal cavities of P elements defined by Sweet (1981). Using this terminology, three types of S elements are recognized: carminiplanate, pastiniplanate and stelliscaphate (Figure 18). The numerical distribution of L. semiflorealis sf. (S element) specimens within these three groups is presented in Table III. The transition from one form to the next among these S elements is continuous. Numerical assignment to each category, therefore, represents a certain degree of subjectivity. Carminiplanate and pastiplanate elements are nearly evenly distributed and generally they outnumber stelliscaphate elements.

The remaining form species of Leptochirognathus recovered include L. primus and L. gracilis. These form-species perhaps represent M or P elements (Sweet, 1981) of the apparatus proposed by Barnes et al.



A - Carminiplanate with continuous anterior and posterior basal grooves.

B - Carminiplanate with discontinuous anterior and posterior basal grooves.

C - Pastiniplanate with continuous posterior and outward process and discontinuous basal grooves.

D - Pastiniplanate with continuous posterior, outward and anterior basal grooves.

E - Stelliscaphate with continuous posterior, anterior, outward and inner basal grooves.

Figure 18. Basal Cavities and Attachment Surface Sketches Illustrating the Transition Series of S Elements of Leptochirognathus semiflorealis from Carminiplanate to Pastiniplanate and Stelliscaphate

TABLE III

Number of Carminiplanate, Pastiniplanate and Stelliscaphate S elements of *Leptochirognathus semiflorealis*

Element type	Section: Cedar Springs Sample No.: CS-2	CS-3	Douglas Lake DL-5
Carminiplanate	22	16	0
Pastiniplanate	22	19	1
Stelliscaphate	11	13	0

(1979). Stratigraphic distribution of these elements with other Leptochirognathus form species suggest that these M and P elements were vicarious to both multielement species interpreted here. The limited number of L. gracilis elements, however, makes this assignment tentative.

LEPTOCHIROGNATHUS QUADRATA Branson and Mehl (emend. herein)

(Pl. 2 Figs. 11, 15)

Leptochirognathus quadratus Branson and Mehl, 1943, p. 378, pl. 63, figs. 23-28.

?Leptochirognathus prima Branson and Mehl, 1943, p. 378, pl. 63, figs. 29-35.

?Leptochirognathus gracilis Branson and Mehl, 1943, p. 377, pl. 63, figs. 39, 40.

?Leptochirognathus tridactyla Branson and Mehl, 1943, p. 380, pl. 64, figs. 17, 19-22.

Diagnosis: Multielement hyaline conodonts with a multimembrate apparatus including (1) S element transition expressed in the disposition of the basal groove - L. quadratus Branson and Mehl, (2) M element possibly L. prima Branson and Mehl s.f. or L. gracilis Branson and Mehl, and, (3) P element possibly L. tridactyla Branson and Mehl.

Occurrence: McLish Fm., Oklahoma; Dutchtown Fm. Missouri (Branson and Mehl, 1943); Five Oaks Fm. at Cedar Springs, Lenoir Fm. at Douglas Lake and Silver City.

Collection: 23 specimens (18 S elements and 5 P elements). The number of vicarious M elements is given in Appendix A and possibly represents

the total present from the occurrence of both multielement species L. quadrata and L. semiflorealis.

LEPTOCHIROGNATHUS SEMIFLOREALIS Branson and Mehl (emend. herein)

(Pl. 2 Figs. 8, 13)

Leptochirognathus semiflorealis Branson and Mehl, 1943, p. 379-380, pl. 63, figs. 11-16.

?Leptochirognathus erecta Branson and Mehl, 1943, p. 377, pl. 63, fig. 18.

?Leptochirognathus prima Branson and Mehl, 1943, p. 378, pl. 63, figs. 29-35.

?Leptochirognathus gracilis Branson and Mehl, 1943, p. 377, pl. 63, figs. 39, 40.

Diagnosis: Multielement hyaline conodonts with a multimembrate apparatus including (1) S element transition expressed in the disposition of the basal groove - L. semiflorealis Branson and Mehl s.f., (2) M element possibly L. prima Branson and Mehl or L. gracilis Branson and Mehl, and (3) P element possibly L. erecta.

Remarks: The similarities between multielement L. quadratus and L. semiflorealis are discussed in the remarks on Leptochirognathus. The major difference between these species is the addition of a dentical on the S and (P?) elements. The remaining elements are presumed to be identical in both species. Consequently, only the S and (P?) elements are listed separately in Appendix A, other elements shared by both species are grouped together.

S elements of Leptochirognathus semiflorealis are not abundant throughout the study area. With the exception of one element recovered

in sample DL-5 at Douglas Lake section, all specimens were recovered from samples CS-2 and CS-3 at Cedar Springs (Appendix A). It is difficult to assess the biostratigraphic significance of any species with such limited data but the very narrow stratigraphic interval occupied by Leptochirognathus semiflorealis at Cedar Springs suggests either a short stratigraphic range or ecological control. The occurrence of L. semiflorealis and Phragmodus sp. A at both Cedar Springs and Douglas Lake sections suggests that its first stratigraphic appearance occurred during Pygodus serra zone age and is not diachronous within the biostratigraphic resolution of the Phragmodus sp. A - P. flexuosus transition. However, the disappearance of L. semiflorealis without ancestors or descendants within the studied stratigraphic interval suggests that the total stratigraphic range of this species probably is not represented. Furthermore, the first occurrence of this species at the sections studied may be related to the onset of transgression establishing a favorable environment.

Occurrence: McLish Fm. Oklahoma, Branson and Mehl (1943); Five Oaks at Cedar Springs and Lenoir Formations at Douglas Lake.

Collection: 104 specimens (98 S elements and 6 P elements) the number of vicarious M elements is given in Appendix A and probably represents the total presence from the occurrence of both L. quadrata and L. semiflorealis.

Genus PHRAGMODUS Branson and Mehl, 1933

Emend. Bergström and Sweet, 1966

Phragmodus Branson and Mehl, 1933, p. 98

Type species: Phragmodus primus Branson and Mehl, 1933

Remarks: Three species of Phragmodus: P. sp. A described herein, P. flexuosus Moskalenko and P. inflexus Stauffer occur within the Five Oaks and lower Lincolnshire Formations at Cedar Springs. Like many Devonian multielement species discussed by Klapper and Philip (1971), these species share several common elements in their septimembrate apparatuses. The following discussion attempts to evaluate the "vicarious" nature of these elements and examine their intraspecific variation.

PHRAGMODONTIFORM ELEMENTS

The phragmodontiform elements of P. flexuosus and P. sp. A are similar and are represented by the description of that element for P. flexuosus Moskalenko. Since all elements of P. sp. A tend to be robust, the phragmodontiform element of that species is generally larger. The phragmodontiform element of P. inflexus is recognized from the form descriptions of P. inflexus Stauffer and P. singularis Stauffer. Consequently, phragmodontiform elements of P. inflexus are distinguished from similar elements of P. sp. A and P. flexuosus by a straight or only slightly flexed posterior process.

