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STRATIGRAPHY, PETROLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE MIDDLE ORDOVICIAN UPPER LENOIR THROUGH LOWER "BAYS" FORMATIONS NEAR CALHOUN, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Robert C. Asreen, Jr.

March 1985

This volume is dedicated with love to my wife, Judith, and our children, Michael Domenic and Daniel, whose constant support made this thesis possible.

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ABSTRACT

Approximately 510 meters of mixed carbonate and terrigenous clastic sedimentary rocks deposited during the Middle Ordovician overly the Athens Formation in the Knoxville-Athens Belt near Calhoun, Tennessee. Nine lithostratigraphic units have been recognized above the Athens Formation from measured sections at Henegar Bluff and along the Louisville and Nashville Railroad cut; these units include from oldest to youngest: the Upper Tongue of the Lenoir Formation; the Holston Formation; the Chapman Ridge Formation which contains a basal "orthocone zone" overlain by the "main body" of the formation; the Lower Unnamed Shale, the Hiwassee, the Middle Unnamed Shale, and the McKnight Members of the Ottosee Formation; and the "Bays" Formation.

Analysis of the conodonts collected during this study suggests that the Upper Tongue of the Lenoir Formation as well as the base of the Holston Formation lie within the Upper Subzone of the Pydogus anserinus Conodont Zone. Based on the evolutionary transition from Cahabagnathus sweeti to Cahabagnathus carnesi found in the Holston Formation at Henegar Bluff, the boundary between the Upper Subzone of the Pygodus anserinus and the Amorphognathus tvaerensis Conodont Zones has been tentatively placed at 9.7 meters above the base of that measured section and approximately 244 meters above the post-Knox unconformity. The remainder of the stratigraphic section exposed within the study area up to and including the lower part of the "Bays" Formation appears to lie within the lower part of the Amorphognathus

tvaerensis Zone and possibly lies almost entirely within the Prioniodus gerdae Subzone.

Field and petrologic studies have shown that the post-Athens rocks within the Calhoun area represent a complex of carbonate and terrigenous clastic lithofacies deposited in predominately shallow subtidal, shelf to shelf margin environments. The Upper Tongue of the Lenoir Formation contains two lithofacies representative of a back-reef lagoon environment which included a deep subtidal lagoon center subenvironment overlain by a shallow subtidal near-reef subenvironment.

The Holston Formation, which interfingers with the Lenoir Formation, contains three lithofacies and represents a shelf margin, skeletal sand bank and reef complex. Algae are common in the Holston Formation in the Calhoun area thus distinguishing the Holston Formation there from most other areas in East Tennessee where this formation outcrops. Inter- and intraformational hardgrounds/corrosion surfaces observed within the Holston may represent the episodic "drowning" of this formation due to a relative rise in sea level coupled with influxes of terrigenous clastic sediment into the Holston environment.

The Chapman Ridge Formation includes two lithostratigraphic units, a basal "orthocone zone" sharply overlain by the "main body" of the formation. The "orthocone zone," which is characterized by abundant cephalopods and ferromanganese (Fe/Mn) nodules as well as numerous hardgrounds, contains two lithofacies and represents a condensed stratigraphic sequence developed at moderate to shallow water depths along the Middle Ordovician shelf margin. The "main body" of the

Chapman Ridge Formation includes three lithofacies which collectively represent a storm? influenced, shallow subtidal, shelf margin, progradational-retrogradational mixed carbonate-terrigenous clastic sand wave environment composed of sand bars and muddy interbar areas.

The Ottosee Formation includes four lithostratigraphic units. The Lower Unnamed Shale Member is very poorly exposed within the study area and may represent muddy shelf and possibly interbar sediments. The Hiwassee Member is composed of two lithofacies which represent deposition in a shelf margin, oolite shoal-organic buildup complex. The Middle Unnamed Shale Member abruptly overlies the Hiwassee Member and is composed of two lithofacies which represent deposition in a storm-dominated carbonate sand/terrigenous sand and mud shelf lagoon. The McKnight Member contains five lithofacies and represents deposition in a shelf margin oolite shoal-organic buildup complex dissected by tidal inlets and channels which typically contain coarse grained mixed terrigenous clastic and carbonate rocks.

The lower "Bays" Formation is composed of one lithofacies and represents sediments deposited along the interface of an oolite shoal complex and a shallow shelf lagoon/sand and mud flat.

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CHAPTER I

INTRODUCTION

Sedimentary rocks of the Middle Ordovician Chickamauga Group outcrop extensively within the linear northeast to southwest trending thrust belts of the Valley and Ridge Province of East Tennessee. These rocks represent a complex pattern of laterally disposed and vertically successive carbonate and terrigenous clastic paleodepositional environments which developed on or above a widely observed post-Knox unconformity.

Previous Investigations

Study of the Middle Ordovician stratigraphic succession in East Tennessee was pioneered by Safford (1869) and Keith (1895, 1896). Subsequent studies by Ulrich (1911), Gordon (1924), Butts (1940), Cooper and Prouty (1943), Rodgers (1953) and Cooper (1956) have produced numerous interpretations of this succession. It was not until 1973 that a coherent scenario was proposed for the Middle Ordovician by Walker and Alberstadt in an effort to explain the stratigraphic and environmental complexities of this sequence. Walker and Alberstadt (1973) conceived the Middle Ordovician as representing a tripartite facies pattern composed of (1) a northwestern carbonate shelf bounded on the southeast by a shelf-edge reef tract, which was separated by a (2) deep water turbidite shale basin from (3) a shallow water nearshore area southeast of the basin near eroding land.

Despite the numerous studies of Middle Ordovician rocks done primarily at The University of Tennessee, Knoxville, this scenario although slightly revised by Walker (1977a, 1980a), has essentially remained unchanged. Thus, it provides a comparative standard for work in the Middle Ordovician of East Tennessee.

Purpose of Investigation

The purpose of the present investigation is two-fold:

1. to reassess the reported ages of the upper Lenoir, Holston, Chapman Ridge, Ottosee and lower "Bays" Formations as exposed within the Calhoun area by means of a systematic examination of microfossils, specifically conodonts,

2. to determine the environments of deposition of these formations by coupling detailed field measurements and observations with petrologic analyses.

Study Area

The area chosen for this study is located within the Knoxville-Athens Belt [="Main Red Belt" of Safford (1869); =the "Friendsville Belt" of Bergström and Carnes (1976)] near Calhoun, Tennessee. This belt is bounded to the northwest by the Knoxville Fault and to the southeast by the Dumplin Valley--Chestuee Fault system. The study area lies within the southwest quarter of the Calhoun, Tennessee, 7.5 Minute Quadrangle, 125-SW.

The stratigraphic sections, located within the Calhoun area at Heneger Bluff (HB) and along the Louisville and Nashville Railroad cut

(LN), were measured and sampled during this study (Fig. 1). The sections are separated along strike by a distance of approximately 4 km and crop out along the northwest limb of the Athens Syncline. Together, these sections represent a thick (≅780 meters), well exposed, nearly complete Middle Ordovician stratigraphic succession ranging from the Lenoir Formation at the base into the "Bays" Formation at the top (Smith, 1976; Walker, 1977d,e)(Fig. 2).

Procedure and Methods of Analysis

Each of the two sections, HB and LN, was measured directly using a Jacob Staff and Brunton Compass; pace-compass traverses were employed to measure large covered intervals especially at the LN section. Detailed field observations were recorded for each section and are included along with the sample locations in Appendix A. The rock classification used in the text follows that of Dunham (1962) for carbonates and Folk (1968) for terrigenous clastics. Bedding thickness descriptions follow McGee and Weir (1953) as modified by Ingram (1954).

The stratigraphic interval measured at each section originated in the Upper Tongue of the Lenoir Formation. At Henegar Bluff, the top of this measured interval approximates the top of the Chapman Ridge Formation and lies 73.8 meters above a base in the Upper Lenoir. At the LN section, the top of the stratigraphic interval studied lies 508.6 meters above a base in the Upper Lenoir and falls within the "Bays" Formation.

The rationale for not including the Lower Tongue of the Lenoir Formation and the Athens Formation in this study is as follows:

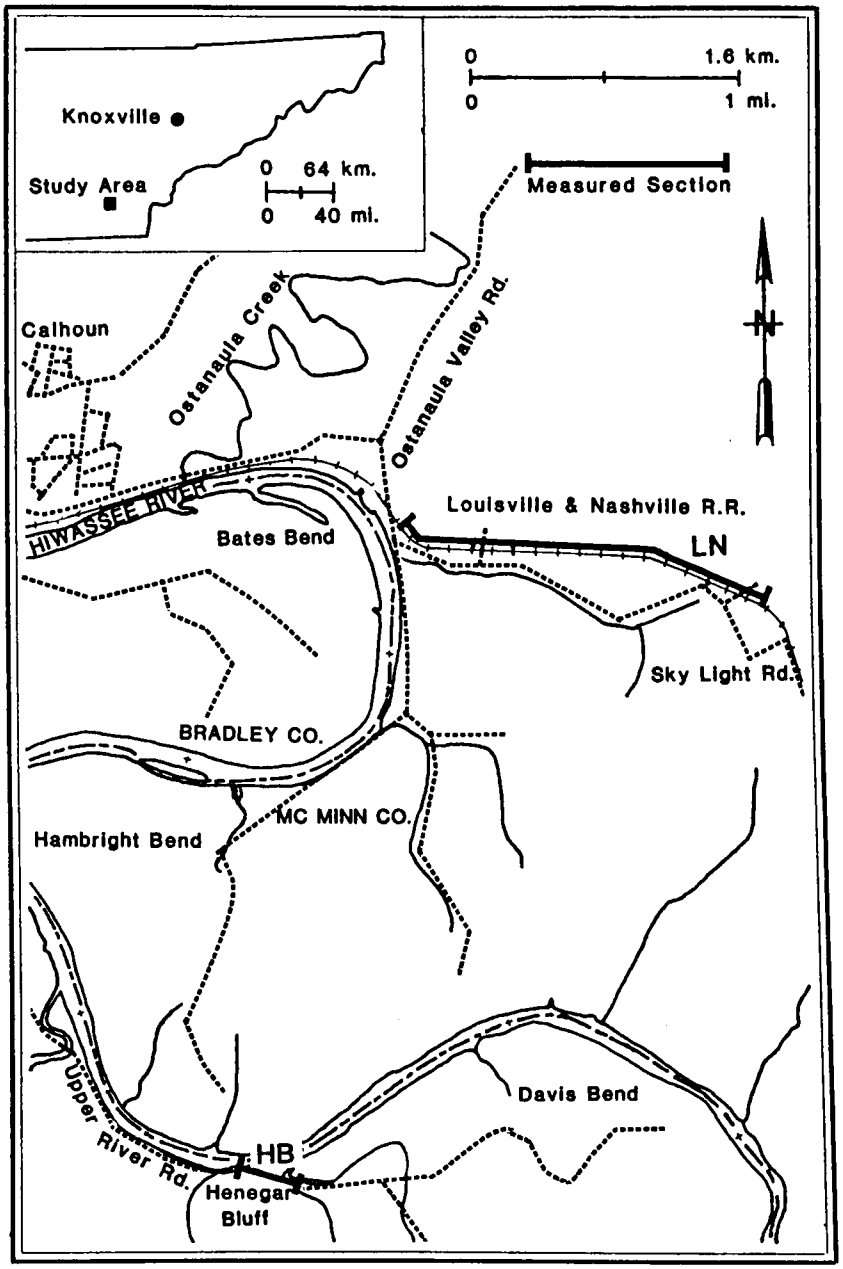


Figure 1. Location of the Calhoun study area and measured stratigraphic sections. LN = L & N Railroad Section and HB = Henegar Bluff Section.

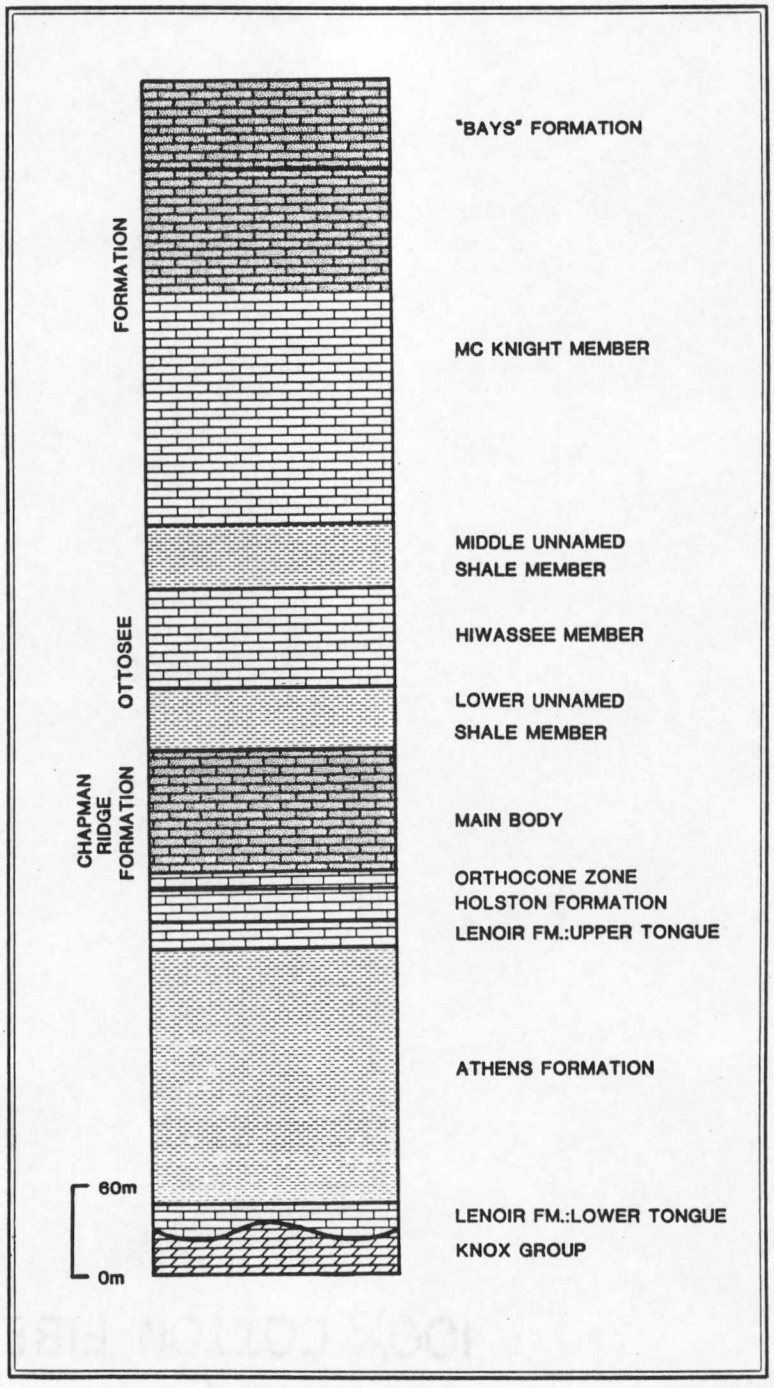


Figure 2. Composite stratigraphic section of Middle Ordovician rocks exposed in the vicinity of Calhoun, Tennessee. Modified after Smith (1976) and Walker (1977d,e).

1. The focus of this study was on the Holston-Chapman Ridge-Ottosee succession. The Upper Tongue of the Lenoir and the lower "Bays" were sampled in order to provide additional background information for this succession.

2. The Pygodus anserinus-Amorphognathus tvaerensis Conodont Zonal boundary as reported by Bergström (1977) lies within the lower part of the Holston Formation at HB. At the LN section, the location of this boundary was unknown. It was an objective of this study to locate this boundary for the purpose of correlating the two measured sections within the study area.

3. The outcrop exposed at HB is nearly continuous from the Upper Tongue of the Lenoir through the Chapman Ridge Formations. At LN, the Lower Tongue of the Lenoir and the Athens Formations are very poorly exposed.

Oriented rock samples for laboratory analyses were collected from successive different lithologies as recognized in the field (see Appendix A). A total of 55 samples was collected from HB and 159 samples were collected from LN. The collected samples were slabbed and described to supplement field descriptions in an effort to divide the sections into lithologic units. In addition, 84 thin sections (33 from HB, and 51 from LN) and 84 acetate peels (31 from HB and 53 from LN) were prepared from selected samples. Applying the methodology of Chayes (1954) and Van Der Plas and Tobi (1965), thirty-two thin sections were point counted (300-350 points/slide) to aid in the determination of the constituent particle composition of the various

lithologies. Point count data have been included in Appendix B. The petrologic data obtained from thin section and acetate peel analysis were integrated with field and slab descriptions to aid in the paleo-environmental interpretation of the lithologic units.

Seventy-six samples [53 samples weighing 75.0 kg (avg. = 1.41 kg per sample) from LN, and 25 samples weighing 33.8 kg (avg. = 1.47 kg per sample) from HB] were processed for conodonts following a modified version of the processing technique of Collinson (1963) as discussed by Harris (1982). Following cleaning, the samples were crushed to a 1 cm modal size and dissolved in a 10% formic acid solution. Due to the significant terrigenous clastic component of most of the lithologies processed for conodonts, the initial weight of 1 kg for each sample was chosen.

Insoluble residues were separated by a tetrabromoethane heavy-liquid separation technique developed by Harris (1982) and the heavy fractions were examined for conodonts. Productive samples were picked and the conodonts were affixed to numbered micropaleontology slides with gum tragacanth. Samples producing either biostratigraphically diagnostic conodonts or elements included within their multi-element apparatuses were rerun, nonproductive samples were rarely reprocessed.

Limitations of the Study

Both measured sections, HB and LN, cropout within roadbeds which have been cut across strike. Most of the exposed rock has been fractured during construction and subsequently subjected to intense

weathering thus creating discontinuous exposures in these roadcuts. Within the immediate study area, outcrops along strike are very poorly exposed and discontinuous.