Phragmodontiform elements from Cedar Springs display the complete transition series described by Bergström (1981) for phragmodontiform elements belonging to the family Phragmodontidae. A review of figured

phragmodontiforms assigned to P. flexuosus and P. inflexus is presented in Table IV. These elements are assigned to three morphologic groups: (1) alate to tertiopedate; (2) quadriramate phragmodontiform elements with adenticulate costae positioned on the cusp; and (3) dolabrate phragmodontiform elements having only one adenticulate costa. The stratigraphic and numerical distribution of phragmodontiform elements within these three morphologic groups is shown in Appendix A.

TABLE IV

Figured Phragmodontiform Elements with Alate to Tertiopedate or Quadriramate Units

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Alate to Tertiopedate Phragmodontiform Elements

P. flexuosus Moskalenko (Carnes, 1975, p. 280=282, Pl. V, fig. 13).

P. flexuosus Moskalenko (Harris, Bergström, Ethington and Ross, 1979, p. 36-37, Pl. 2, fig. 1).

Quadriramate Phragmodintiform Elements

Phragmodus sp. A Sweet, Ethington, and Barnes (1971, p. 173-174, Pl. 2, fig. 3).

P. flexuosus Moskalenko, Carnes, 1975 (p. 280-282, Pl. V, fig. 15).

P. flexuosus flexuosus Moskalenko (Tipins, Chatterton, and Ludvigsen, 1978, p. 74-75, Pl. V, fig. 6).

P. flexuosus cf. P. flexuosus M.S. Moskalenko (Tipins, Chatterton, and Ludvigsen, 1978, p. 74-75, Pl. V, fig. 11).

Phragmodus n. sp. A (of Sweet et al., 1971) (Barnes, 1974, p. 230, 236-237, Pl. I, fig. 10).

Dolobrate Phragmodontiform Elements

Phragmodus inflexus Stauffer (Sweet, Ethington and Barnes, 1971, p. 70-71, Pl. I, fig. 15).

Quadriramate phragmodontiform elements are the dominant type for P. sp. A (53 of 77 spms) at Cedar Springs, Douglas Lake and Silver City, and P. flexuosus (79 of 125 spms) at Cedar Springs. Alate to tertiopedate are second most abundant, P. sp. A (24 of 77 spms) and P. flexuosus (33 of 125 spms). Dolabrate phragmodontiform elements are least abundant, P. sp. A (0 of 77 spms) and P. flexuosus (13 of 125 spms). Dolobrate (7 of 13 spms) and alate to tertiopedate (5 of 13 spms) phragmodontiform elements are the most abundant types for P. inflexus at Cedar Springs. Only one quadriramate type phragmondontiform element of P. inflexus was recovered. These abundance relationships for morphologic groups of phragmodontiform elements are fairly consistent in most samples.

CYRTONIODONTIFORM ELEMENT

The crytoniodontiform (M) element of P. sp. A conforms to the description and illustration of Plectodina glenwoodensis Stauffer by Moskalenko (1973). This M element differs from that of P. flexuosus and P. inflexus by having a laterally flexed costa on the cusp and its apparently larger size and more robust nature. Votaw (1971) and Sweet and Bergström (1972) included cyrtoniodontiform elements in P. inflexus which are of the same general form as those previously referred to Crytoniodus flexuosus (Branson and Mehl, 1933) and Cyrtoniodus complicatus Stauffer (Carnes, 1975). These elements possess a longer posterior process which distinguishes them from similar elements of P. flexuosus. Ethington and Clark (1981) report an absence of cyrtoniodontiform elements in their collections of Phragmodus from the Ibex area, Utah. Oistodontiform elements, however,

were very abundant co-occurring with other elements of Phragmodus. Consequently, two species of Phragmodus were proposed, one with oistodontiform elements and the other with cyrtoniodontiform elements. Collections of east Tennessee Phragmodus specimens discussed by Carnes (1975) did not include oistodontiform elements. Similarly, collections of Phragmodus specimens recovered in this study include cyrtoniodontiform elements and do not occur with abundant oistodontiform elements.

DICHOGNATHIFORM ELEMENTS

Two morphologic varieties of dichognathiform elements, typiciform and breviform were assigned to P. flexuosus by Moskalenko (1972) and are believed also to be characteristic of dichognathiform elements of P. sp. A. Consequently, only the larger size of P. sp. A dichognathiform elements distinguishes them from similar elements of P. flexuosus. Typiciform and breviform elements are distinguished by the "outer process angle" measured between the anterior and lateral processes. Typiciform elements have a small (10-20°) angle, breviform elements possess a larger (>20°) angle (Carnes, 1975).

Dichognathus typicus s.f. was included in the apparatus of P. inflexus by Fay (1952). The dichognathiform element of P. inflexus was distinguished from the same form element of other species by a small denticle anterior to the main cusp (Bergstrom and Sweet, 1966). This definitive concept of the P. inflexus dichognathiform element was expanded by Webers (1966) and later by Carnes (1975) to include dichognathiform elements with unerupted germ denticle or no denticle at all. Carnes (1975) reported that P. inflexus dichognathiform elements included only breviform types, suggesting less morphologic variation of the element in this species than in

P. sp. A and P. flexuosus. Dichognathiform elements of P. inflexus which lack an anterior denticle on the cusp are virtually indistinguishable from similar elements in P. sp. A and P. flexuosus.

Dichognathiform elements of all species of Phragmodus at Cedar Springs are poorly preserved. Most specimens have both processes broken. Consequently, the angle between anterior and lateral processes cannot be determined, prohibiting a division into breviform and typiciform elements. It is evident from the few unfractured specimens present that both forms occur.

The number of dichognathiform elements possessing an anterior denticle on the cusp is small (22 of 711 spms). The denticle seems best developed in the three specimens from Cedar Springs, samples CS-5a and CS-5b. The remaining 10 specimens possess a subdued denticle which has little or no white matter and appears to be a small extension of the anterior costa of the cusp. These specimens resemble the dichognathiform, illustrated by Carnes (1975, p. 281, Pl. V, fig. 17) as P. inflexus.

In the past, considerable biostratigraphic significance was placed on the development of this small denticle on the dichognathiform of P. inflexus. Sweet, Ethington, and Barnes (1971) used this event to recognize the boundary between North American conodont faunas 6 and 7. Subsequent workers have used this faunal boundary as a means of correlation, especially for Midcontinent strata. Correlation of this event with the North Atlantic Conodont Zonation casts doubt upon the validity of this stratigraphic marker. According to Carnes (1975) figures 7, p. 57 and 8, p. 64, the first appearance of a dichognathiform

with an anterior denticle on the cusp is diachronous, occurring in the upper Pygodus anserinus zone at Cuba, Tennessee, and in the upper Prioniodus variabilis subzone of the overlying Amorphognathus tvaerensis zone at Thorn Hill, Tennessee.