Second, the lack of directional data (e.g., paleocurrent orientation) has prohibited the location of the source area and the direction of transport of the terrigenous clastic sediment found within the study area. The lack of paleocurrent directional data is due to the fact that there were no bedding plane surfaces exposed at either HB or LN which contained cross-strata. Vertical outcrop faces containing cross-beds were inaccessible.

Third, inadequate biostratigraphic control has not permitted a reliable correlation between the sections within the study area. Fourth, analogous Recent mixed terrigenous clastic and carbonate depositional environments have not been well studied whereas similar ancient sedimentary environments have not been well documented.

CHAPTER II

THE STRATIGRAPHY OF THE UPPER LENOIR THROUGH LOWER "BAYS" FORMATIONS NEAR CALHOUN, TENNESSEE

Introduction

Controversy surrounding the status of lithostratigraphic and biostratigraphic units within the Chickamauga Group along with their correlation has been long-standing. The lack of an environmental framework for the interpretation of these rock units and the use of "facies fossils" such as brachiopods (Cooper, 1956) in correlation has been responsible for perpetuating the controversy (see Moehl, 1965; McLaughlin, 1973; Stephenson, 1973; Twenhofel et al., 1954, for discussions on "facies fossils" in the Middle Ordovician of East Tennessee). Complex structural deformation has further complicated the problems of belt-to-belt correlation.

The diverse lithotypes of the Chickamauga Group occur at various stratigraphic positions within the outcrop belts of East Tennessee, and this has led to a proliferation of stratigraphic nomenclature applied to these Middle Ordovician rocks on a belt-by-belt basis. The stratigraphic nomenclature which workers have proposed for rocks primarily within the Knoxville-Athens Belt where the Upper Lenoir, Holston, Chapman Ridge and Ottosee Formations are best exposed is illustrated in Figure 3. Because rocks of all these formations are represented in the thesis area, the history of their study and interpretation is included here as background to the present investigation. The locations of

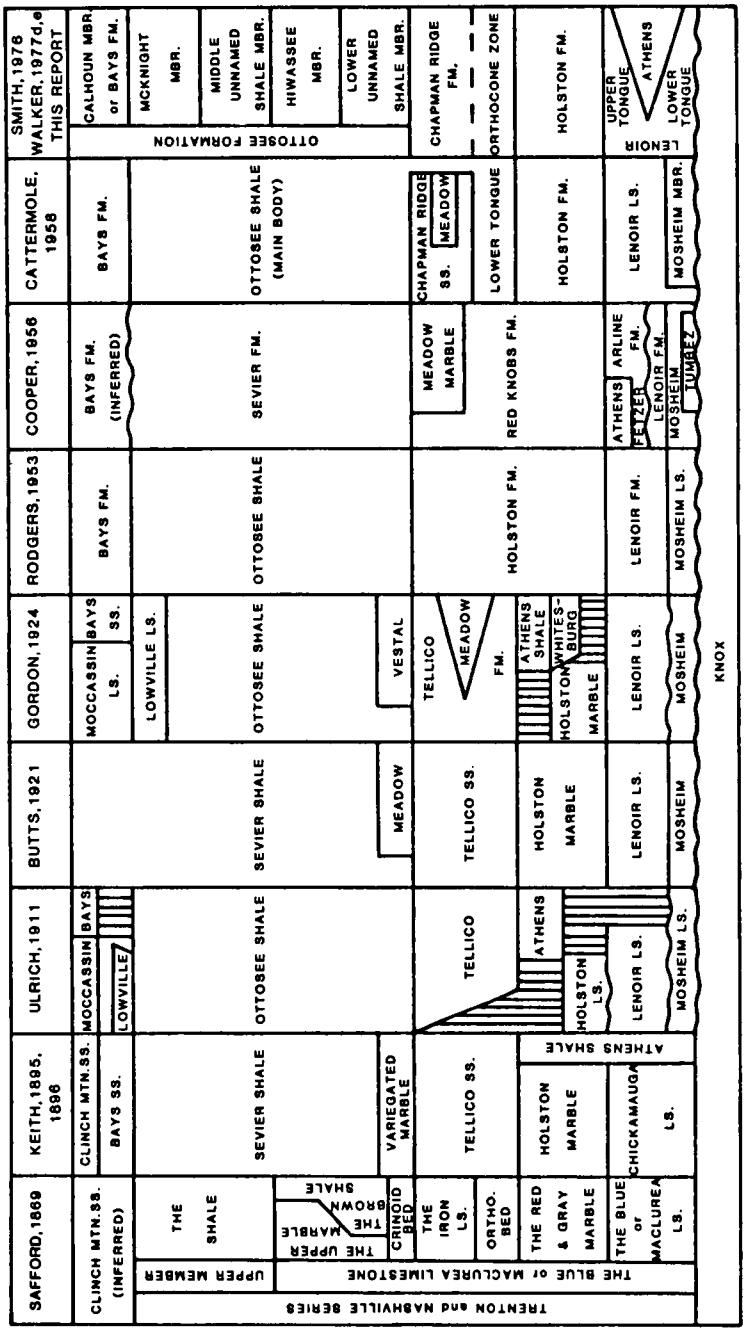


Figure 3. Stratigraphic nomenclature applied to Middle Ordovician lithologies within the Knoxville-Athens Belt.

measured sections discussed in the text have been illustrated in Figure 4.

Lithostratigraphy

Over the past century, rocks of the Middle Ordovician Chickamauga Group in the Knoxville-Athens Belt have been the focus of numerous geological investigations. However, until recently, these studies have been mainly concerned with the field-stratigraphic and economic aspects of these rocks.

Safford (1869) assigned the clastic and carbonate rocks overlying the Knox Dolomite in his "Main Red Belt" (=Knoxville-Athens Belt of this study) to the Trenton and Nashville Series. In this belt, he recognized the occurrence of two "marble" units, an "Upper Red Marble" and a lower "Red and Gray Marble." Gordon in 1924 correlated his Vestal Marble with Safford's "Upper Red Marble" and, according to La Follette (1974), he also correlated the lower "Red and Gray Marble" of Safford (1869) with the Holston Formation of Keith (1896). Safford also recognized an "Iron Limestone" (equivalent to the Chapman Ridge Formation according to Sitterly, 1976) which was separated from the (Holston) marble below by an "orthoceratite bed" of shaley limestone (equivalent to the "lower tongue" of the Ottosee Shale of Cattermole, 1958).

Most of the lithostratigraphic units within this belt were formally named by Keith (1895). In 1896, Keith correlated his nomenclature with that used by Safford in 1869. In addition, he noted

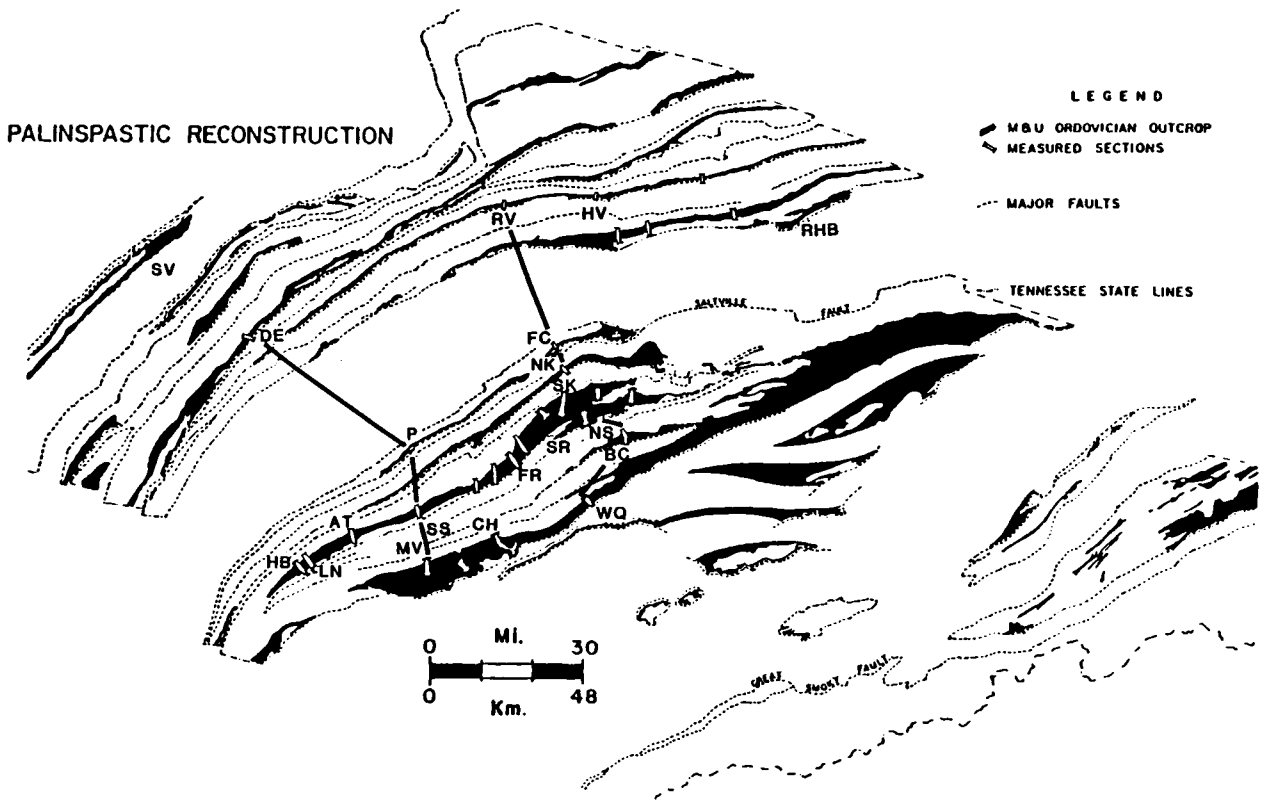


Figure 4. Location of the Calhoun study area (HB, LN) and stratigraphic sections discussed in text restored palinspastically on the base map of Roeder and Witherspoon (1978). (Modified after Walker, 1977a and Ruppel, 1979.)

that both the Holston Marble and Chickamauga Limestone grade eastward into the Athens Shale and that a "variegated marble" [the Vestal?] occurred at the base of the Sevier shale.

The Ottosee Formation was named by Ulrich (1911) as a substitute for the name "Sevier Shale" within the Athens and Knoxville "Troughs" without an accompanying description or location of a type section. According to Twenhofel et al. (1954), it wasn't until an inclusion in the Lexicon of Geologic Names by Wilmarth that the type locality of the Ottosee was stated as being Lake Ottosee in Chilhowee Park, Knoxville, Tennessee. The Athens Formation was limited by Ulrich to occurrences in the Athens Trough whereas the Holston Formation was claimed to occur only in troughs west of and inclusive of the Knoxville Trough.

The Meadow Marble was mapped by Butts (1921) at the base of the Sevier Shale at Friendsville, Tennessee. Gordon (1924), however, considered the Sevier Shale at Friendsville to be the Ottosee Shale of Ulrich (1911) and so renamed the "marble" occurring at the base, the "Vestal Limestone." Gordon then applied the term "Meadow Marble" to a limestone in a similar stratigraphic position close to the base of the Sevier Shale.

Rogers (1953) included within the Holston Formation an upper quartzose phase to which the name "Tellico Sandstone" had been applied by previous workers (e.g., Keith, 1895; Ulrich, 1911; Butts, 1921; Gordon, 1924). This unit (at the top of Rodger's Holston) was renamed the Chapman Ridge Formation by Cattermole (1958).

Cooper (1956) proposed the Arline Formation as a substitute for the upper part of the Lenoir Formation of other workers and combined

the Holston and Tellico Formation of other workers under a single name, the Red Knobs Formation. Because he considered the Ottosee Formation to be a facies of the Sevier Shale, he did not use the term "Ottosee" in his monograph. Cooper believed that both the Vestal and Meadow marbles occupied a similar stratigraphic position close to the base of the Sevier Shale.

To distinguish the type Tellico Sandstone from units in the Knoxville area to which the name "Tellico" had been given but which he considered not to be correlative, Cattermole (1958) established a new unit, the Chapman Ridge Sandstone, based on a type section along Alcoa Highway in South Knox County. He included within the base of the Chapman Ridge Sandstone a thin shaley unit which he regarded as the "lower tongue" of the Ottosee Formation. Interbedded within the Chapman Ridge Sandstone were lithologies and fossils characteristic of the Ottosee Formation which led Cattermole (1958) to conclude that a facies relationship existed between the two formations.

Smith (1976) studied the stratigraphic succession of Middle Ordovician rocks in the vicinity of Calhoun, Tennessee, and informally recognized five members within the Ottosee Formation in the Calhoun area. He also suggested that the "orthocone zone" overlying the Holston Formation in the Calhoun area might be stratigraphically equivalent to the "lower tongue" of the Ottosee Formation recognized by Cattermole (1958).

Walker (1977d,e) modified Smith's stratigraphic nomenclature by recognizing that within the Calhoun area, the Athens Shale was bounded

by an upper and a lower tongue of the Lenoir Formation. Walker (1977d) also suggested that Smith's Calhoun Member of the Ottosee Formation was probably equivalent to the "Bays" Formation but because the section was too far removed from the Bays type area, formal recognition of this formation could not be made. Walker's modified version of Smith's nomenclature (see Fig. 3) will be followed in this report.

Since the mid-1960s, studies addressing specific paleodepositional environments of Middle Ordovician rocks in East Tennessee have been conducted primarily by workers from The University of Tennessee, Knoxville. Several of these studies are relevant to the specific interval under consideration in the present investigation. Stephenson (1973), Stephenson, Walker and McLaughlin (1973), Benedict (1977) and Walker and Benedict (1980) have studied the paleodepositional environments of the Upper Lenoir Formation. According to these authors, the Upper Lenoir Formation represents sediments accumulated in a deep to shallow subtidal back-reef shelf lagoon paleoenvironment.

The paleodepositional environment and paleocology of the Holston Formation have been studied by Ferrigno (1973), Ferrigno and Walker (1973a,b), Walker and Ferrigno (1973a,b), Walker (1977b,c; 1980b), Benedict (1977), Walker and Benedict (1980) and Ruppel and Walker (1982). The Holston Formation according to these studies represents two shelf-edge environments: (1) a bryozoan-dominated reef tract with flanking skeletal sands and (2) a skeletal-sand-bank environment. McGill (1982) has studied the diagenesis and trace element geochemistry of a portion of the Holston Formation along an off-shelf to fully

on-shelf environmental transect. In evaluating the effect of the shelf-edge position on diagenesis across the three outcrops which she studied, McGill (1982) observed that syntaxial overgrowths and radiaxial cement were the most abundant cements encountered in the Holston Formation. She also noted that the values for both Fe and Mn increase basinward with the highest values observed at the deepest water section studied (Midway Road).

Lithologies of the Chapman Ridge Formation near Knoxville and their paleodepositional environments were analyzed by McWilliams (1975). He concluded that Chapman Ridge lithologies represent a subtidal sand flat-barrier island complex overlying an earlier tidal mud-flat-carbonate bank-lagoon complex. Sitterly (1976) interpreted the Meadow Marble Member of the Chapman Ridge Formation as representing a bryozoan-echinoderm-dominated biohermal patch reef with flanking sands built on a shallow water carbonate shelf.

According to La Follette (1974), the Vestal Limestone Member of the Ottosee Formation represents a series of shallow water carbonate shelf biostromal patch reefs dominated by sponges, encrusting bryozoans and echinoderms. Walker (1980d) and Cantrell (1982) have identified oolite beds within the Ottosee Formation in Blount County as a shelf-edge oolite shoal analogous to those presently forming in Florida and the Bahamas. This oolite body is approximately coevel with the patch-reefs studied by La Follette.

Based on the studies noted above and several others, Walker (1977a, 1980a) and Walker et al. (1983) has refined the depositional

model for Middle Ordovician strata in East Tennessee initially proposed by Walker and Alberstadt (1973). In this model, the Middle Ordovician sequence is conceived as representing a four-part facies pattern (illustrated in Fig. 5A and B) composed of a western semirestricted carbonate shelf-lagoon bounded by a shelf-edge skeletal sand bank/reef tract to the southeast and separated by a deep water turbidite basin from a shallow nearshore area adjacent to eroding land along the extreme southeastern margin of the basin.

The above facies pattern began on a carbonate ramp which was subsequently differentiated into shelf and basin by an initial pulse of tectonic subsidence (Walker, 1977a; Shanmugam, 1978; Shanmugam and Walker, 1978, 1980, 1983) coupled with the bipolar distribution of rapid depositional rates in carbonate environments to the northwest and clastic environments to the southeast with much lower rates in the basin between (Walker, Shanmugam and Ruppel, 1983). Evolution of this sequence through the Middle Ordovician led to the filling of the basin with terrigenous clastic sediments (e.g., the Blockhouse, Tellico and Sevier Formations) which subsequently prograded northwestward over portions of the Holston shelf-edge reef tract (e.g., the Chapman Ridge and Ottosee Formations) inhibiting carbonate production. Irregular cyclic variations in the supply of terrigenous clastics to the shelf-edge were due to the trapping of sediments in the temporarily rejuvenated basin which allowed the reestablishment of shelf-edge carbonate environments (e.g., Meadow and Vestal Marbles and Ottosee oolites) within this prograding clastic sequence. Walker (1977a, 1980a) attributes this basinal rejuvenation to renewed subsidence.