SUBCORDYLODONTIFORM ELEMENTS

Fay (1952), Webers (1966) and Bergström and Sweet (1966) emended the description of the apparatus of P. inflexus Stauffer to include the form species Subcordylodus sinuatus Stauffer and Subcordylodus elongatus Stauffer. Carnes (1975) stated that most Phragmodus flexuosus subcordylodontiform elements in his collections conformed to descriptions and illustrations of the form-species Subcordylodous sinuatus Stauffer. Carnes referred to the four figures of Stauffer's S. sinuatus (1935, Pl. 11, figs. 28, 37, 42, 45), also included in Fay's (1952) emended P. inflexus. Thus, P. inflexus and P. flexuosus apparently contained indistinguishable subcordylodontiform element. P. sp. A does not possess a subcordylodontiform element, but rather has a gothodontiform element.

GOTHODONTIFORM ELEMENT

Gothodontiform elements are found only in P. sp. A and conform to the description and illustrations of Gothodus evenkiensis Moskalenko. Carnes (1975) described gothodontiform elements as essentially subcordylodontiform elements with an extremely laterally flexed anterior margin. He also suggested that with time gothodontiform elements were replaced by subcordylodontiforms, in a Phragmodus apparatus. This hypothesis could not be verified because these elements did not occur

together in any one section studied. At Cedar Springs, gothodontiform elements of P. sp. A stratigraphically underlie subcordylodontiform elements of P. flexuosus. The transition of gothodontiform to subcordylodontiform morphology is discussed in the subsequent description of Phragmodus sp. A.

PHRAGMODUS SP. A

(Pl. 2 figs. 3, 6, 7, 10, 12, 14, 17)

1) Cordylodus sp. indet. Branson and Mehl, 1943, p. 382, Pl. 64, figs. 42, 43.

2) Phragmodus sp. nov. Moskalenko, 1972, p. 48-50, fig. 1, Nos. 1-2, not fig. 1, nos. 13-15.

3) Plectodina glenwoodensis Stauffer, Moskalenko, 1973, Pl. XI, figs. 7-9.

4) Gothodus evenkiensis Moskalenko, 1973, p. 76, Pl. XI, figs. 3a and 3b.

5) Phragmodus flexuosus Moskalenko, 1973, p. 73-74, Pl. XI, figs. 4 and 5 not 6.

Diagnosis: Multielement lamellar conodonts with multimembrate apparatus consisting of: (1) phragmodontiform (S) elements conforming to the description of P. flexuosus Moskalenko which displays a transition series, expressed in disposition of adenticulate costae on cusp, from tertiopedate and alate to quadriramate units; with multidenticulate, sinuous, posterior process and shallow basal cavity extending along entire length of process; (2) dichognathiform (P) element conforming to the description of Dichognathus typicus Stauffer s.f., pastinate or angulate and pastinate, with distinct cusp and multidenticulate anterior and posterior processes; (3) cyrtoniodontiform

(M) element conforming to description of Plectodina glenwoodensis Stauffer s.f. described and figured by Moskalenko (1973), dolabrate, with well-developed cusp and laterally flaring base; (4) gothodontiform element conforms to the description of Gothodus evenkiensis Moskalenko s.f., morphologically similar to subcordylodontiform elements of P. flexuosus Moskalenko with an extremely laterally flexed anterior margin, and forms a transition to subcordylodontiform elements of P. flexuosus Moskalenko as the anterior margin becomes less flexed, such that transition forms possess an antero-lateral offset-costa on an anteriorly rounded cusp and base.

Remarks: Carnes (1975) added gothondontiform elements to P. flexuosus Moskalenko when he synonomized Gothodus evenkiensis Moskalenko with that species. He further proposed that gothodontiform elements assigned to P. flexuosus by Moskalenko (1972) were essentially subcordylodontiform elements with an extreme laterally flexed anterior margin. He also reported that a few subcordylodontiform elements from his east Tennessee collections possessed an antero-lateral offset-costa on an anteriorly rounded cusp and base. However, the condition was far too subdued to be described as elements of Gothodus evenkiensis s.f.

Gothodontiform elements assigned to P. flexuosus from the McLish Formation of Oklahoma, were briefly described by Carnes (1975) as identical to those named G. evenkiensis by Moskalenko (1973) and were reported to be numerically dominant over subcordylondontiform elements. Carnes (1975) described these elements as follows,

> In addition to the pronounced antero-lateral offset costa on one face, some of the McLish gothodontiform elements also have a costa on the opposite face, in or slightly anterior to the middle of the cusp and continuous onto the base.

P. flexuosus specimens, described by Carnes (1975), from the McLish Formation and those described from his east Tennessee collections also differ in size and stratigraphic distribution. Elements of P. flexuosus from the McLish Formation are more robust and are Pygodus serra zone age. While elements of P. flexuosus, collected by Carnes (1975) are less robust and no older than upper Pygodus anserinus zone age. Consequently, Carnes (1975) suggested that while environmental conditions could play a role in the gothodontiform condition, it is likely that gothodontiform elements were replaced with subcordylodontiform elements with time, in which case two separate taxa could be recognized.

It is proposed that the difference between gothodontiform and subcordylodontiform elements and the difference in general size and stratigraphic position warrants the designation of a new Phragmodus species, herein referred to as P. sp. A.

Specimens of Phragmodus from Cedar Springs are significant because the transition from gothodontiform to subcordylodontiform elements occurs within a narrow stratigraphic interval. This provides an excellent opportunity to study details of intraspecific variation, ontogeny, and evolution. Large, robust elements of P. sp. A have been obtained from the base of the unnamed member of the Five Oaks Formation (Sample CS-2). In this sample, gothodontiform elements conform to the description given by Carnes (1975) of specimens from the McLish

Formation and are identical to illustrations of Gothodus evenkiensis s.f. by Moskalenko (1973, p. 67-68, Pl. XI, figs. 1-3). Only 5 of the 53 gothodontiform elements in sample CS-2 have both the pronounced antero-lateral offset costa on one side and another weaker costa on the opposite side. The 48 remaining gothodontiform elements possess an extreme laterally flexed anterior margin extending to the base, arranged on the cusp in a bipennate unit, Pl. 2 fig. 6 . No subcordylodontiform elements are present in this sample. However, the gothodontiform condition is somewhat subdued in 14 elements which possess an antero-lateral offset costa on an anteriorly-rounded cusp and base. These elements represent a gothodontiform-subcordylodontiform transition, Pl. 2 figs. 3, 7.

In sample CS-3, less than 1 meter above CS-2 the ratio of gothodontiforms to transitional forms changes substantially. Only one gothodontiform element was recovered while the number of transitional forms increased to 16. Also present, are 9 subcordylodontiform elements of Phragmodus flexuosus which possess remnants of the lateral flexure Pl. 2 fig. 5 . The remaining stratigraphically higher elements of Phragmodus collected from Cedar Springs include no gothodontiform elements; only one other transitional specimen occurs higher (Sample CS-17). Subcordylodontiform elements of Phragmodus flexuosus above sample 17 conform to the description and illustrations of Subcordylodus sinuatus Stauffer s.f.