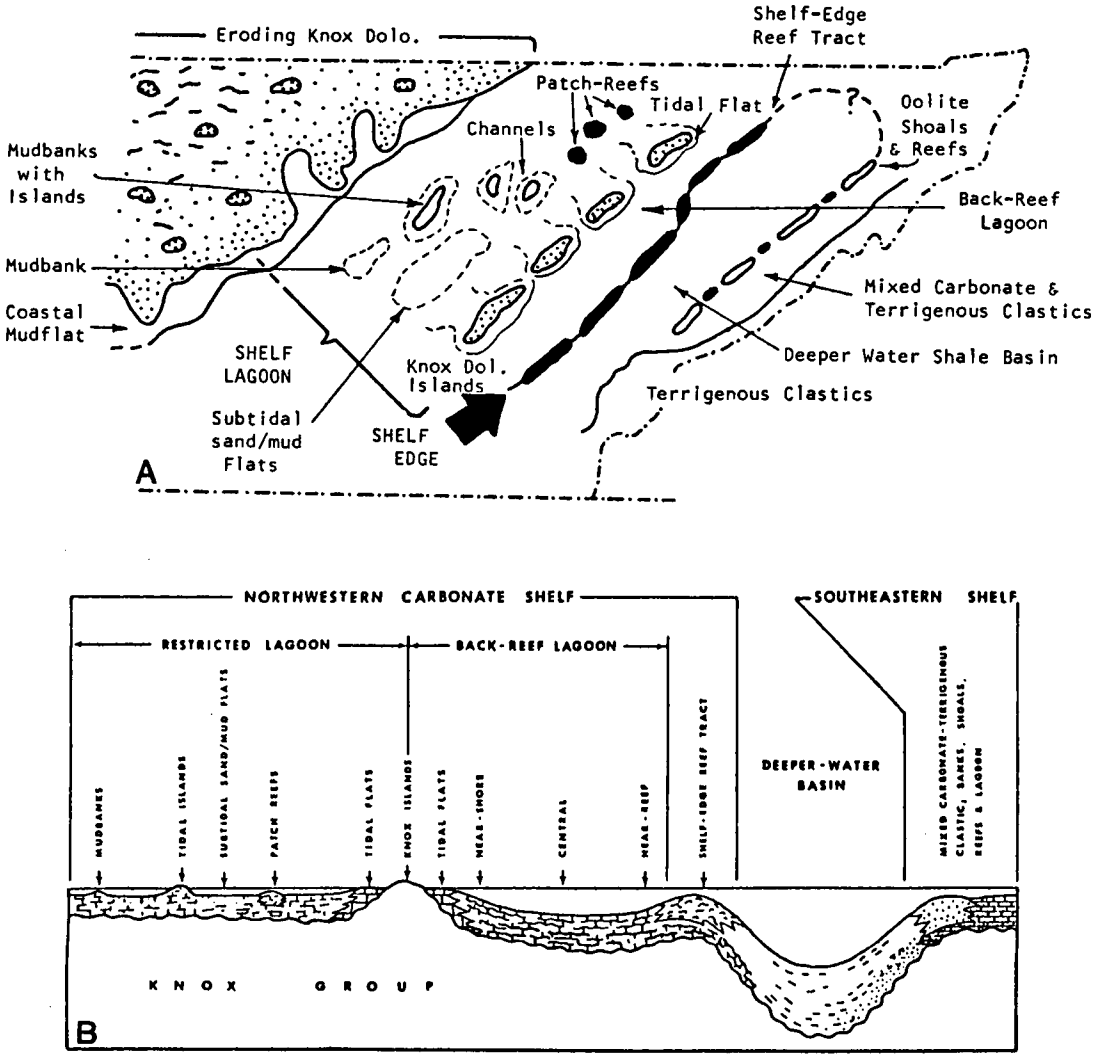


Figure 5. Proposed facies patterns for the Middle Ordovician of East Tennessee.

A. Environmental array proposed for T2 (=base of the Prioniodus gerdae Conodont Subzone) by Walker (1977a).

B. Diagrammatic cross-section for the environmental array proposed for T2 by Walker (1974). [After Moore (1978)].

The depositional events noted above have been utilized to construct time lines T3 and T4 illustrated in the regional cross sections of Walker (1977a, 1980a) (see Fig. 6), in Middle Ordovician paleobathymetric maps prepared by Benedict and Walker (1978), and also in the sediment distribution maps of Walker (1980a). The paleobathymetric and sediment distribution maps have been subsequently modified by Walker, Shanmugam and Ruppel (1983). The rational for these time-lines is explained more fully in the Appendix to Benedict and Walker, 1978.

The inferred paleobathymetry of the study area for four times during the Middle Ordovician is illustrated in Figure 7 using the maps of Benedict and Walker (1978) as a base. It may be noted that conodont zonal boundaries are shown for two of the times, T1 and T2.

Biostratigraphy and Chronostratigraphy

Prior to the treatise by G. A. Cooper (1956) on brachiopods, few systematic biostratigraphic studies of fossils related to the Middle Ordovician stratigraphic succession in East Tennessee had been published. Earlier references to fossils from the area are scattered in regional reconnaissance surveys such as Butts (1940) which contain limited locality information and questionable stratigraphic association.

The earliest workers in the area, Safford (1869) and Keith (1895, 1896) assigned the stratigraphic interval represented by the Upper Lenoir through the Ottosee Formations in the study area to the Silurian Period, as the Ordovician System had not yet been differentiated.

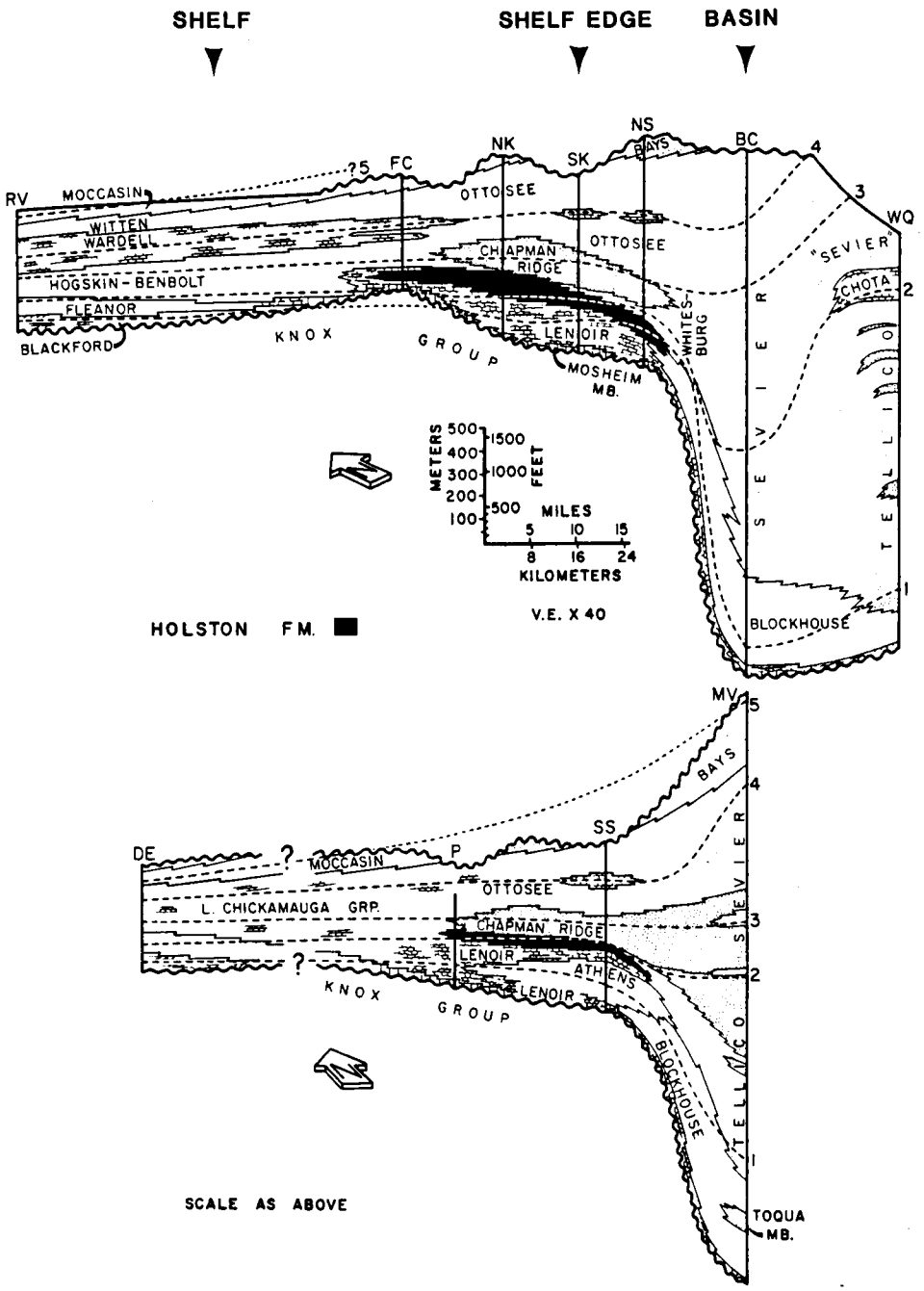


Figure 6. Stratigraphic cross sections for the Middle Ordovician of Eastern Tennessee illustrating reconstructed regional facies patterns along two shelf to basin transects. Figure 4 (p. 12) shows the location of these two cross sections. (Modified after Walker, 1980a.)

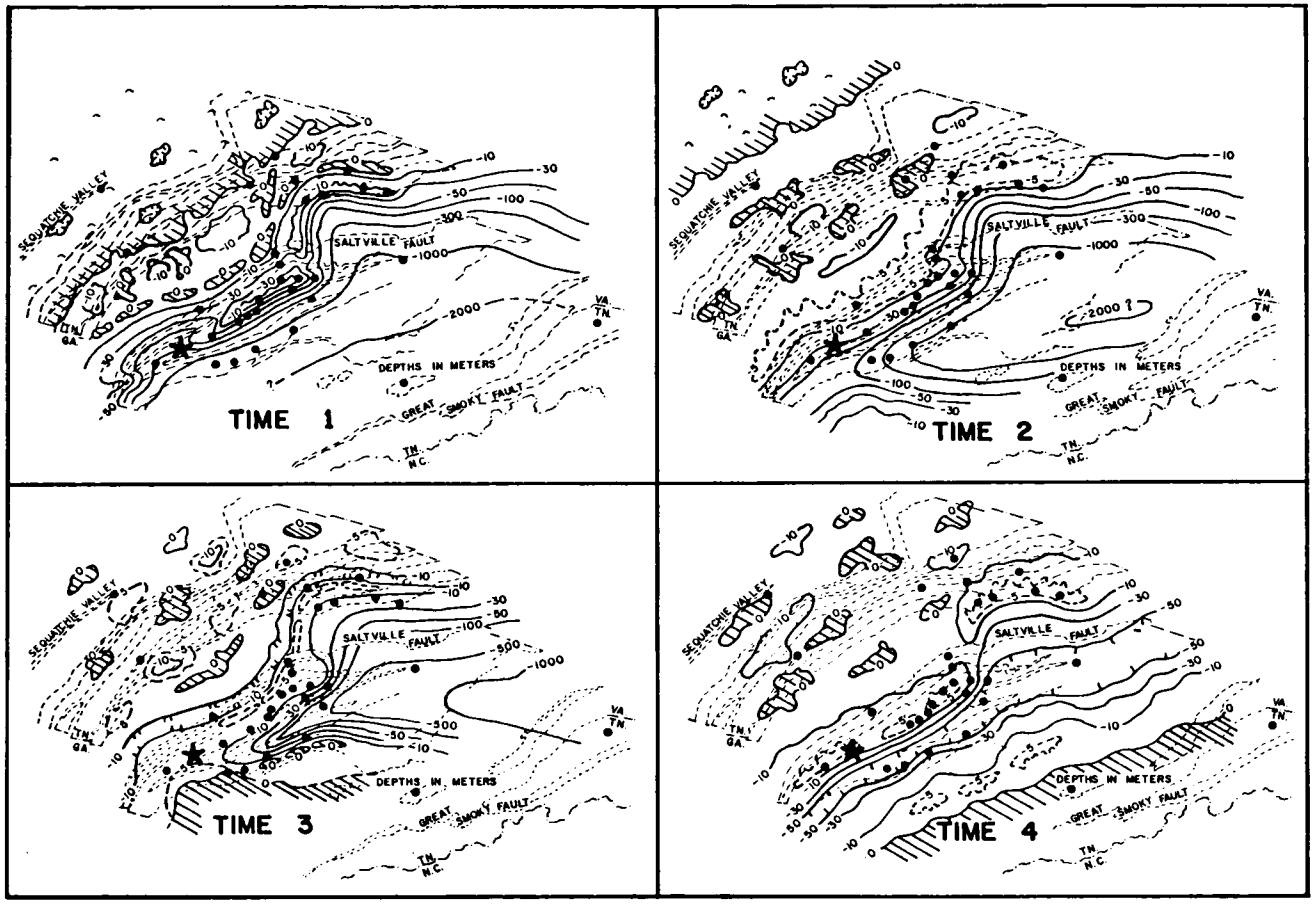


Figure 7. Middle Ordovician paleobathymetric maps on palinspastic base map of Roeder and Witherspoon (1978). (After Benedict and Walker, 1978.)
Time 1 = Base of Pygodus anserinus Conodont Zone.
Time 2 = Base of Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Conodont Zone.
Time 3 = Progradation-retrogradation of the Chapman Ridge Sandstone.
Time 4 = Maximum resurgence of limestone deposition on the carbonate shelf.
* = Calhoun area.

Ulrich (1911) included this stratigraphic interval within his Blount Group which he assigned to the Chazyan Stage. Gordon (1924) supported Ulrich's age assessment of these formations. In 1953, Rodgers assigned both the Lenoir Formation and the Holston Formation to the Chazyan Stage. He recognized that the Ottosee Shale occurred as a facies within the stratigraphic interval represented by the Lower and Middle Chickamauga Limestone and could at best be correlated in part to the Blackriveran as well as to parts of the Trenton and Chazyan Stages.

Twenhofel et al. (1954) suggested that at Friendsville, Tennessee, the Upper Lenoir through Sevier Formations were Blackriveran. The Ottosee was recognized as a facies within the Benbolt-Wardell interval and was also Blackriveran (=lower part of the Caradoc Series of Great Britain). However, because it also occurred within lower horizons of the Middle Ordovician elsewhere, the Ottosee was regarded as having no precise time-stratigraphic significance.

Cooper (1956) proposed five new stages for the Middle Ordovician System in North America based on the stratigraphic distribution of brachiopods. Four of these five stages, the Marmor, Ashby, Porterfield and Wilderness Stages, were based on type sections located in the Southern Appalachians of Virginia and Tennessee on either side of the Saltville Fault. The Ashby and Wilderness type sections lie to the northwest of the Saltville Fault whereas the Marmor and Porterfield type sections lie to the southeast of the fault (Broadhead, 1980). Subsequent studies (e.g., McLaughlin, 1973 and Bergström, 1971) have recognized the Saltville Fault as a major Middle Ordovician megafossil

and microfossil provincial boundary which contributes to the difficulties of correlation across the fault and causes overlap in Cooper's stages. Nonetheless, Cooper (1956) assigned the Red Knobs Formation (=Holston and Chapman Ridge Formations) to the Upper Porterfield Stage.

During the last 15 years, a number of biostratigraphic studies of Middle Ordovician lithostratigraphic units have been conducted in East Tennessee, including the Knoxville-Athens Belt, in an effort to determine chronostratigraphic relationships. In the Knoxville-Athens Belt, these studies have employed two fossil taxa, the bryozoans and the conodonts. Application of bryozoan biostratigraphy has been limited to the "reefal" environments of the Holston, Meadow and Vestal Marbles, while conodont biostratigraphy has been used in studies of the predominantly carbonate lithologies of the Lenoir, Holston and Meadow Formations.

Ferrigno (1973), and Walker and Ferrigno (1973b) suggested a Middle Wilderness age for the bryozoan assemblage present within the Holston Limestone. On the basis of conodonts, Bergström and Line (1979) have assigned the base of the Holston Formation to the Upper Subzone of the Pygodus anserinus Conodont Zone (=Porterfield Stage). The top of the Holston Formation as well as the base of the Chapman Ridge Formation at the Alcoa Highway section in the Knoxville-Athens Belt have been determined to be no younger than the Prioniodus gerdae Subzone of the Amorphognathus tvacrensis Zone and thus lie within the Porterfield Stage.

Sitterly (1976), in his analysis of the bryozoan assemblage from the Meadow Marble, suggested a range of medial Wilderness to early

Barnveld (Trenton) for this member of the Chapman Ridge formation. Bergström and Carnes (1976) state that based on conodonts, the Meadow Marble is no younger than the Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Conodont Zone (=Porterfield/Wilderness) in the Knoxville-Athens Belt.

A late Wilderness to early Barnveld (Trenton) time range was suggested by La Follette (1974) for the bryozoan assemblage within the Vestal Marble.

Prior to the present study, conodont data to support an age assessment of the Ottosee Formation have not been available. In spite of this, Carnes (1975) concluded that the Ottosee-Chapman Ridge "complex" was correlative to the Hogskin-Rockdell succession and, therefore, should lie within the Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Conodont Zone.

Because conodont biostratigraphy is a major concern of this thesis, a detailed account of principles and methods with particular references to studies of Ordovician faunas is given in the following section.

Conodont Biostratigraphy and Chronostratigraphy

According to Bergström (1971, p. 128) ". . . Ordovician conodont faunas exhibit a strikingly high degree of provincialism." Conodont provincialism has been discussed extensively by Sweet et al. (1959), Bergström (1971, 1973, 1977c), Barnes et al. (1973), Barnes and Fåhraeus (1975), Fåhraeus (1976), Rhodes and Austin (1977), Sweet and

Bergström (1974), Jaanusson (1979), Jaanusson and Bergström (1980) and Harris (1982). A major conclusion of these authors is that two conodont provincial faunas were contemporaneous during the Middle Ordovician within the Southern Appalachians. These faunas are representative of a westerly cratonic Midcontinent province and an amphicratonic North Atlantic province to the east. The boundary between the two faunal provinces coincides with the Helena-Saltville Fault system (Bergström, 1971), an apparent provincial boundary for megafossils as well (McLaughlin, 1973; Jaanusson, 1979; Jaanusson and Bergström, 1980).