In addition to collections from Cedar Springs, Phragmodus sp. A elements also occur at Douglas Lake and Silver City, but in very low abundance (Appendix A). At both sections, subcordylodontiform elements

were absent however, gothodontiform elements and gothodontiform-subcordylodontiform transitional elements were recovered. Furthermore, two of the 4 gothodontiform elements from Douglas Lake display two antero-lateral costa.

Although these collections of P. sp. A are small, two faunal associations occur that are of paramount importance. Gothodontiform and gothodontiform-subcordylodontiform transition elements occur stratigraphically below Polyplacognathus friendsvillensis at Silver City suggesting an age equivalent to the Pygodus serra zone or older. Furthermore, the first occurrence of Phragmodus sp. A at Douglas Lake stratigraphically underlies Ecoplacognathus foliaceus. The highest stratigraphic occurrence of Phragmodus sp. A at Silver City occurs in Sample SC-24 which also contains specimens of Polyplacognathus friendsvillensis. Finally, at Cedar Springs the highest occurrence of gothodontiform elements of P. sp. A falls well below the first occurrence of typical forms of Polyplacognathus sweeti. Thus, the composite range of P. sp. A, begins below Eoplacognathus foliaceus, occurs with Polyplacognathus friendsvillensis and ends prior to the first occurrence of P. sweeti, probably below the top of the Pygodus serra zone.

Occurrence: McLish Formation, Oklahoma (Branson and Mehl, 1943), Volginsky beds, Siberian Platform (Moskalenko, 1972), Five Oaks Formation at Cedar Springs, Asbury Member of theLenoir at Silver City and the Lenoir Formation at Douglas Lake.

Collection: Specimens (77 phragmodontiform, 34 gothodontiform transition, 60 gothodontiform, 66 dichognathiform, 65 cyrtoniodontiform.)

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APPENDICES

APPENDIX A

STRATIGRAPHIC CONODONT ELEMENT DISTRIBUTION

TABLE V

List of Conodont Elements Recovered Per Sample at Cedar Springs

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Acodus mutatus Branson & Mehl																							
acodontiform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–
distacondontiform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
"*Acontiodus*" sp. cf. "A" *curvatus* Mound																							
acontiodontiform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–
"*Acodus*" *variabilis* (Webers)																							
acondontiform	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	1	–	2	3	–
distacondontiform	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	5	2	2	4	–
Appalachignathus delicatulus Bergstrom et al.																							
zygognathiform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	1	–	3	–	–
neoprioniodontiform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–
ozarkodiniform	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	2	1	–	–	–	–	–
spathognathodont form	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	3	2	–	1	1	–	–
trichonodelliform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	5	–
eoligonodiniform	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Belodella n. sp. A Bergström																							
opekodontiform dentulate	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
opekodontiform adenticulate	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	7	–	–	–	–	–	7
biconvex belodellaform denticulate	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	3	9	1	6	–	–	–	–

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
biconvex belodellaform adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	1	—
triangular belodellaform denticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	2	7	—	1	—	3	—	—	—	—
triangular belodellaform adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	10	6	7	13	3
oistodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14	—	—	—	—	—	—	1	—
Belodella nevadensis Ethington & Schumaker																							
oepkodontiform adenticulate	—	—	11	—	—	—	—	6	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
oepkodontiform denticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
biconvex adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
biconvex denticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
oistodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
triangular belodellaform adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
triangular belodellaform denticulate	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Belodina aff. B. inelinate (Branson & Mehl)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	3	1	2
Belodina monitorensis (Ethington & Schumaker)																							
monitorensiform	—	—	—	—	—	—	—	1	—	—	—	—	2	7	11	—	4	4	16	5	15	16	2
monitorensiform juvenile	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	2	3	6	—	1
eobelodiniform	—	—	—	—	—	—	—	—	—	—	—	1	1	6	4	—	2	—	4	1	4	5	—
margintiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	1	1	1	—	2	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Bryantodina typicalis Stauffer																							
bryantodiniform	—	—	—	—	—	—	1	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Cardiodella sp. (this paper)																							
cardiodelliform	—	—	—	—	—	—	—	—	1	2	2	—	—	—	—	—	—	—	—	—	2	—	—
trucherognathiform	—	—	—	—	—	—	—	—	—	1	2	—	—	—	—	—	—	—	1	2	2	—	—
curtognathiform	—	—	—	—	—	—	4	5	2	—	4	—	—	—	—	—	1	3	1	2	1	1	—
Drepanoistodus n. sp. (of Carnes, 1975)																							
oistodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—
Drepanoistodus suberectus (Branson & Mehl)																							
homocurvatiform form A	—	—	—	4	1	2	3	—	—	—	—	—	—	—	7	—	1	—	5	13	5	1	—
homocurvatiform form B	—	—	—	1	—	1	2	—	—	—	—	—	—	4	—	—	3	—	8	—	—	—	2
homocurvatiform form C	—	1	—	1	—	—	—	1	—	—	—	—	—	—	—	—	4	3	6	1	11	3	—
inclinatiform	—	—	—	8	—	2	2	—	—	—	—	—	—	—	1	—	—	1	—	1	6	—	1
suberectiform	—	2	—	1	—	4	3	—	—	—	—	1	—	10	2	—	5	4	19	3	15	12	1
Erismodus sp. cf. *E. radicon* (Hinde)																							
migrocoleodiform	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
erismodiform symmetrical	—	2	—	—	—	—	2	2	6	2	4	—	—	—	—	—	—	—	—	5	4	2	—
erismodiform asymmetrical	—	5	—	—	—	—	3	3	2	3	6	—	—	—	2	—	7	7	—	4	3	2	—
eoligonodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Erraticodon sp. (of Harris et al., 1979) cordylodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Leptochirognathus quadratus Branson & Mehl																							
(L. quadrata s.f.)	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(L. tridactyla s.f.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptochirognathus semiflorealis Branson & Mehl																							
(L. semiflorealis s.f.)	—	44	48	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(L. erecta s.f.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
L. quadratus or L. semiflorealis																							
(L. prima s.f.)	—	37	45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(L. gracilis s.f.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(L. obesa s.f.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N. gen., n. sp. A Sweet, Ethington & Barnes (1971)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
N. gen., n. sp. (this paper)	—	—	—	—	—	—	—	—	—	—	—	—	—	6	18	—	—	4	34	8	6	9	—
N. gen. n. sp. (of Harris et al., 1979)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Oistodus inequalis Pander	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	6	5	—	—	—
Oistodus linguatus Lindström	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Oistodus pseudoabundans (Schopf)	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
Oistodus sp. cf. O. venustus (Stauffer)	—	—	—	—	—	—	—	—	—	—	1	—	—	5	7	—	1	2	11	—	3	7	—
Oistodus tablepointensis Stouge	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Paltodus? sp. (of Carnes, 1975)																							
paltodontiform form A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
paltodontiform form B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
paltodontiform form C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
oistodontiform	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	8	—	—	—	—
acodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Panderodus sp. cf. P. gracilis (Stauffer)	—	11	31	15	—	6	18	151	—	20	6	—	—	—	43	2	33	31	122	96	105	128	30
Panderodus sp. cf. P. panderi (Stauffer)	2	—	—	—	—	—	8	—	—	—	—	—	1	9	11	—	50	63	121	43	—	—	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Phragmodus flexuosus Moskalenko																							
subcordylodontiform	—	—	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	24	25	13	4
cyrtoniodontiform	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	2	4	11	19	20	34	1
dichognathiform	—	—	—	5	1	—	—	—	—	—	—	—	—	—	—	—	—	8	6	12	39	53	5
phragmodontiform	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	1	3	4	12	24	34	41	5
alate-tertiopedate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	4	12	4	9	1
quadriramate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	3	6	10	30	26	4
dolabrate	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—	1	—	2	2	—	6	—
Phragmodus inflexus Stauffer																							
subcordylodontiform	—	—	—	2	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
cyrtoniodontiform	—	—	—	—	—	—	1	1	—	—	—	—	—	1	3	—	1	3	4	1	—	17	—
dichognathiform	—	—	—	—	1	2	1	—	—	—	—	—	—	—	6	—	—	—	1	—	—	2	—
phragmodontiform	—	—	—	1	—	—	—	—	—	—	—	—	—	—	3	—	1	—	5	—	—	3	—
alate-tertiopedate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	2	—	—	2	—
quadriramate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
dolabrate	—	—	—	1	—	—	—	—	—	—	—	—	—	—	2	—	1	—	2	—	—	1	—
Phragmodus sp. A																							
gothodontiform	—	53	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
gotho-transition	—	14	16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
cyrtoniodontiform	—	55	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
dichognathiform	—	56	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
phragmodontiform	—	61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
alate-tertiopedate	—	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
quadriramate	—	41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
dolabrate	—	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Plectodina aculeata (Stauffer)																							
zygognathiform	—	—	—	1	—	2	1	9	1	1	—	—	—	2	—	—	—	15	8	8	3	17	—
ozarkodinaform	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	1	—	1	—	—	—	—
cordylodontiform	—	—	—	—	—	1	1	5	4	—	—	—	—	3	—	—	9	11	11	10	4	8	1
prioniodiniform	—	—	—	—	—	—	—	1	1	—	—	—	—	1	—	—	—	2	—	—	—	—	—
dichognathiform	—	—	—	4	—	3	8	9	4	—	—	—	—	—	—	—	8	12	21	9	13	18	2
trichonodelliform symmetrical	—	—	—	2	1	1	5	3	5	—	—	—	—	4	1	—	2	7	12	5	5	10	—
trichonodelliform asymmetrical	—	—	—	—	5	2	3	—	1	—	—	—	—	—	—	—	—	17	8	6	11	9	1
Plectodina joachimensis (Andrews)																							
cordylodontiform	—	—	4	46	2	4	9	—	6	—	—	—	—	6	25	—	10	—	31	19	45	67	9
eoligonodiniform	—	1	25	—	—	1	—	—	—	—	1	—	1	—	2	—	—	—	6	—	3	1	—
ozarkodiniform	1	3	60	13	4	3	1	2	1	—	4	—	—	1	4	2	4	—	5	4	3	1	—
prioniodiniform	—	1	16	—	—	1	—	—	1	—	2	—	—	—	2	—	1	—	1	—	—	—	—
trichonodelliform	—	—	3	12	—	9	3	—	5	—	—	—	—	—	1	—	—	—	9	4	6	6	—
zygognathiform	1	2	54	44	5	3	2	—	2	—	4	—	—	—	2	—	—	—	—	—	—	—	—
dichognathiform	—	—	21	31	3	4	6	—	6	—	1	—	—	1	0	—	8	—	9	7	17	8	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Plectodina n. sp. (of Carnes, 1975)																							
falodontiform	—	—	—	3	—	5	6	1	9	—	—	—	—	—	—	—	1	3	6	3	9	9	6
oistodontiform	—	—	—	44	4	5	14	12	7	—	—	—	—	—	7	—	5	9	16	9	19	31	4
eoligonodiniform	—	—	—	1	—	1	2	2	1	2	—	—	—	—	—	—	—	—	2	—	3	—	3
cordylodontiform	—	—	—	8	9	10	18	26	9	—	—	—	1	6	10	—	4	24	69	25	38	82	8
dichognathiform	—	—	—	—	—	4	3	5	1	—	—	—	—	2	2	—	5	13	7	6	15	9	16
ozarkodiniform	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
zygognathiform	—	—	—	9	1	6	6	4	2	—	—	—	1	1	—	1	2	1	8	4	25	38	8
trichonodelliform symmetrical	—	—	—	—	—	—	1	1	1	—	—	—	1	1	—	—	—	4	4	1	1	4	9
trichonodelliform asymmetrical	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
tetraprioniodiniform	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	1	2	—	4	—
Plectodina? sp. (of Carnes, 1975)																							
prioniodiniform	—	—	—	—	—	—	—	7	2	—	—	—	—	—	—	—	1	2	2	1	2	2	—
eoligonodiniform	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	1	3	—	—	—
zygognathiform	—	—	—	1	2	6	4	10	3	—	—	—	—	1	6	—	6	3	4	5	8	3	—
trichonodelliform symmetrical	—	—	—	3	—	—	1	3	4	—	—	—	—	1	1	—	3	2	5	—	6	2	—
trichonodelliform asymmetrical	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	2	5	14	7	—
Polyplacognathus sweeti Bergstrom																							
ambalodontiform typical	—	—	—	—	—	—	—	—	—	—	—	—	—	1	6	—	1	—	—	—	—	—	—
ambalodontiform late	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	15	9	7	7	—
polyplacognathiform	—	—	—	—	—	—	—	—	—	—	1	—	2	—	—	—	—	1	7	2	9	4	—

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Protopanderodus varicostatus (Sweet & Bergstrom)																							
varicostatiform symmetrical	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pygodus anserinus Lamont & Lindström																							
pygodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Triangulodus sp. cf. T. brevibasis (Sergeeva)																							
symmetrical costate element	—	—	—	3	2	3	3	1	1	—	—	—	—	—	—	—	2	—	2	1	—	2	—
asymmetrical costate element	—	—	—	2	1	—	4	—	2	—	—	—	—	—	1	—	1	—	1	2	2	2	—
oistodontiform	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
scandodontiform	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
drepanodontiform	—	—	—	6	1	—	6	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Walliserodus sp. cf. W. trigonis (Schopf)																							
debol tiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
dyscritiform	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
unicostatiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	—	—	—	52	29	61	51	2
multicostatiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
curvatiform	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	2	—	2