For zonation within the North Atlantic conodont province, Bergström (1971) has used the Swedish Middle and Late Ordovician conodont succession in defining five conodont zones which he further subdivided into ten conodont subzones (see Fig. 8, Column 6). Characteristic evolutionary stages in the rapidly evolving conodont lineages in the North Atlantic province provide the basis for this zonation; therefore, these conodont zones are "phylozones" or "lineage" zones as defined by Hedberg (1976). Recognition of these conodont zones and subzones in Middle Ordovician rocks in eastern North America and elsewhere in Europe has allowed Bergström (1971) to correlate the North Atlantic zones with European graptolite zones and the Middle Ordovician "standard" series and stages of Europe and North America.

Up to the present time, the Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Zone is the youngest North Atlantic conodont subzone recognized in the Middle Ordovician of East Tennessee. In

Figure 8. Correlation proposed for the Middle and Upper Ordovician as determined by the graphic correlation method. (Modified from Sweet, 1983.)

Columns 1 and 2: Middle and Upper Ordovician chronostratigraphic units.

Column 3: Conodont faunal units of Sweet, Ethington and Barnes, 1971.

Column 4: Conodont-based chronozones. The names and scope of pre-Mohawkian conodont chronozones are provisional.

Column 5: Post-Whitrockian standard time units (1 s.t.u. = 462,500 years).

Column 6: North Atlantic Conodont Zones of Bergström (1971).

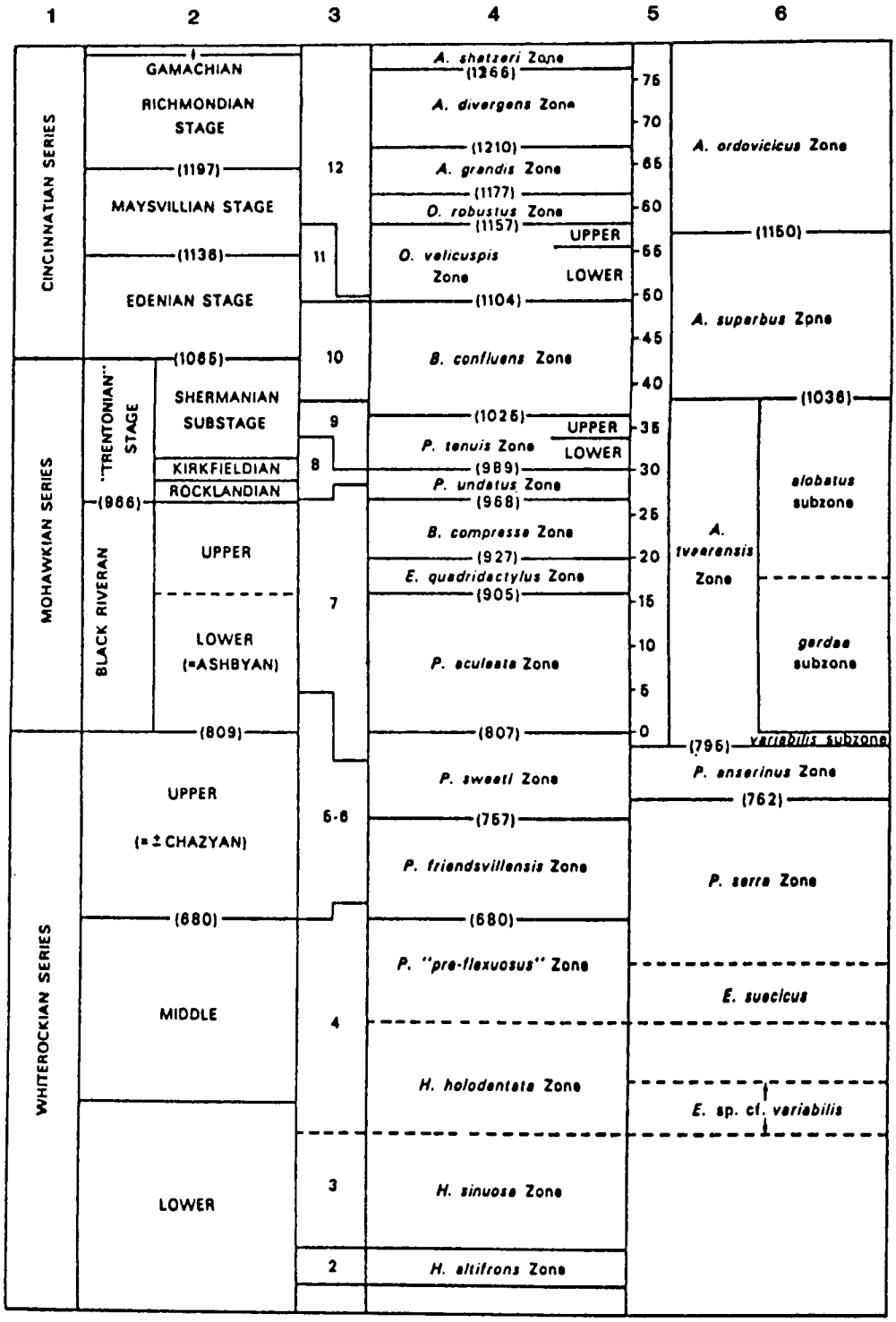

1
2
3
4
5
6
CINCINNATIAN SERIES
MOHAWKIAN SERIES
WHITEROCKIAN SERIES
GAMACHIAN
RICHMONDIAN STAGE
(1197)
MAYSVILLIAN STAGE
(1138)
EDENIAN STAGE
(1085)
"TRENTONIAN" STAGE
SHERMANIAN SUBSTAGE
KIRKFIELDIAN
ROCKLANDIAN
(986)
BLACK RIVERAN
UPPER
LOWER (=ASHBYAN)
(809)
UPPER (=±CHAZYAN)
(680)
MIDDLE
LOWER
12
11
10
9
8
7
6-6
4
3
2
A. shetzeri Zone
(1266)
A. divergens Zone
(1210)
A. grandis Zone
(1177)
O. robustus Zone
(1157)
UPPER
O. velicuspis Zone
LOWER
(1104)
B. confluens Zone
(1026)
UPPER
P. tenuis Zone
LOWER
(989)
P. undatus Zone
(968)
B. compressa Zone
(927)
E. quadridactylus Zone
(905)
P. aculeata Zone
(807)
P. sweeti Zone
(757)
P. friendsvillensis Zone
(680)
P. "pre-flexuosus" Zone
H. holodentata Zone
H. sinuosa Zone
H. altifrons Zone
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
A. ordovicicus Zone
(1150)
A. superbus Zone
(1038)
A. tvaerensis Zone
alobatus subzone
gerdae subzone
variabilis subzone
(796)
P. anserinus Zone
(762)
P. serra Zone
E. suecicus
E. sp. cf. variabilis

Figure 8.

Sweden, the P. gerdae Subzone is succeeded by the P. alobatus Subzone, which is also within the A. tvaerensis Zone, the base of which is ". . . marked by the disappearance of P. gerdae n. sp. and the appearance of P. alobatus n. sp." according to Bergström (1971, p. 101). Unfortunately, the multielement conodont species P. alobatus (Bergström), the index of the P. alobatus Subzone, has not been recovered from rocks outside of Sweden (Bergström, 1971). Therefore, because this subzone can be recognized only in Sweden, the problem of determination of a top of the P. gerdae Subzone elsewhere remains unresolved.

Based on the ranges of stratigraphically important Middle and Upper Ordovician Midcontinent conodonts, Sweet, Ethington and Barnes (1971) delineated twelve successive conodont faunas (see Fig. 8, Column 3). However, this sequence was not formalized as a succession of conodont zones by Sweet et al. (1971), due to the incomplete nature of the conodont range values at the time of publication and the absence of single zonation scheme completely continental in scope. Even so, since 1971, the successive Midcontinent faunas of Sweet, Ethington and Barnes (1971) have been treated by authors as constituting chronostratigraphic and biostratigraphic units which, according to Sweet (1983), the conodont faunas were not intended to define.

Admixtures of North Atlantic and Midcontinent conodont faunas have permitted somewhat limited correlation between the two provincial faunas (Sweet et al., 1971; Carnes, 1975) and between North American and British stages, series and graptolite zones (Sweet and Bergström, 1976). Such correlation as in Sweet and Bergström (1976, Text

Figure 4, p. 134) illustrates the diachronous nature of several of the Middle and Late Ordovician Midcontinent conodont faunal units which is also illustrated by Sweet (1983) shown here in Figure 8, Column 3.

In 1982a, Sweet informally proposed a succession of Midcontinent conodont chronozones based on the graphic correlation method of Shaw (1964) with each chronozone named for the conodont species making a first appearance at the base of the chronozone (Sweet, 1982a). Application of the chronozone concept follows Hedberg (1976) in meaning. To date, names have been formally proposed for post-Whiterockian chronozones in Sweet (1983) while the names and scope of pre-Mohawkian conodont chronozones remain provisional. The conodont-based chronozones are illustrated in Figure 8, Column 4.

The lithostratigraphic correlation presented by Sweet (1983, Fig. 3, p. 14) indicates that at Hogskin Valley, Tennessee, the Hogskin-Rockdell succession of Carnes (1975) lies within the Erismodus quadridactylus and Belodina compressa chronozones (see Fig. 8) which represent the upper Blackriveran Stage of the Mohawkian Series. The E. quadridactylus and B. compressa chronozones have been tentatively correlated by Sweet (1983) to the uppermost P. gerdae and lowermost P. alobatus Subzones of the A. tvaerensis Zone of Bergström (1971) (see Fig. 8).

Description and Interpretation of Sections

Henegar Bluff

The Henegar Bluff section (HB), exposed on the south side of Upper River Road along Henegar Bluff in Bradley County, is located 4 km

southeast of Charleston, Tennessee. The section, which includes approximately 312 meters of Middle Ordovician sedimentary rocks, was measured and described by Smith (1976) and appears in modified form in Walker (1977d). The conodont biostratigraphy of the pre-Holston and lower Holston lithostratigraphic units has been reported by Bergström (1971, 1977) and Bergström and Carnes (1976). Figure 9 illustrates the stratigraphic distribution of lithologies and conodonts at HB.

Lithostratigraphy

The lower most 5.5 meters examined by the present author at HB have been assigned to the Upper Tongue of the Lenoir Formation. The basal 0.9 meters of cobbly bedded, poorly fossiliferous, burrowed, argillaceous wackestone becomes interbedded towards the top of the unit with poorly fossiliferous, calcareous sedlitharenite and quartz-rich, bryozoan-echinoderm packstone. Megafossil diversity increases upsection with an assemblage including bryozoans, echinoderms, brachiopods, trilobites, ostracodes, sponges, rare molluscs and the algae Girvanella, Solenopora:Type P (Moore, 1977) and possibly Hedstroemia. The contact between the Upper Tongue of the Lenoir Formation and the Holston Formation is transitional through the upper 4.6 meters of this unit.

The Holston Formation is 20.0 meters thick and consists of medium to thick bedded, slightly sandy, echinoderm-bryozoan packstone and grainstone. The uppermost 2 meters of the Holston contains pyrite which has been concentrated in pods and especially in stylolites as a

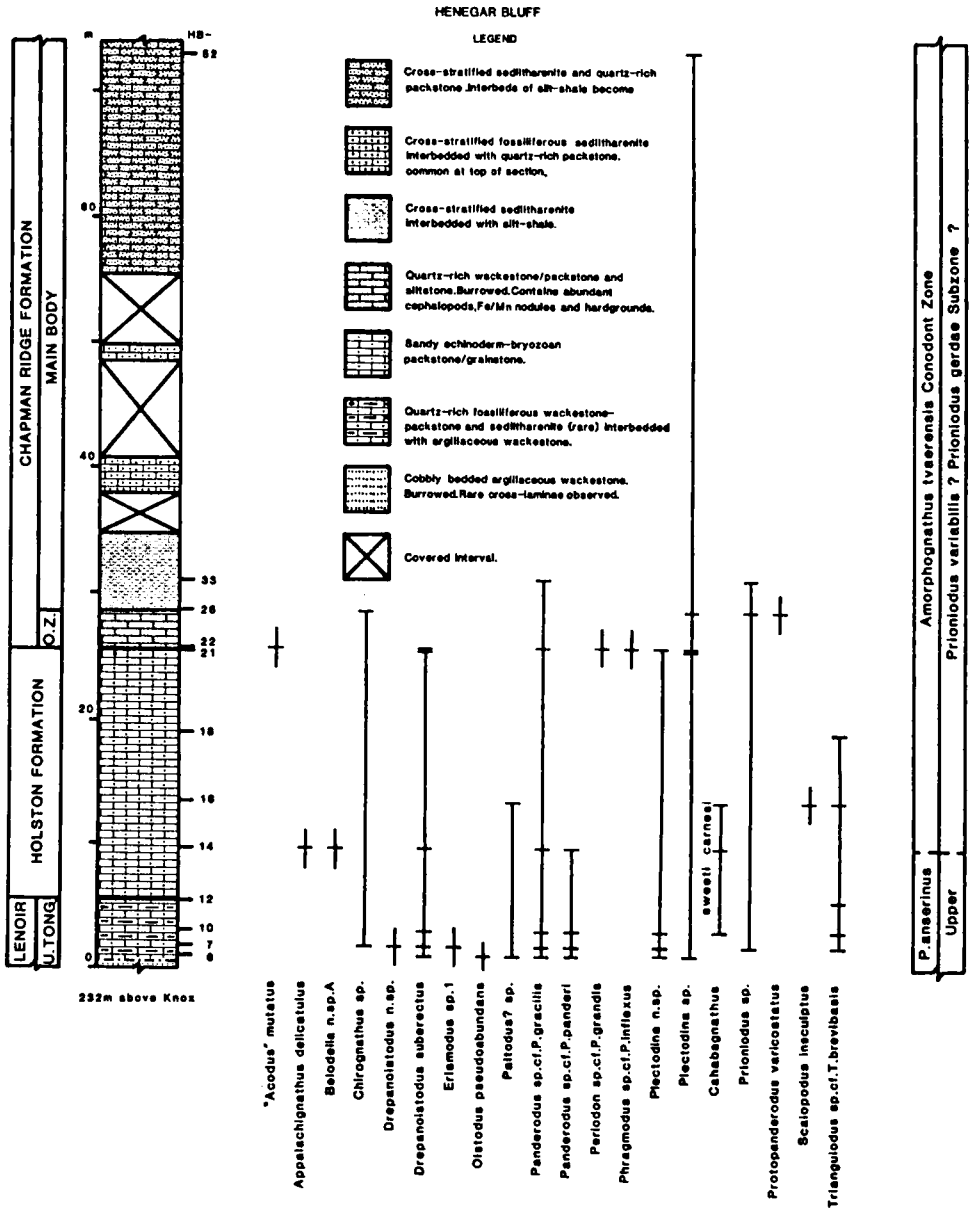


Figure 9. Stratigraphic distribution of lithologies and conodonts at the Henegar Bluff (HB) Section, Bradley County, Tennessee.

pyrite-rich stylocumulate. Besides being echinoderm- and bryozoan-rich, the lithologies of the Holston contain ostracodes, brachiopods, trilobites, and the algae Girvanella and Hedstroemia. Cephalopods and gastropods occur along with an increase in mud just below the sharp upper contact of the Holston Formation with the overlying Chapman Ridge Formation (Fig. 10A).

The Chapman Ridge Formation comprises the remaining 48.4 meters of section exposed at Henegar Bluff and has been subdivided into two informal units, a lower "orthocone zone" overlain by a unit herein referred to as the "main body" of the Chapman Ridge Formation.

The "orthocone zone" is 3.0 meters thick and contains abundant orthocone cephalopods. Lithologies are complex admixtures of burrowed cephalopod wackestone-packstone, quartz-rich echinoderm wackestone and sandy siltstone. The terrigenous clastic component increases upsection at the expense of the carbonate component. The unit contains chamosite ooids, ferromanganese (chamosite-hematite-phosphate rich) nodules and pavements along with some mineral-impregnated intraclasts. Gastropods, bryozoans, trilobites, ostracodes, Solenopora and Girvanella occur within the "orthocone zone." The contact between the orthocone zone and the main body of the Chapman Ridge Formation is Sharp (Fig. 10A).

The "main body" of the Chapman Ridge Formation is 45.4 meters thick and consists of interbedded fine grained, thin bedded sedlitharenite and calcareous silty shale at the base (Fig. 10B) and medium grained, medium to thick bedded, sedlitharenite and quartz-rich echinoderm packstone at the top (Fig. 10C). Calcareous silty shale

Figure 10. Outcrop features of the Upper Tongue of the Lenoir, the Holston and the Chapman Ridge Formations.

A. Contact between the Holston (H) and Chapman Ridge (CR) Formations at HB. Note the sharp corrosion surface (a) between the Holston and the "orthocone zone" (OZ) and the sharp, scoured surface (b) between the Orthocone Zone and the overlying "main body" (MB) of the Chapman Ridge Formation. Scale = 33.5 cm.

B. Crossbedded sedlitharenite interbedded with laminated silty shale in the lower "main body" of the Chapman Ridge Formation at HB. Scale = 33.5 cm.

C. Interbedded sedlitharenite, quartz-rich packstone and laminated silty shale in the upper "main body" of the Chapman Ridge Formation at HB. Note the planar tabular cross bedding. Scale = 33.5 cm.