TABLE V (continued)

SAMPLE NUMBER	1	2	3	4	5a	5b	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SAMPLE WEIGHT IN KG.	2.1	2.7	2.5	2.0	2.1	2.3	2.2	2.3	2.2	2.6	2.1	2.5	2.5	2.2	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.3
METERS ABOVE UNCONFORMITY	0.8	1.5	2.3	9.7	9.9	10.1	10.9	11.4	13.0	15.1	17.1	18.3	19.0	19.5	19.9	20.2	23.2	24.1	25.1	26.5	27.1	28.3	28.9
Walliserodus tuatus (Hamar)																							
tuatiform symmetrical	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
tuatiform asymmetrical	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
unicostatiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
curvatiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2

TABLE VI

List of Conodont Elements Recovered Per Sample at Silver City

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	23	24	25
SAMPLE WEIGHT IN KG.	2.4	2.6	2.1	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.6	2.6	2.5	2.5	2.5	2.1	2.4	5.0	—
METERS ABOVE BASE	0.2	1.5	2.7	4.0	5.7	6.6	7.8	8.5	9.7	10.9	12.3	13.1	14.6	15.3	16.0	16.9	18.5	19.4	21.3	23.7	27.3	56.0
Acodus mutatus Branson & Mehl	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Belodella nevadensis (Ethington & Schumaker)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—
oepkodontiform adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
oepkodontiform denticulate	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
biconvex adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
oistodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
triangular belodelliform adenticulate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
triangular belodelliform denticulate																						
Belodina monitorensis Ethington & Schumaker	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	3	2	—
monitorensiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
monitorensiform juvenile	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	3	1	—
eobelodiniform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—
marginatiform																						
Cardiodella sp. (this paper)	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
cardiodelliform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
curtognathiform	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
polycaulodiform																						
"Distacodus" n. sp. (of Carnes, 1975)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
acodontiform																						

TABLE VI (continued)

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	23	24	25
SAMPLE WEIGHT IN KG.	2.4	2.6	2.1	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.6	2.6	2.5	2.5	2.5	2.1	2.4	5.0	—
METERS ABOVE BASE	0.2	1.5	2.7	4.0	5.7	6.6	7.8	8.5	9.7	10.9	12.3	13.1	14.6	15.3	16.0	16.9	18.5	19.4	21.3	23.7	27.3	56.0
Drepanoistodus suberectus Branson & Mehl																						
homocurvatiform form C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—
inclinatiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
suberectiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Eoplacognathus lindstroemi (Hamar)																						
polyplacognathiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Erraticodon sp. (of Harris et al., 1979)																						
cordylodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—
cyrtoniodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
oistodontiform	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
prioniodiniform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Leptochirognathus quadratus Branson & Mehl																						
(*L. quadrata* s.f.)	—	2	2	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(*L. tridactyla* s.f.)	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
L. quadratus or *L. semiflorealis*																						
(*L. prima* s.f.)	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(*L. gracilis* s.f.)	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N. gen., n. sp. (of Harris, et al., 1979)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—

TABLE VI (continued)

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	23	24	25
SAMPLE WEIGHT IN KG.	2.4	2.6	2.1	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.6	2.6	2.5	2.5	2.5	2.1	2.4	5.0	—
METERS ABOVE BASE	0.2	1.5	2.7	4.0	5.7	6.6	7.8	8.5	9.7	10.9	12.3	13.1	14.6	15.3	16.0	16.9	18.5	19.4	21.3	23.7	27.3	156.0
Oepikodus communis (Ethington & Clark) gothodiform	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oistodus sp. cf. *O. lanceolatus* Pander triangulariform	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
drepanoistodiform	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oistodus sp, cf. *O. venustus* (Stauffer)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Panderodus sp. *P. gracilis* (Stauffer)	—	1	1	—	—	—	—	—	—	—	—	—	—	1	2	11	—	2	1	6	24	—
Peridon aculeata Stauffer prioniodinaform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
falodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
hibbardellaform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
cordylodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Phragmodus sp. A gothodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
gotho-transition	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
cyrtoniodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
dichognathiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE VI (continued)

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	23	24	25
SAMPLE WEIGHT IN KG.	2.4	2.6	2.1	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.6	2.6	2.5	2.5	2.5	2.1	2.4	5.0	—
METERS ABOVE BASE	0.2	1.5	2.7	4.0	5.7	6.6	7.8	8.5	9.7	10.9	12.3	13.1	14.6	15.3	16.0	16.9	18.5	19.4	21.3	23.7	27.3	156.0
phragmodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—
alate-tertiopelate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
quadriramate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
dolobrate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Polyplacognathus friendsvillensis Bergström																						
polyplacognathiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
ambalodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
Polyplacognathus sweeti Bergström																						
polyplacognathiform typical	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
ambalodiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Pygodus anserinus Lamont and Lindström																						
pygodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12
Scolopodus insculptus (Branson & Mehl)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	22
Triangulodus sp. cf. T. brevibasis (Sergeeva)																						
symmetrical costate element	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
asymmetrical costate element	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
drepanodontiform	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE VII

List of Conodont Elements Recovered Per Sample at Douglas Lake

SAMPLE NUMBER	S-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SAMPLE WEIGHT IN KG.	1.9	2.0	2.0	2.0	2.0	4.0	2.0	1.9	1.9	2.0	1.9	2.0	2.4	2.5	—
METERS ABOVE UNCONFORMITY	4.1	*0.3	2.4	3.7	4.1	5.0	6.3	9.1	10.1	11.5	12.3	15.1	16.7	20.0	33.2
Belodella nevadensis (Ethington & Schumaker)															
oepkodontiform adenticulate	3	—	—	1	2	2	4	10	1	1	—	—	—	—	2
oepkodontiform denticulate	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
biconvex adenticulate	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
biconvex denticulate	—	—	—	5	2	2	2	4	—	1	—	—	—	2	1
oistodontiform	1	—	—	8	19	8	2	3	3	—	—	—	—	1	—
triangular belodelliform denticulate	2	—	—	11	16	10	15	23	7	1	—	—	—	1	1
Belodina monitorensis Ethington & Schumaker															
monitorensiform	4	—	4	—	12	8	2	8	2	1	2	—	—	—	—
eobelodiniform	2	—	2	—	2	4	—	3	2	—	—	—	—	—	—
marginatiform	—	—	—	—	—	—	—	6	2	1	—	—	—	—	—
Cardiodella sp.															
cardiodelliform	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
polycaulodiform	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—
Chirognathus delicatulus Stauffer	—	—	—	—	—	1	1	2	—	—	—	—	—	—	—
Cordylodus spinatus (Hadding)	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Drepanoistodus suberectus (Branson & Mehl)															
homocurvatiform A	—	—	—	1	4	—	—	—	—	—	—	—	—	—	—

TABLE VII (continued)

SAMPLE NUMBER	S-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SAMPLE WEIGHT IN KG.	1.9	2.0	2.0	2.0	2.0	4.0	2.0	1.9	1.9	2.0	1.9	2.0	2.4	2.5	—
METERS ABOVE UNCONFORMITY	4.1	*0.3	2.4	3.7	4.1	5.0	6.3	9.1	10.1	11.5	12.3	15.1	16.7	20.0	33.2
homocurvatiform B	—	—	—	2	—	2	1	2	2	—	—	—	—	—	—
homocurvatiform C	3	—	2	—	—	2	1	5	3	—	—	—	—	1	—
inclinatiform	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—
suberectiform	1	—	1	—	6	5	—	9	4	3	1	—	—	—	—
Eoplacognathus foliaceus (Fåhraeus) ambalodiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Erismodus sp. cf. *E. cadicans* (Hinde) erismodiform symmetrical	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
erismodiform asymmetrical	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—
Erraticodon sp. (of Harris et al., 1979) cordylodontiform	—	—	—	1	—	—	—	3	1	—	1	—	—	—	—
cyrtoniodontiform	1	—	—	1	1	1	—	1	—	—	—	—	—	—	—
dichognathiform	—	—	—	—	—	2	1	—	1	—	—	—	—	—	—
roundyaform	1	—	—	1	—	—	—	2	—	—	—	—	—	—	—
oistodontiform	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptochirognathus quadratus Branson & Mehl (*L. quadrata* s.f.)	—	—	—	1	1	4	2	3	—	—	—	—	—	—	—
(*L. tridactyla*)	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—

TABLE VII (continued)

SAMPLE NUMBER	S-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SAMPLE WEIGHT IN KG.	1.9	2.0	2.0	2.0	2.0	4.0	2.0	1.9	1.9	2.0	1.9	2.0	2.4	2.5	—
METERS ABOVE UNCONFORMITY	4.1	*0.3	2.4	3.7	4.1	5.0	6.3	9.1	10.1	11.5	12.3	15.1	16.7	20.0	33.2
Leptochirognathus semiflorealis Branson & Mehl															
(L. semiflorealis s.f.)	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
(L. erecta s.f.)	—	—	—	—	1	4	2	—	—	—	—	—	—	—	—
L. quadrata or L. semiflorealis															
(L. prima s.f.)	—	—	2	6	6	4	3	1	4	1	—	—	—	—	—
(L. gracilis s.f.)	—	—	—	—	1	—	1	—	1	—	—	—	—	—	—
Oepikodus communis (Ethington & Clark)															
oistodiform	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Oistodus cf. O. linguatus Lindström	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—
Oistodus venustus (Stauffer)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Paltodus? sp. (of Carnes, 1975)															
oistodontiform	—	—	—	—	1	—	3	1	2	2	—	—	—	—	—
acodontiform	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
paltodontiform form A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
paltodontiform form B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
paltodontiform form C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Panderodus sp. cf. P. gracilis (Stauffer)	6	—	4	21	34	23	32	47	22	11	5	—	2	3	10

TABLE VII (continued)

SAMPLE NUMBER	S-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SAMPLE WEIGHT IN KG.	1.9	2.0	2.0	2.0	2.0	4.0	2.0	1.9	1.9	2.0	1.9	2.0	2.4	2.5	—
METERS ABOVE UNCONFORMITY	4.1	*0.3	2.4	3.7	4.1	5.0	6.3	9.1	10.1	11.5	12.3	15.1	16.7	20.0	33.2
Periodon aculeatus Stauffer															
cordylodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	22
prioinodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
faltodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13
hibbardellaform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Phragmodus sp. A															
gothodontiform	—	—	—	—	1	2	—	1	—	—	—	—	—	1	—
gotho-transition	—	—	—	—	—	—	1	—	—	—	—	—	—	1	—
cyrtoniodontiform	—	—	—	—	1	2	2	1	—	—	—	—	—	2	—
dichognathiform	—	—	—	—	2	2	2	1	—	—	—	—	—	3	—
phragmodontiform	—	—	—	—	4	4	1	2	—	—	—	—	—	2	—
alate-tertiopedate	—	—	—	—	1	—	—	1	—	—	—	—	—	1	—
quadriramate	—	—	—	—	3	4	1	1	—	—	—	—	—	1	—
dolobrate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Plectodina joachimensis Andrews															
ozarkodiniform	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Plectodina n. sp. (of Carnes, 1975)															
falodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
oistodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
eoligonodiniform	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—

TABLE VII (continued)

SAMPLE NUMBER	S-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SAMPLE WEIGHT IN KG.	1.9	2.0	2.0	2.0	2.0	4.0	2.0	1.9	1.9	2.0	1.9	2.0	2.4	2.5	—
METERS ABOVE UNCONFORMITY	4.1	*0.3	2.4	3.7	4.1	5.0	6.3	9.1	10.1	11.5	12.3	15.1	16.7	20.0	33.2
cordylodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
dichognathiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ozarkodiniform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
zygognathiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
trichonodelliform symmetrical	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Polyplacognathus friendsvillensis Bergström															
ambalodontiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Protopanderodus insculptus Branson & Mehl	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Pygodus serra (Hadding)															
haddingodiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15
pygodiform	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11
Scolopodus insculptus (Branson & Mehl)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
Triangulodus sp. cf. T. brevibasis (Sergeeva)															
drepanodontiform	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Walliserodus tuatus (Hamar)															
unicostatiform	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
curvatiform	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—

*Meters below unconformity.

APPENDIX B

PLATES

Plate 1. *Phragmodus*, *Periodon*, *Polyplacognathus*, *Pygodus*, *Eoplacognathus*.

Figure

1-4. *Phragmodus inflexus* Stauffer.

1. Phragmodontiform element, X60. Cedar Springs sample CS-14.

2. Subcordylodontiform element, X60. Cedar Springs sample CS-4.

3. Dichognathiform element, X60. Cedar Springs sample CS-14.

4. Cyrtoniodontiform element, X60. Cedar Springs sample CS-21.

5,6,9,10. *Periodon aculeatus* Stauffer.

5. Hibbardellaform element, X60. Douglas Lake sample DL-14.

6. Cordylodontiform element, X60. Douglas Lake sample DL-14.

9. Faltodontiform element, X60. Douglas Lake sample DL=14.

10. Prioniodontiform element, X60. Douglas Lake sample DL-14.

7,8. *Polyplacognathus sweeti* (typical) Bergstrom.

7. Ambalodontiform element, X60. Cedar Springs sample CS-14.

8. Ambalodontiform element, X60. Cedar Springs sample CS-14.

12,16. *Pygodus serra* (Hadding).

12. Haddingodontiform element, X60. Douglas Lake sample DL-14.

16. Pygodontiform element, X60. Douglas Lake sample DL-14.

13. *Pygodus anserinus* Lamont and Lindstrom.