D. Argillaceous wackestone of the Upper Tongue of the Lenoir Formation at LN. Note the cobbly bedding. Scale = 28 cm.

E. Contact between the Holston (H) and Chapman Ridge (CR) Formations at LN. Note the lens of Lenoir-like argillaceous wackestone (L) underlying a bryozoan wackestone/boundstone core (C) within the reef core complex (RC) of the Holston. A sharp, corrosion surface (a) separates the reef core complex from the overlying quartz-rich packstones and grainstones of the Holston reef flank (F). The "orthocone zone" (OZ) of the Chapman Ridge Formation overlies the reef flank of the Holston. Scale = 1 meter.

F. Reef core complex of the Holston Formation at LN. Note the lens of Lenoir-like argillaceous wackestone (L) underlying a stromatactis structure (S) which in turn is overlain by a bryozoan wackestone/boundstone core (C) within the reef core complex (RC). Scale = 33.5 cm.

G. Contact between the reef core complex (RC) and the reef flank (F) of the Holston Formation at LN (at arrow). Note the highly irregular, sharp nature of the contact which represents an intraformational corrosion surface/ hardground. Scale = 33.5 cm.

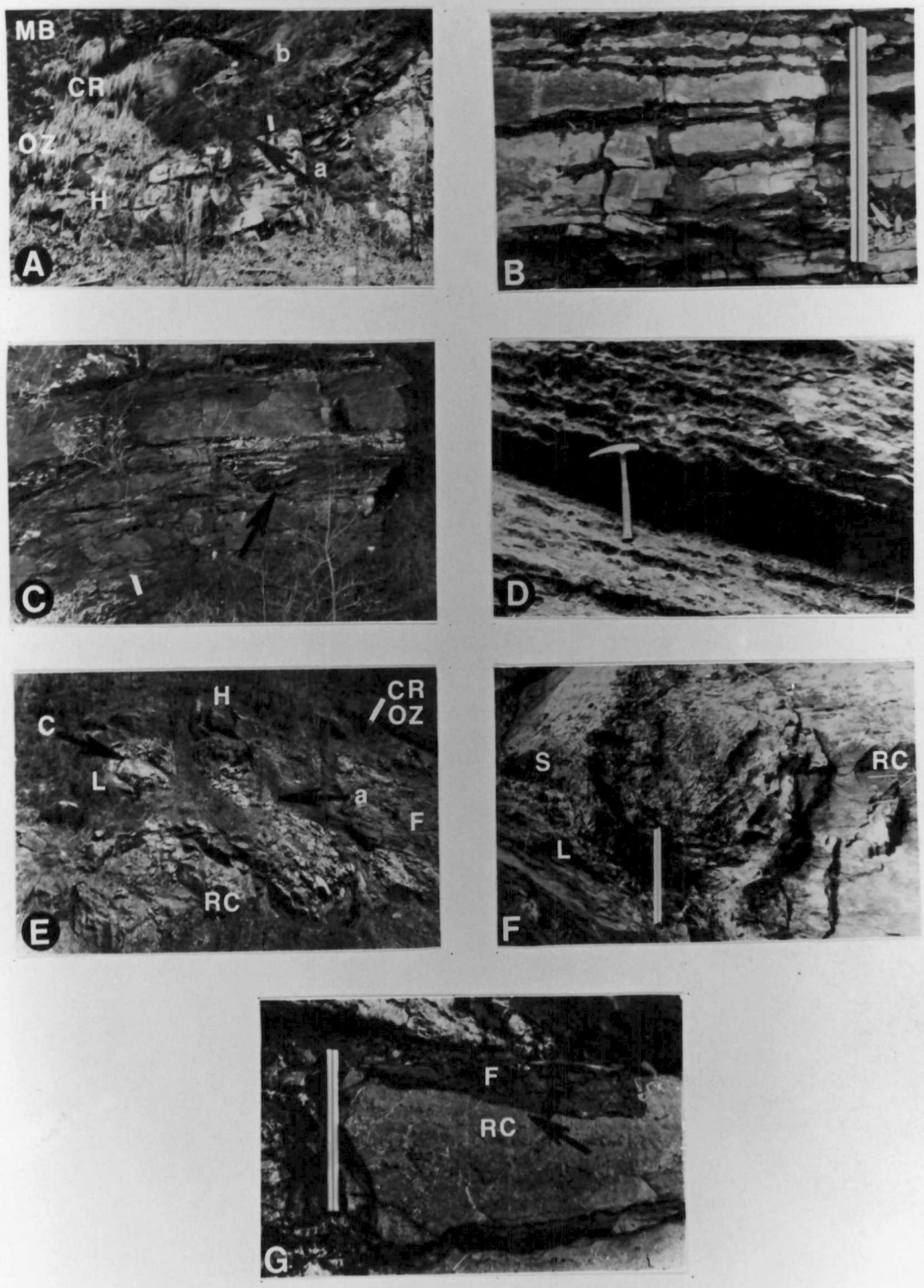


Figure 10.

interbeds become common once again near the top of the section. Planar cross-stratification (Fig. 10B is common both in the sedlitharenite and in the packstone; cross-laminae are typically either fossil- or quartz-rich. The upper contact of this unit is covered.

Conodont Biostratigraphy

Conodont yield from HB samples was generally poor in numbers but a few biostratigraphically significant taxa were recovered. The stratigraphic distribution of conodonts at Henegar Bluff is illustrated in Figure 9 and listed in Table 3 in Appendix C.

Samples from the Upper Tongue of the Lenoir Formation contained an assemblage of Panderodus sp. cf. P. gracilis (Stauffer), Panderodus sp. cf. P. panderi (Stauffer), Plectodina n. sp. of Carnes (1975), Drepanoistodus suberectus (Branson and Mehl), Plectodina sp., rare Prioniodus sp., Erismodus sp. 1 of Carnes (1975), Chirognathus sp., Paltodus? sp. of Carnes (1975), Appalachignathus delicatulus (Bergström et al.), Triangulodus sp. cf. T. brevibasis (Sergeeva) and "Oistodus" pseudoabundans (Schopf). A polyplacognathiform element assignable to the biostratigraphically-important Cahabagnathus sweeti (Bergström) apparatus was recovered from sample HB-10, 3.1 meters above the measured base of the section. The association of C. sweeti and Prioniodus sp. suggests that this lithostratigraphic unit lies within the Upper Subzone of the Pygodus anserinus Zone.

The Holston Formation contains a less diverse and abundant conodont fauna. Taxa include Plectodina n. sp., Plectodina sp., Drepanoistodus suberectus, Panderodus sp. cf. P. gracilis, Panderodus

sp. cf. P. panderi, Appalachignathus delicatulus, Paltodus sp., and Triangulodus sp. cf. T. brevibasis all of which continue into this interval from the underlying unit. Additional taxa are Belodella n. sp. A. of Bergström (1971) and Scalopodus insculptus (Branson and Mehl). C. sweeti co-occurs with C. carnesi in sample HB-14, 9.7 meters above the measured base of the section. C. carnesi was also recovered from sample HB-16, 13.6 meters above the base of the section. Bergström and Carnes (1976) and Bergström (1977b) report the presence of C. carnesi from Henegar Bluff at 10 meters (31 feet) above the base of the Holston Formation which Bergström (1977b) suggests is indicative of the Upper Subzone of the Pygodus anserinus Zone. According to Carnes (1975) and Harris (1982), in the absence of specimens of Pygodus anserinus and Amorphognathus tvaerensis, the transition from Cahabagnathus sweeti to C. carnesi can be used to approximate the P. anserinus-A. tvaerensis zonal boundary. Therefore, at Henegar Bluff, the top of the P. anserinus Zone has been tentatively placed at 9.7 meters above the base of the measured section in sample HB-14 where the last occurrence of C. sweeti was observed.

The Chapman Ridge Formation contains a sparse conodont fauna. Within the "orthocone zone," conodonts were only recovered from a carbonate-rich lithotype (HB-22) along the base of this zone at 25.6 meters above the base of the measured section. Disaggregation of samples from within this zone proved to be difficult due primarily to mineral (e.g., sulfide, phosphate and manganese?) impregnation of hardgrounds and burrows and a significant increase in the volume percent

of terrigenous clay within the rock. The conodont fauna includes representatives of Panderodus sp. cf. P. gracilis, Phragmodus sp. cf. P. inflexus (Stauffer), Plectodina sp., Drepanoistodus suberectus and Periodon sp. cf. P. grandis (Ethington). Carnes (1975) recovered Periodon grandis from the Holston Formation at Thorn Hill in the lower P. gerdae Subzone of the A. tvaerensis Zone and also from the Tumbez Formation at the Lay School section in Hogskin Valley, Grainger County, Tennessee, in a stratigraphic interval which he considered to be, in all probability, older than the base of the P. gerdae Subzone. Based on these range data, the occurrence of Periodon sp. cf. P. grandis at HB suggests that the base of the "orthocone zone" of the Chapman Ridge Formation may represent an interval in the lower A. tvaerensis Zone possibly close to the base of the Prioniodus gerdae Subzone.

Samples from the "main body" of the Chapman Ridge Formation yielded few conodonts. These recovered include representatives of Prioniodus sp., Plectodina sp., Chirognathus sp. and Protopanderodus varicostatus (Sweet and Bergström). Vicarious form elements of the multielement Prioniodus apparatus were recovered from sample HB-26 at the base of the "main body" 28.6 meters above the base of the measured section and also from ample HB-33, 31.0 meters above the base of the section. Therefore, it appears that at least the lower part of the "main body" of the Chapman Ridge Formation may possibly lie within the P. gerdae Subzone of the A. tvaerensis Zone.

Summary of the Biostratigraphic Zonation

Based on the previous discussion of the stratigraphic occurrence of conodonts at Henegar Bluff, the Pygodus anserinus-Amorphognathus tvaerensis Zonal boundary has been placed 9.7 meters above the base of the measured section, approximately 244 meters above the post-Knox unconformity, in the Holston Formation. Thus, the base of the Holston Formation at Henegar Bluff lies within the Upper Subzone of the Pygodus anserinus Zone as it does at all other sections in East Tennessee for which conodont data are available (Bergström, 1971, 1973, 1977a,b; Bergström and Carnes, 1975; and Bergström and Line, 1979).

Chronostratigraphy

Bergström (1971) and Carnes (1975) have shown that in their type sections the Ashby Stage and the succeeding Porterfield Stage of Cooper (1956) overlap in terms of the North Atlantic Conodont Zonation. According to Carnes (1975), the base of the Porterfield Stage is older than the base of the Ashby Stage, therefore, invalidating the term Ashby. At the same time, a stratigraphic interval is created in the Marmor and Porterfield Stages, corresponding to the Upper P. serra Zone through the P. variabilis Subzone of the A. tvaerensis Zone, to which none of the stages of Cooper (1956) can be assigned (Harris, 1982).

As best as can be determined, using the conodont-based chronozones of Sweet (1983) (see Fig. 8, p. 26), the stratigraphic interval investigated at Henegar Bluff lies within the Cahabagnathus sweeti (Upper Tongue of the Lenoir and Lower Holston Formations) and possibly the succeeding Plectodina aculeata (Holston and Chapman Ridge

Formations) Zones. If correct, part of the upper stage of the Whiterockian Series and the lower Blackriveran Stage of the Mohawkian Series, respectively, is represented at HB. Thus, the study interval at this section is equivalent to the upper Llandeilo and lower Caradoc within the British Standard Series (Ross et al., 1982).

L and N Railroad Section

The L and N section (LN), exposed along a railroad cut in McMinn County, is located approximately 2.1 km east-southeast of Calhoun, Tennessee, and 4 km northeast of the HB section. Smith (1976) measured and described 780 meters of Middle Ordovician sedimentary rocks at this section which is included in Walker (1977) in modified form. The present investigation focused on a 509 meter thick interval, the base of which lies within the Upper Tongue of the Lenoir Formation approximately 244 meters above the post-Knox unconformity. The rationale for this stratigraphic limitation has been previously explained. The stratigraphic distribution of lithologies and conodonts at LN is illustrated in Figure 11.

Lithostratigraphy

The lower 13.6 meters of rock studied at LN have been assigned to the Upper Tongue of the Lenoir Formation. The basal 1.1 meters consists of cobbly bedded, poorly fossiliferous, argillaceous wackestone (Fig. 10B, p. 33). Upsection this lithology becomes interbedded with thin to medium bedded, wackestone, packstone and calcareous siltstone. The wackestone and packstone contain a diverse biota of bryozoans,

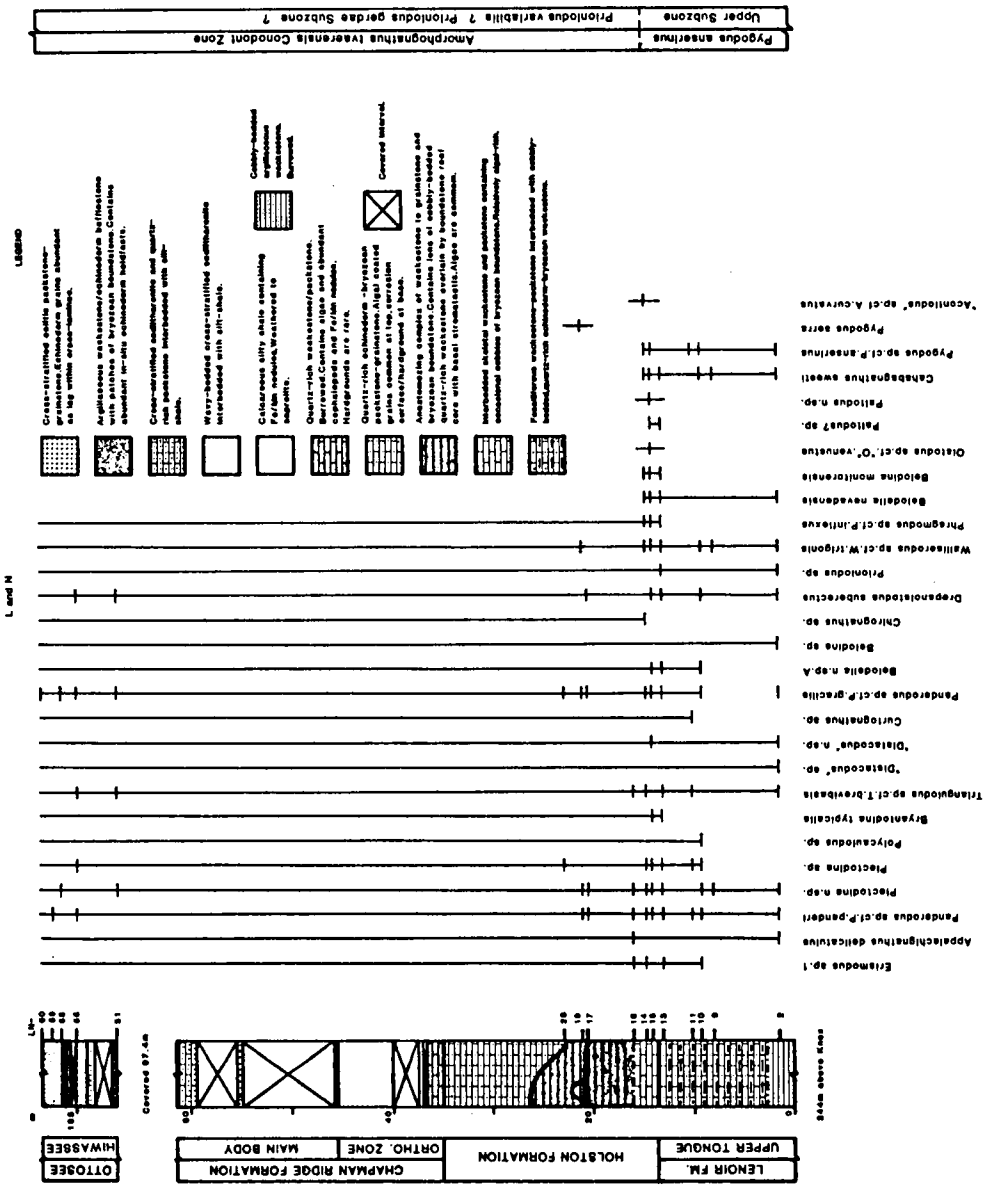


Figure 11. Stratigraphic distribution of lithologies and conodonts at L and N Railroad.