13. Pygodontiform element, X60. Cedar Springs sample CS-17.

14. *Eoplacognathus foliaceus* (Fahraeus).

14. Ambalodiform element, X60. Douglas Lake sample DL-14.

Plate 1 (continued)

Figure

15. Polyplacognathus friendsvillensis (early) Bergstrom.

15. Ambalodiform element, X60. Douglas Lake sample DL-14.

17,18. Polyplacognathus sweeti (late) Bergstrom.

17. Ambalodontiform element, X60. Cedar Springs sample CS-20.

18. Ambalodontiform element, X60. Cedar Springs sample CS-18.

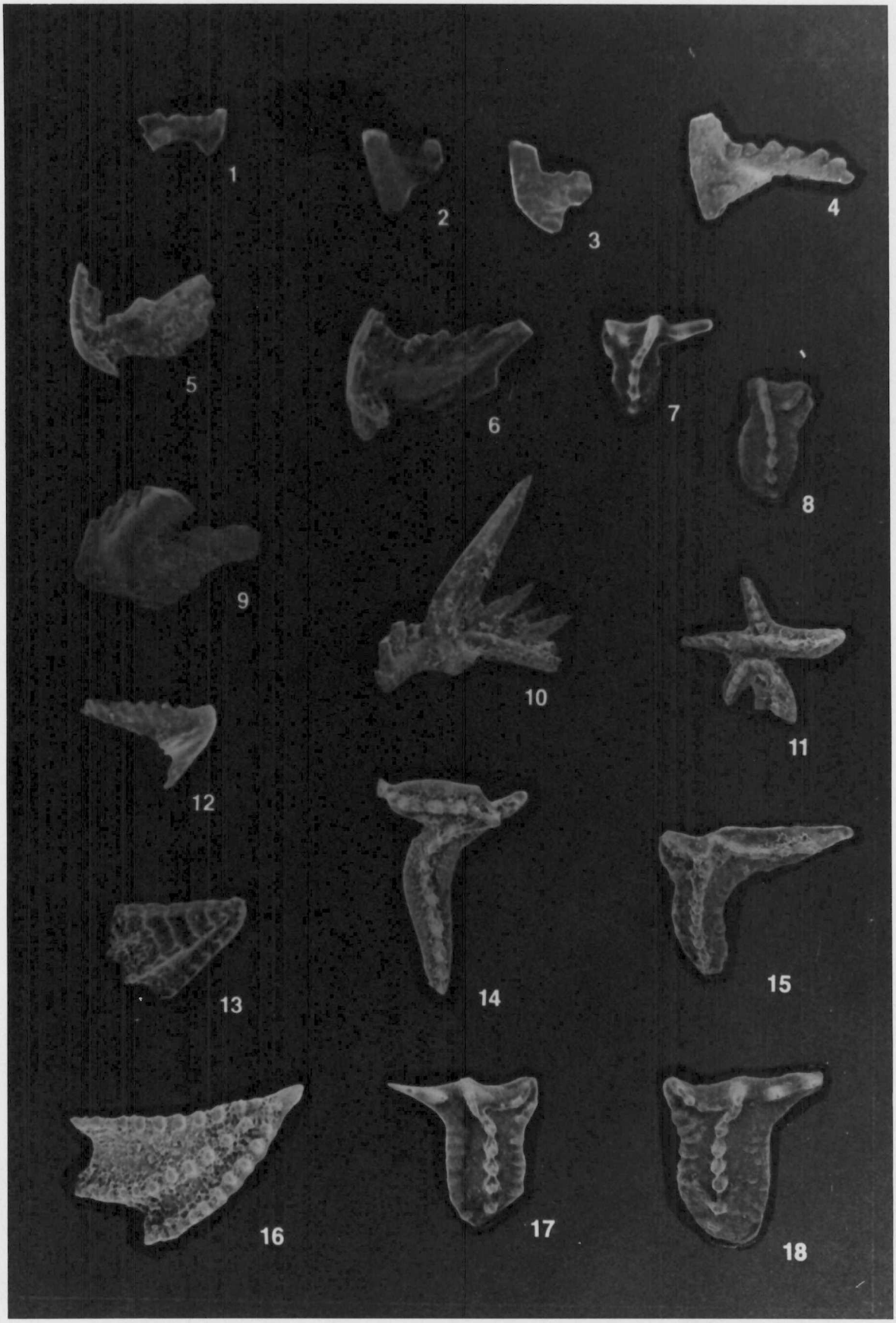


Plate 1

Plate 2. *Phragmodus*, *Leptochirognathus*.

Figure

1,2,5,9. *Phragmodus flexuosus* Moskalenko.

1. Dichognathiform element, X60. Cedar Springs sample CS-3.

2. Phragmodontiform element, X60. Cedar Springs sample CS-21.

5. Subcordylodontiform element, X60. Cedar Springs sample CS-3.

9. Cyrtoniodontiform element, X60. Cedar Springs sample CS-3.

3,6,7,10, 12,14,17. *Phragmodus* sp. A.

3. Gothodontiform transitional element, X60. Cedar Springs sample CS-3.

6. Gothodontiform element, X60. Cedar Springs sample CS-2.

7. Gothodontiform transitional element, X60. Cedar Springs sample CS-3.

10. Cyrtoniodontiform element, X60. Cedar Springs sample CS-2.

12. Phragmodontiform element, X60. Cedar Springs sample CS-3.

14. Dichognathiform element, X60. Cedar Springs sample CS-3.

17. Phragmodontiform element, X60. Cedar Springs sample CS-3.

4,16. *Leptochirognathus quadrata* Branson and Mehl.

4. *Leptochirognathus quadrata* s.f., X60. Cedar Springs sample CS-3.

16. *Leptochirognathus tridactyla* s.f., X60. Douglas Lake sample DL-7.

Plate 2 (continued)

Figure

8,13. Leptochirognathus semiflorealis Branson and Mehl.

8. Leptochirgoanthus semiflorealis s.f., X60. Cedar Springs sample CS-2.

13. Leptochirognathus erecta s.f., X60. Douglas Lake sample DL-6.

11,15. Leptochirognathus quadrata or L. semiflorealis Branson and Mehl.

11. Leptochirognathus gracilis s.f., X60. Douglas Lake sample DL-6.

15. Leptochirognathus prima s.f., X60. Cedar Springs sample CS-2.



Plate 2

VITA

Charles Steven Harris was born in Dawson, Georgia on November 19, 1957. He graduated from High School in 1975 and later received his Bachelor of Science degree in Geology in 1979 from Georgia Southern College. He worked as an Assistant Geologist for the Georgia Geologic Survey before entering the graduate school of The University of Tennessee, Knoxville, in September, 1980. He received his M.S. in December, 1982. Charles is currently employed as an Exploration Geologist by Exxon U.S.A. in Houston, Texas.