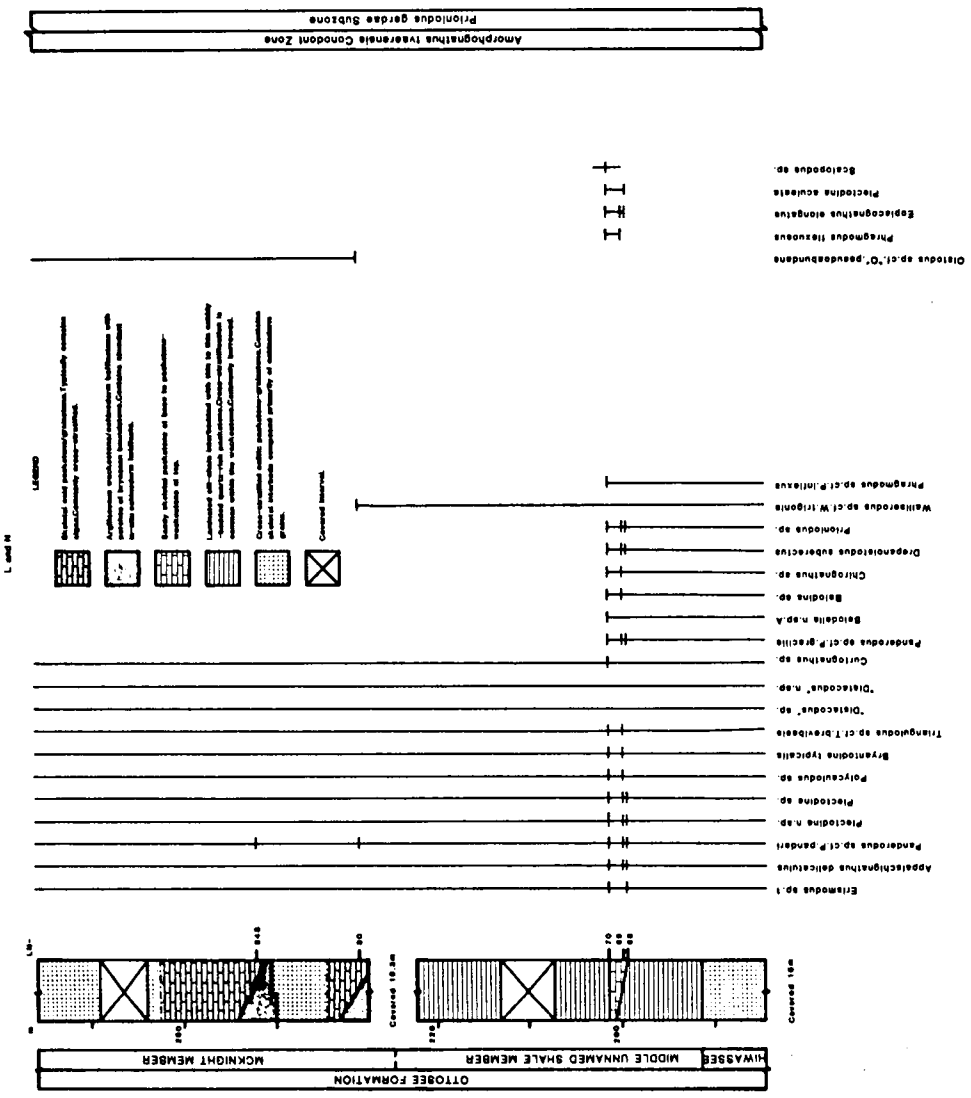


Figure 11 (continued).

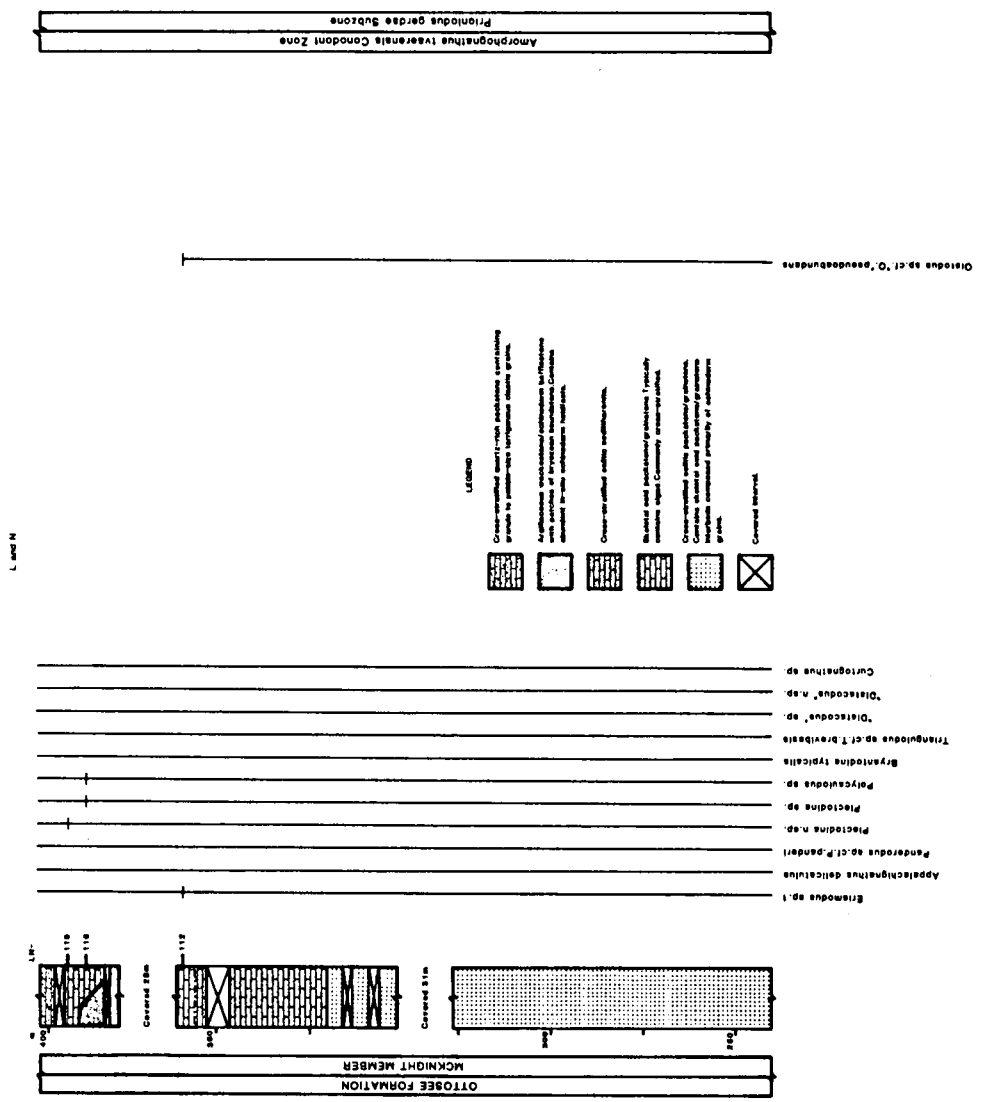


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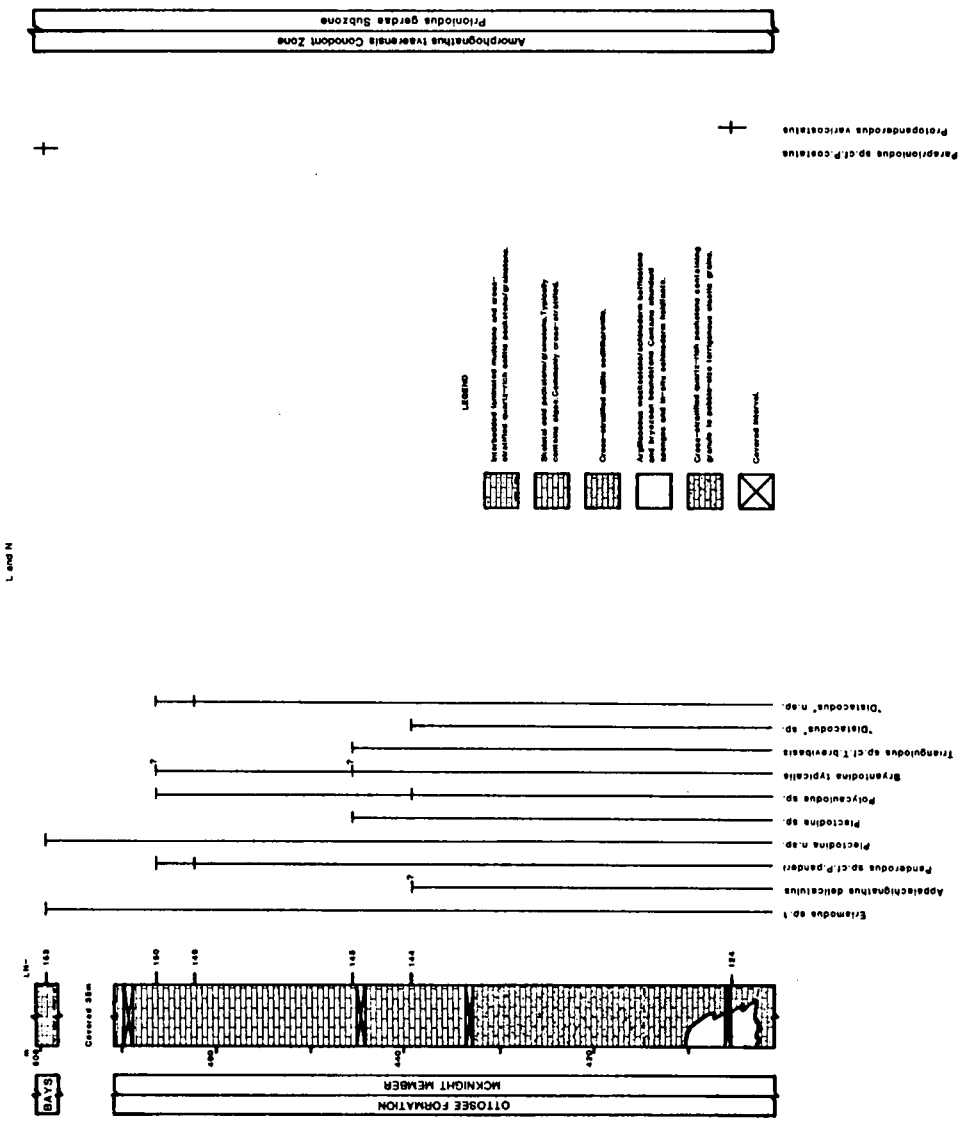


Figure 11 (continued).

echinoderms, brachiopods, trilobites, ostracodes and the algae, Girvanella, Spongiostroma, Solenopora:Type P and Hedstroemia. Silicified allochems and/or matrix also occur within wackestone and packstone. The calcareous siltstone contains ramose bryozoans along with occasional oncolites. Argillaceous interbeds decrease upsection. The upper contact between the Upper Tongue of the Lenoir and the Holston Formation is transitional through the upper 12.5 meters of this interval. The top of the Upper Tongue of the Lenoir was placed at the last occurring argillaceous wackestone interbed.

The Holston Formation at the LN section is 22.0 meters thick. Lithologically, it consists of a lower, 2.5 meter thick algal-rich echinoderm-bryozoan packstone/grainstone unit containing several boundstone cobbles, a middle 10.0 meter thick anastomizing reef complex consisting of echinoderm-bryozoan wackestone packstone, bryozoan boundstone, and stromatactis interbedded with a 1.1 meter thick lens of cobbly, quartz-rich wackestone (Figs. 10C, 10D, p. 33). Overlying the middle unit is an upper quartz-rich echinoderm-bryozoan packstone-grainstone (Fig. 10C) 12.5 meters thick, which becomes pyrite rich at the top. The contacts between units are sharp (Figs. 10C, 10E). Trilobites, brachiopods, ostracodes, echinoderms, bryozoans, Girvanella, Spongiostroma and Solenopora are common to all three units. Sponges, cephalopods, gastropods and the algae Vermiporella? and Kazahkstanelia have been observed within the reef complex. The contact between the Holston and Chapman Ridge Formations is poorly exposed (Fig. 10C), but can be delineated by the occurrence of a 0.1 meter

thick, shaley saprolite between the two formations and by an abundance of orthocone cephalopods at the base of the Chapman Ridge Formation.

The Chapman Ridge consists of a lower "orthocone zone" and an upper "main body." At the LN section, both units are very poorly exposed and in most instances have been weathered to saprolite.

The "orthocone zone" is 10.4 meter thick, carbonate rich at the base, and consists primarily of thin bedded, quartz sandy, echinoderm-bryozoan wackestone to packstone with occasional boundstone patches and coated grains. The unit becomes argillaceous at the top. The calcareous siltstone contains large single and compound ferromanganese (Fe/Mn) nodules; mineral impregnated hardgrounds are present but rare. Megafossils observed include: cephalopods, bryozoans, echinoderms, trilobites, brachiopods and the alga Receptaculites sp. The contact between the "orthocone zone" and the overlying "main body" of the Chapman Ridge Formation is sharp and represents a scour surface.

The "main body" of the Chapman Ridge Formation consists of very scattered, small outcrops exposed within 49.3 meters of interbedded sandy and shaley saprolite. The lithologies found within this unit include interbedded calcareous siltstone, quartz-rich packstone, and sedlitharenite. Beds are commonly wavy and cross-laminated with bed thickness ranging from thin to medium bedded. Brachiopods, bryozoans, echinoderms, trilobites and rare bivalves comprise the faunal assemblage. The upper contact of this unit is covered.

The Ottosee Formation overlies the Chapman Ridge Formation at the LN section. Smith (1976) subdivided the Ottosee Formation into five

members, the lowermost of which he called the Lower Unnamed Shale Member. This unit is no longer exposed at the LN section but according to Smith (1976) and Walker (19773) is 39.9 meters thick.

As originally described, the Lower Unnamed Shale Member is overlain by the Hiwassee Member. However, only the upper 30.5 meters of this member are currently exposed at the LN section. Lithologically, what remains of this unit consists of interbedded silty bryozoan-echinoderm wackestone and cross-laminated, echinoderm ooid packstone and grainstone. Patches of bryozoan boundstone occur within the wackestone which also contains abundant in situ echinoderm holdfasts. Bedding is thick to very thick in the oolitic lithologies and very thick to massive in the wackestone. The megafossil assemblage includes: echinoderms, bryozoans, brachiopods, ostracodes, trilobites and worm tubes; the alga Hedstroemia occurs in the oolite. The uppermost oolite in the Hiwassee Member of the Ottosee Formation is overlain by the mudrocks and sandstones of the Middle Unnamed Shale Member; this contact, though poorly exposed, is sharp (Fig. 12A).

Presently only the lower 30.6 meters of the Middle Unnamed Shale Member of the Ottosee Formation are exposed along the railroad cut. A 0.6 to 2.0 meter thick lens of echinoderm-bryozoan packstone lies between a lower and upper slightly cobbly weathering, laminated, very fine grained calcareous silt-shale with interbeds of quartz-rich wackestone (Fig. 12B). With the exception of a very few graptolites, fragments of ostracodes, echinoderms, brachiopods and Girvanella oncoids, this lithology is poorly fossiliferous. The wackestone/

Figure 12. Outcrop features of the Ottosee and the lower "Bays" Formations.

A. Ottosee Formation at LN. The contact between the uppermost oolitic grainstone (O) of the Hiwassee Member (HM) and the lowermost silty shale (SH) of the Middle Unnamed Shale Member (MUS) is poorly exposed. Scale = 33.5 cm.

B. The uppermost silty shale of the Middle Unnamed Shale Member of the Ottosee Formation at LN. Note the rhythmic cobbly bedding. Scale = 33.5 cm.

C. The sharp contact (shown by the arrow) between an echinoderm buildup (B) and by an overlying oolite shoal (O) in the lower part of the McKnight Member of the Ottosee Formation at LN. The buildup is composed of echinoderm wackestone/bafflestone with abundant in situ echinoderm holdfasts; the oolite shoal is composed of cross-stratified oolitic packstone/grainstone. Scale = 6 cm.

D. Herringbone cross-bedded sedlitharenite (a) overlain by quartz-rich fossiliferous ooid packstone-grainstone (b) in the McKnight Member of the Ottosee Formation at LN. Scale = 6 cm.

E. The sharp contact between the echinoderm-bryozoan reef core (C) and trough cross-bedded ooid and intraclastic-rich sedlitharenite (S) in the upper part of the McKnight Member of the Ottosee Formation at LN is shown by the arrow. Note the trough cross-beds have been truncated against the reef core. Scale = 6 cm.

F. Cross-stratified, quartz-rich packstone with granule size rock fragments and quartz grains in the upper part of the McKnight Member of the Ottosee Formation at LN. Note the sharp basal scour surface (a); the arrow at (b) points to ferruginous quartz-rich laminae within the packstone. Scale = 6 cm.

G. Shale (S) interbeds within the cross-stratified, ferruginous quartz-rich oolitic packstone/grainstone (O) of the lower "Bays" Formation at LN. Scale = 33.5 cm.

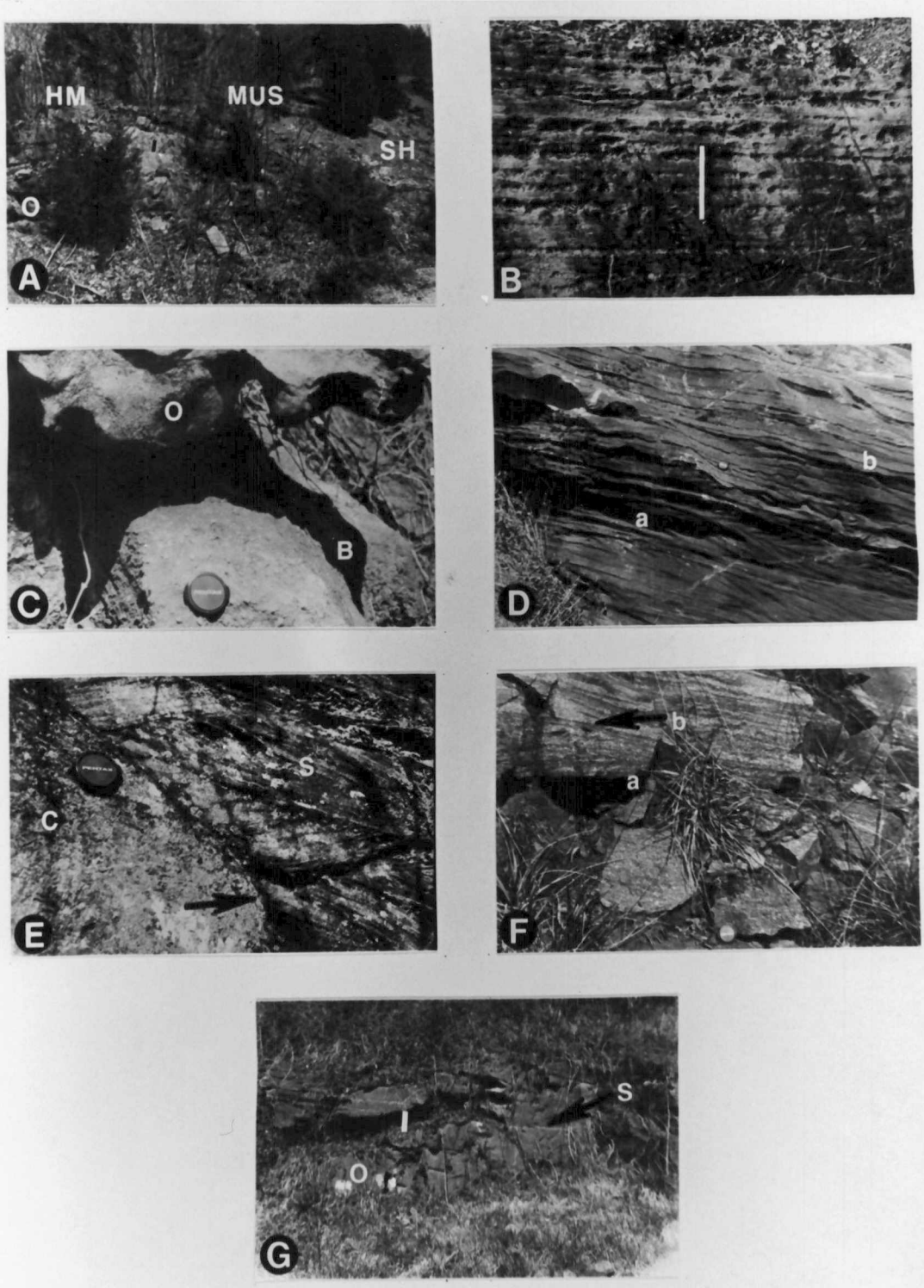


Figure 12.

packstone, on the other hand, contains a diverse biotic assemblage of bryozoans, brachiopods, echinoderms, trilobites, cephalopods, sponges, gastropods, ostracodes and Girvanella. Silicified allochems are common within this lithology. The contact between the Middle Unnamed Shale Member and the overlying McKnight Member of the Ottosee Formation is covered.

The McKnight Member is comprised of 230.6 meters of interbedded sandy, fossiliferous, oolitic packstone and grainstone (Figs. 12C, 12D, 12E), echinoderm/bryozoan wackestone (Figs. 12C, 12E), calcareous sedlitharenite (Figs. 12D, 12E), and quartz-rich packstone (Fig. 12F) containing granule and rare pebble-size clastic debris (="pebble conglomerates" of Smith, 1976, pp. 42, 56). This terrigenous clastic debris includes chert (especially a jasperoid variety); sedimentary rock fragments (quartzarenite, siltstone, shale); rare metamorphic rock fragments; and monocrystalline and polycrystalline (metamorphic and vein) quartz. Rare grains of blue quartz have also been observed within this terrigenous clastic component which was derived from a tectonic upland to the southeast during the Blountian Phase of the Taconic Orogeny (Rodgers, 1953). This tectonic upland source area included rocks of the Precambrian Ocoee Supergroup, the Cambrian Conasauga/Rome Formations, the Lower Ordovician Knox Group and the Middle Ordovician Lenoir Formation (Kellberg and Grant, 1956). Cross-stratification is common and often bidirectional (Fig. 12D). Bed thicknesses range from medium to very thick. Megafossils observed include in situ holdfasts of echinoderms, bryozoans, sponges,

brachiopods, cephalopods (rare), trilobites, ostracodes, worm tubes and the algae Solenopora Type P, Hedstroemia and Girvanella. At LN, the upper contact between the McKnight Member and the "Bays" Formation [=Calhoun Member of the Ottosee Formation of Smith (1976)] is covered.

Only 2.8 meters of the "Bays" Formation was described and sampled at LN as part of the present study. The "Bays" Formation consists of medium to thick bedded, cross laminated, quartz-rich ooid grainstone and oolitic sedlitharenite with interbedded, laminated mudstone (Fig. 12G). The fossil assemblage includes echinoderms, bryozoans, trilobites and a few cephalopods.

Conodont Biostratigraphy

The stratigraphic distribution of conodonts at LN is illustrated in Figure 11 (p. 40) and also in Table 4 in Appendix C. Generally, as is the case at Henegar Bluff, samples processed for conodonts were not overly productive. However, several biostratigraphically significant taxa have been recovered from this section.

The Upper Tongue of the Lenoir Formation contains a diverse conodont faunal assemblage consisting of elements of "Distacodus" n. sp. of Carnes (1975), Appalachignathus delicatulus (Bergström et al.), Cahabagnathus sweeti (Bergström), Prioniodus sp., "Distacodus" sp., Pygodus sp. cf. P. anserinus (Lamont and Lindström), Belodina monitorensis (Ethington and Schumacher), Drepanoistodus suberectus (Branson and Mehl), Panderodus sp. cf. P. gracilis (Stauffer), Panderodus sp. cf. P. panderi (Stauffer), Plectodina n. sp. of Carnes (1975), Belodella nevadensis (Ethington and Schumacher), Belodella n.

sp. A of Bergström (1971), Walliserodus sp. cf. W. trigonis (Schopf), Triangulodus sp. cf. T. brevivasis (Sergeeva), Erismodus sp. 1 of Carnes (1975), Curtognathus sp., Polycaulodus sp., Bryantodina typicalis (Stauffer). C. sweeti co-occurs with Prioniodus sp. and Pygodus sp. cf. P. anserinus in sample LN-2 from 1.5 meters above the base of the measured section. According to Bergström (1971), this association represents a level within the Upper Subzone of the Pygodus anserinus zone. It is concluded, therefore, that the Upper Tongue of the Lenoir Formation at the LN section lies within this subzone.

Conodont diversity decreases from the base of the Holston Formation to its top. Belodella n. sp., Belodella nevadensis, "Acontiodus" sp. cf. "A." curvatus (Mound), Triangulodus sp. cf. T. brevibasis, Walliserodus sp. cf. W. trigonis, Erismodus sp. 1 of Carnes (1975) Chirognathus sp., Plectodina n. sp. of Carnes (1975), Belodina monitorensis, Panderodus sp. cf. P. gracilis, Panderodus sp. cf. P. panderi, Bryantodina typicalis, Drepanoistodus suberectus, Appalachignathus delicatulus, Paltodus? sp., Cahabagnathus sweeti, a single pygodiform of Pygodus serra (Hadding) and two haddingodontiform elements of Pygodus sp. cf. P. anserinus comprise the Holston conodont fauna at the LN section. Only single specimens of Panderodus sp. cf. P. panderi and Plectodina sp. occur in sample LN-28 which is 22.6 meters above the base of the section. Above this interval, all samples processed for conodonts within the Holston Formation proved to be barren. C. sweeti has been recovered from the Holston Formation and occurs stratigraphically lower (LN-13 at 13.0 meters, LN-15 at

14.0 meters, and LN-14 at 14.6 meters above the base of the section) than the single occurrence of Pygodus serra in sample LN-19 at 20.9 meters above the base of the section.

Single haddingodontiform elements have been recovered from samples LN-15 at 14.0 meters and LN-14 at 14.6 meters above the base of the LN section. Based on the angle between the anterior and posterior processes, which approximate the 80° to 90° angle typical of the haddingodontiform elements from Pygodus anserinus as stated by Bergström (1971), these haddingodontiform elements have been assigned to Pygodus sp. cf. P. anserinus.

The occurrence of Pygodus serra stratigraphically above elements of Prioniodus sp., Cahabagnathus sweeti and Pygodus sp. cf. P. anserinus all of which are characteristic of the Upper Subzone of the Pygodus anserinus Zone is anomalous. P. serra typically co-occurs with Cahabagnathus friendsvillensis in the upper part of the P. serra Conodont Zone (Bergström, 1972). Bergström (1972) also states that specimens of Pygodus serra occur within the Pygodus anserinus Zone and suggests that these anomalous occurrences may either represent (1) fragments of the anterior part of the pygodiform of P. Anserinus, (2) juvenile specimens of Pygodus anserinus, (3) an extreme type of Pygodus anserinus, or (4) survivors of the Pygodus serra stock. Fåhraeus (1982), based on a study in Newfoundland, states that during the Pygodus serra to Pygodus anserinus transition, which probably represented allopatric speciation, the ancestral species (Pygodus serra) survived for an unknown length of time. An additional

explanation for this anomalous P. serra occurrence is that the specimen could be reworked. Based on the nature of this study, additional detailed sampling of the Holston Formation would be necessary in order to adequately explain this occurrence of P. serra.

Conodont data suggest that the lower meter of the Holston Formation at L and N lies within the Upper Subzone of the Pygodus anserinus Zone. The remaining 21 meters of this formation can be no older than the Upper Subzone of the Pygodus anserinus Zone. However, based on conodont data from the Holston Formation at Henegar Bluff and at other sections within the Knoxville-Athens Belt (Bergström, 1971, 1973, 1977a,b; Bergström and Carnes, 1976; Bergström and Line, 1979), it is probable that the Pygodus anserinus-Amorphognathus tvaerensis Zonal boundary lies within the Holston Formation at L and N.

Conodonts were not recovered from the single "orthocone zone" sample from the Chapman Ridge Formation processed for these microfossils. Samples from the "main body" of the Chapman Ridge Formation could not be processed sufficiently for microfossils due to their ferruginous nature which produced large insoluble residues inseparable by heavy liquid. It is apparent, however, that the Chapman Ridge Formation at the LN section lies stratigraphically within the A. tvaerensis Zone. Unpublished data from a separate study of the Sky Ranch section in South Knox County (McLaughlin and Asreen, 1983) suggests that the top of the Chapman Ridge Formation is no younger than the lower part of the P. gerdae Subzone as P. gerdae was recovered 50 meters above the base of the Ottosee Formation there. Bergström

(1971, 1977a) and Bergström and Carnes (1976), as previously stated, have determined that the base of the Chapman Ridge Formation at the Alcoa Highway section lies within the Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Zone. Therefore, in the Knoxville area, the Chapman Ridge Formation was deposited within the lower part of the P. gerdae Subzone of the A. tvaerensis Zone. Barring diachroneity, the Chapman Ridge Formation probably represents part of the Prioniodus gerdae Subzone at the LN section also but in the absence of conodont confirmation this remains a possibility only.

Conodonts recovered from the Hiwassee Member of the Ottosee Formation include elements of the multielement taxa Plectodina n. sp. of Carnes (1975), Plectodina sp., Panderodus sp. cf. P. gracilis, Panderodus sp. cf. P. panderi, Triangulodus sp. cf. T. brevibasis, and Drepanoistodus suberectus. This member probably lies within the A. tvaerensis Zone but assignment of the Hiwassee Member to a particular conodont subzone within the A. tvaerensis Zone cannot be made because the recovered fauna lacks biostratigraphically definitive taxa.

Abundant specimens of Phragmodus flexuosus (Moskalenko), Plectodina n. sp. of Carnes (1975) Panderodus sp. cf. P. panderi, Panderodus sp. cf. P. gracilis, Erismodus sp. 1 of Carnes (1975) Scalopodus sp., Drepanoistodus suberectus along with Plectodina aculeata (Stauffer), Triangulodus sp. cf. T. brevibasis, Appalachignathus delicatulus, Phragmodus sp. cf. P. inflexus (Stauffer), Eoplacognathus elongatus (Bergström), Prioniodus sp., Belodina sp.,

Chirognathus sp., Paltodus sp., Polycalodus sp., Bryantodina typicalis and Curtognathus sp. were recovered from the wackestone to packstone of the Middle Unnamed Shale Member of the Ottosee Formation. Based on the co-occurrence of Prioniodus sp. and Eoplacognathus elongatus, this shale member has been assigned to the lower part of the A. tvaerensis Zone. According to Bergström (1971), the stratigraphic range of E. elongatus is limited to a narrow interval between the Upper Subzone of the Pygodus anserinus Zone and the lower part of the Prioniodus gerdae Subzone of the A. tvaerensis Zone. Therefore, this member can be no younger than the lowermost Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Zone.

Samples from the McKnight Member of the Ottosee Formation yielded few conodonts. The conodont fauna consists of Panderodus sp. cf. P. panderi, Panderodus sp. cf. P. gracilis, Drepanoistodus suberectus, Oistodus sp. cf. "O". pseudoabundans (Stauffer), Erismodus sp. 1 of Carnes (1975), Plectodina n. sp. of Carnes (1975), Polycaulodus sp., Curtognathus sp., Triangulodus sp. cf. T. brevibasis, "Distacodus" n. sp. of Carnes (1975), Distacodus sp., Protopanderodus varicostatus (Sweet and Bergström), Phragmodus flexuosus and Appalachignathus delicatulus. Based upon the presence of P. varicostatus in sample LN-124, 405.3 meters above the base of the measured LN section, the base of the McKnight Member apparently lies within the lower part of the A. tvaerensis Zone. According to Bergström (1971), Protopanderodus varicostatus ranges into the lower part of the P. gerdae Subzone of the A. tvaerensis Zone before evolving into Protopanderodus sp. cf.

P. insculptus (Branson and Mehl). On this basis, therefore, the lower McKnight Member of the Ottosee Formation can be no younger than the lower part of the P. gerdae Subzone of the A. tvaerensis Zone.

Only one sample from the "Bays" Formation, LN-153 located 507.4 meters above the base of the measured section, produced conodonts. Elements of Plectodina sp., Erismodus sp. 1 of Carnes (1975) and Paraprioniodus sp. cf. P. costatus (Ethington and Clark) were recovered from this sample. J. Repetski and A. G. Harris (personal communication, 1983) suggested that this specimen of Paraprioniodus sp. cf. P. costatus closely resembles Paraprioniodus costatus which has been reported by Ethington and Clark (1981) from Middle Ordovician strata in the southwestern United States and northwest Canada ranging from Whiterockian (Pygodus serra Zone) to upper Chazyan (Pygodus anserinus Zone) in age.

Although the "Bays" Formation lacks biostratigraphically significant conodont taxa at present, it is no older than the lower part of the Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Zone.

Summary of the Biostratigraphic Zonation

The stratigraphic distribution of conodonts in the LN section suggests that the Pygodus anserinus-Amorphognathus tvaerensis zonal boundary lies within the Holston Formation at least 14.6 meters above the base of the measured section, at least 259.0 meters above the post-Knox unconformity. Thus, at both L and N and Henegar Bluff, and all other sections in East Tennessee for which conodont data are

available, the base of the Holston Formation apparently lies within the Upper Subzone of the Pygodus anserinus Zone confirming earlier workers' conclusions (Bergström, 1971, 1973, 1977a,b; Bergström and Carnes, 1976, and Bergström and Line, 1979) regarding the conodont biostratigraphy of this unit.

Chronostratigraphy

As previously discussed, there are problems inherent in the application of the Stage names of Cooper (1956) to strata within the southern Appalachians which correspond to the interval extending from the Upper Pygodus anserinus Zone through the Prioniodus variabilis Subzone of the Amorphognathus tvaerensis Zone. The stratigraphic interval investigated at the LN section ranges from a level within the Cahabagnathus sweeti chronozone of Sweet (1983) in the Upper Tongue of th Lenoir Formation to a level within the Plectodina aculeata chronozone in the "Bays" Formation. This interval represents the uppermost part of the Upper Stage of the Whiterockian Series and the lower Blackriveran Stage of the Mohawkian Series. Accordingly, the interval is equivalent to part of the upper Llandeilo and lower Caradoc in the British Standard Series (Ross et al., 1982).

Summary of the Biostratigraphy and Chronostratigraphy of the Upper Lenoir through Lower "Bays" Formation within the Calhoun Study Area

1. Biostratigraphically significant conodont elements have been collected from the Upper Tongue of the Lenoir Formation and include representatives of Prioniodus sp., Cahabagnathus sweeti (typical) and

Pygodus sp. cf. P. anserinus. These taxa co-occur within the Upper Subzone of the Pygodus anserinus Conodont Zone.

2. Based on the co-occurrence of Cahabagnathus sweeti and Cahabagnathus carnesi in samples collected from the Henegar Bluff section, the Pygodus anserinus-Amorphognathus tvaerensis zonal boundary has been placed in the lower Holston Formation 9.7 meters above the base of the measured section and approximately 244 meters above the post-Knox unconformity. Only Cahabagnathus sweeti and elements assignable to Pygodus sp. cf. P. anserinus have been recovered from the lower part of the Holston Formation at the Louisville and Nashville railroad section. Therefore, the basal Holston Formation at the LN section can be no younger than the Upper Subzone of the Pygodus anserinus Zone.

3. The biostratigraphically significant assemblage recovered from Chapman Ridge samples includes Periodon sp. cf. P. grandis from the "orthocone zone" and Prioniodus sp. and Protopanderodus varicostatus from the "main body." These taxa co-occur in the lower Amorphognathus tvaerensis Zone specifically near the base of the Prioniodus gerdae subzone.

4. The Hiwassee Member of the Ottosee Formation did not produce any biostratigraphy significant conodont taxa. On the other hand, specimens of Eoplacognathus elongatus and Prioniodus sp. have been recovered from the Middle Unnamed Shale Member of the Ottosee Formation and a specimen of Protopanderodus varicostatus has been recovered from the McKnight Member. These taxa represent a level in the Amorphognathus tvaerensis Zone near the base of the Prioniodus gerdae Subzone.

5. The lower "Bays" Formation failed to produce any biostratigraphically significant conodonts during this study.

6. The sedimentary succession between the Upper Tongue of the Lenoir and the lower "Bays" Formations represents the Cahabagnathus sweeti through Plectodina aculeata conodont chronozones of Sweet (1983) which are correlative to the Upper Stage of the Whiterockian Series and the lower part of the Blackriveran Stage of the Mohawk Series.

CHAPTER III

THE PETROLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE UPPER LENOIR THROUGH LOWER "BAYS" FORMATIONS NEAR CALHOUN, TENNESSEE

Introduction

The scenario of Walker and Alberstadt (1973), which has since been revised by Walker (1977a, 1980a), proposed a three-part facies pattern for the Middle Ordovician of East Tennessee. This scenario has been based on numerous detailed petrologic, paleoenvironmental and paleoecological investigations conducted primarily by workers from The University of Tennessee, Knoxville, over the last two decades. Most of these investigations have been carried out in Middle Ordovician rocks exposed north of Friendsville, Tennessee (see Fig. 13). Apart from the present study, only a few investigations have dealt with Middle Ordovician rocks south of this point.

Kashfi (1971) conducted a stratigraphic and structural investigation of Middle Ordovician rocks near Mount Vernon, Tennessee, while a similar investigation of the rocks near Calhoun, Tennessee, was conducted by Smith (1976). Le Roux (1974) and Blythe (1974) studied the petrology and depositional environments of the Chota-Sevier Formations near Pumpkin Center, Tennessee, and the Chickamauga Group in the Sequatchie Valley of East Tennessee, respectively.

Ghazizadeh (in preparation, 1985) is currently analyzing the stratigraphy, petrology, and depositional environments of the

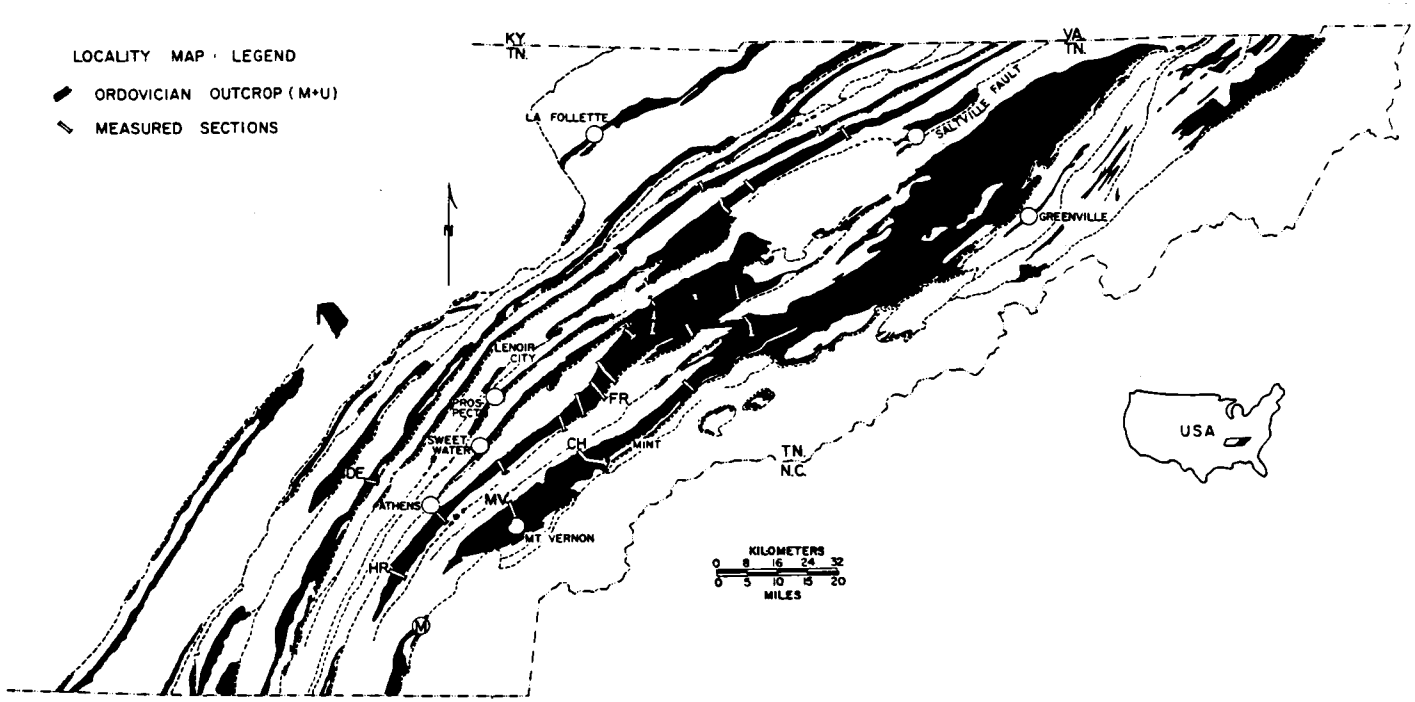


Figure 13. Outcrop of Ordovician rocks in East Tennessee. (Modified from Walker et al., 1983.) FR = Friendsville; MV = Mount Vernon; HR = Hiwassee River (Calhoun area); DE = Decatur.

Chickamaunga group in sections near Decatur, Tennessee, located in the next strike belt to the west-northwest of the Calhoun area. Thus far, biostratigraphically significant conodonts have not been recovered above the base of the measured sections within the Decatur area where gothodontiforms of Phragmodus sp. A of Harris (1982) have been found. Therefore, the base of these sections is no younger than the Pygodus serra Conodont Zone.

The petrology and depositional environments of the Middle Ordovician Upper Lenoir through lower "Bays" Formations in the Knoxville-Athens Belt within the Calhoun area, the primary concern of the present study, are described in this chapter. The details of the stratigraphy of these rocks have been discussed in Chapter II. Figure 14 illustrates the lateral relationships observed in these and associated units.

Methods of Study

Eighty-four acetate peels and eighty-four thin sections have been prepared from the approximately 220 oriented samples collected in the field from the two sections studied. Thirty-two thin sections, representative of most of the lithologies observed in the study area, have been point-counted to determine the percentage by volume of the constituent particles within these samples (see Appendix B). Field and lab data thus compiled have provided the basis for recognizing the eight lithostratigraphic units and the subfacies within them which are exposed in the study area above the Athens Formation. These units are described in the following section.

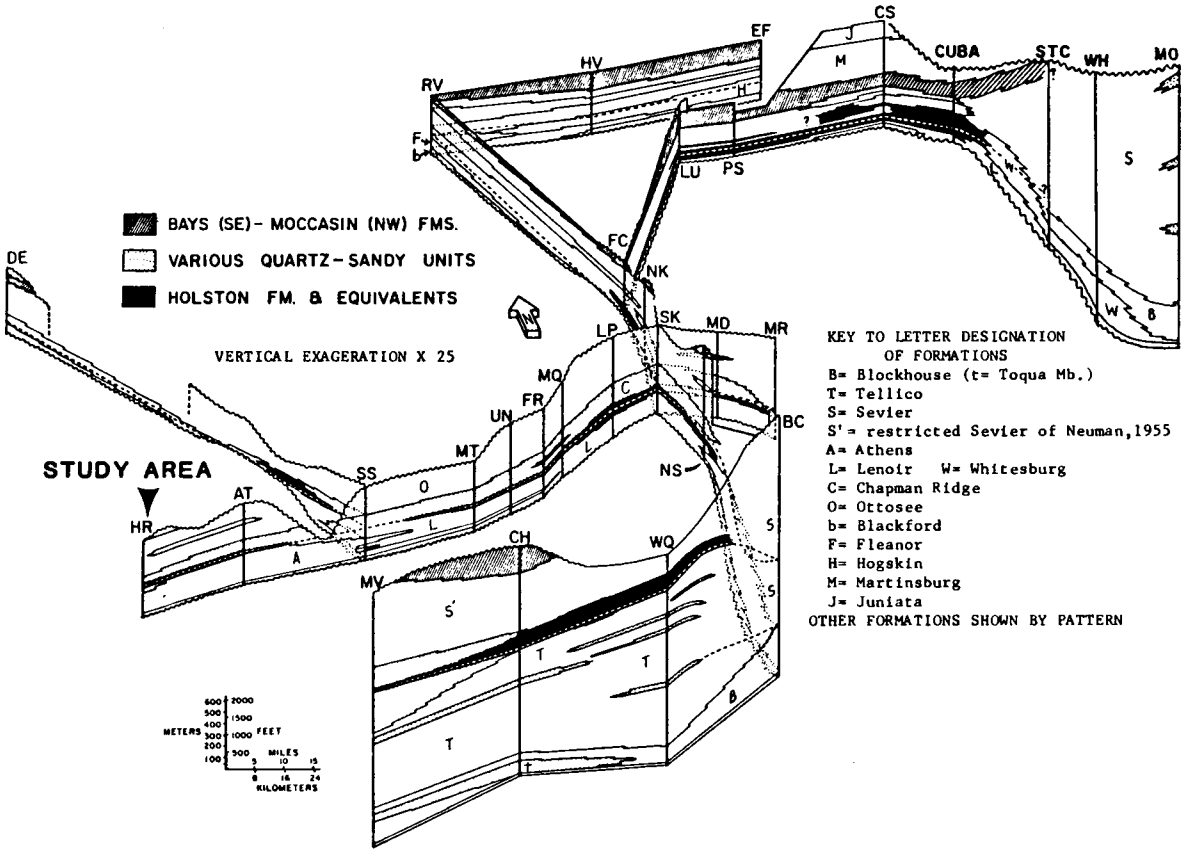


Figure 14. Lateral relationships of Middle Ordovician rocks in East Tennessee. (From Walker et al., 1983.)

Petrology and Depositional Environments

Lenoir Formation: Upper Tongue

The Upper Tongue of the Lenoir Formation is exposed at both HB and LN sections in the Calhoun area. Two lithofacies have been recognized within this unit and are illustrated in Figure 15.

Lithofacies 1 consists of blue-gray, cobbly bedded, quartz-rich wackestone (see Fig. 16A). Cobbles of wackestone have an average diameter of 3 cm, and commonly exhibit burrow mottling. The cobbles are bounded by laminae of subangular to subrounded, very fine sand to coarse grained silt-sized quartz and minor amounts of feldspar (Fig. 16B) which make up an estimated 30% of this rock-type by volume. Detrital clay is also present as laminae in approximately 15% of this rock by volume and is usually associated with numerous microstylolites. Laminae are planar to wavy and usually parallel where they have not been disrupted by vertical horizontal burrows. Small-scale ripple cross-laminae, which have been overlain by laminated silty clay, were also observed in this lithofacies. The biota of this lithofacies consists of sponge spicules, trilobites (e.g., Lonchodomas which has been found only at the LN section), rare echinoderm and bryozoan debris, rare pelloidal-size (<0.1 mm) fragments of the alga Girvanella and ostracode valves, which are rarely articulated. Micritic pelloids, which are probably of fecal origin, constitute 4% of the wackestone by estimated volume. Lithofacies 1 is overlain by lithofacies 2 and the contact between them is gradational.

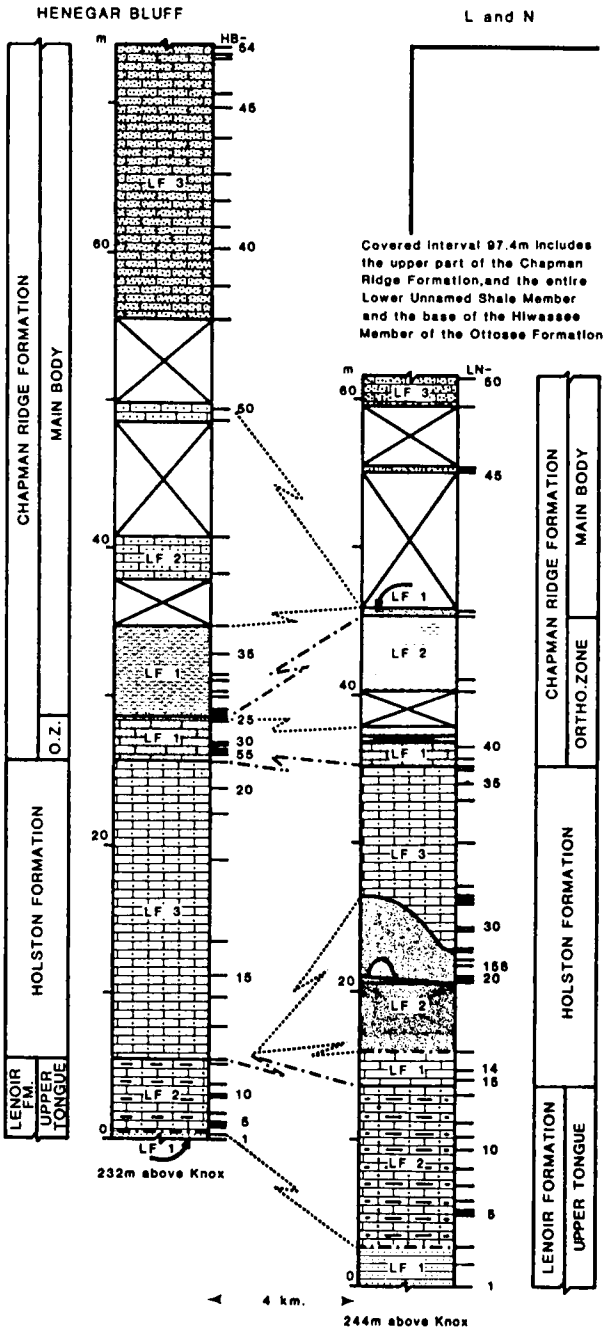


Figure 15. Lithofacies distribution at Henegar Bluff and LN. Note that the sections are hung from the top of Holston Formation.

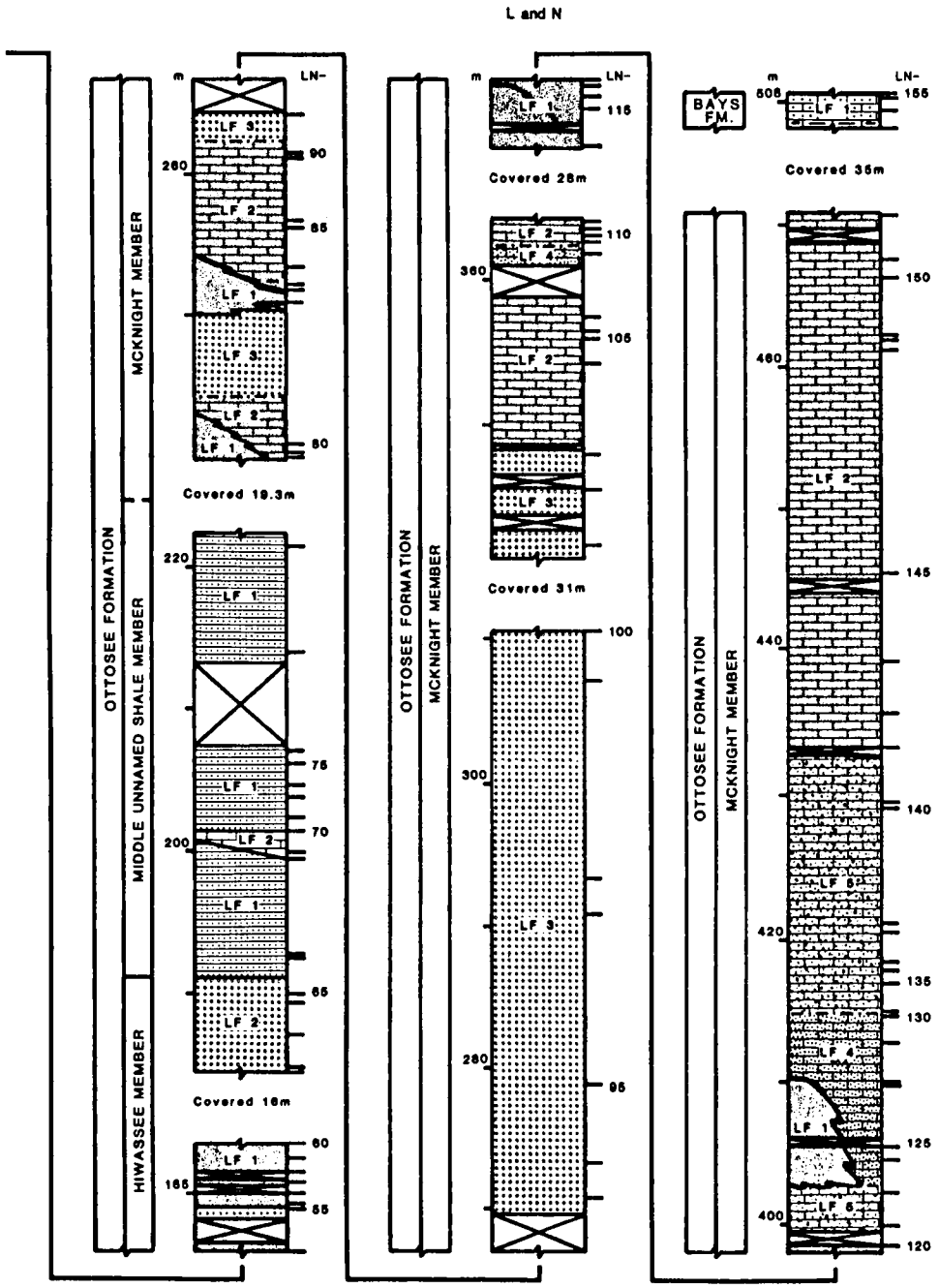


Figure 15 (continued).

Figure 16. Petrographic features of the Upper Tongue of the Lenoir Formation.

A. Sample HB-1. Laminated quartz-rich wackestone of lithofacies 1. Thin-section negative print. Bar scale = 1 cm.

B. Sample HB-1. A close up of the laminated quartz-rich wackestone lithotype. Note the graded laminae. Crossed polars. Bar scale = 1 mm.

C. Sample LN-13. Quartz-rich, echinoderm-bryozoan wackestone to packstone of lithofacies 2. Thin-section negative print. Bar scale = 1 cm.

D. Sample HB-5. A close-up of the sedlitharenite lithotype in lithofacies 2. Crossed polars. Bar scale = 1 mm.

E. Sample LN-2. A close up of a spine from the trilobite Lonchodomas (L) and a clump of the alga, Girvanella (G) in lithofacies 2. Crossed polars. Bar scale = 1 mm.

F. Sample HB-4. The dasyclad alga, Kazahkstanelia (K) and the blue-green alga, Girvanella (G) in lithofacies 2. Plane light. Bar scale = 0.5 mm.

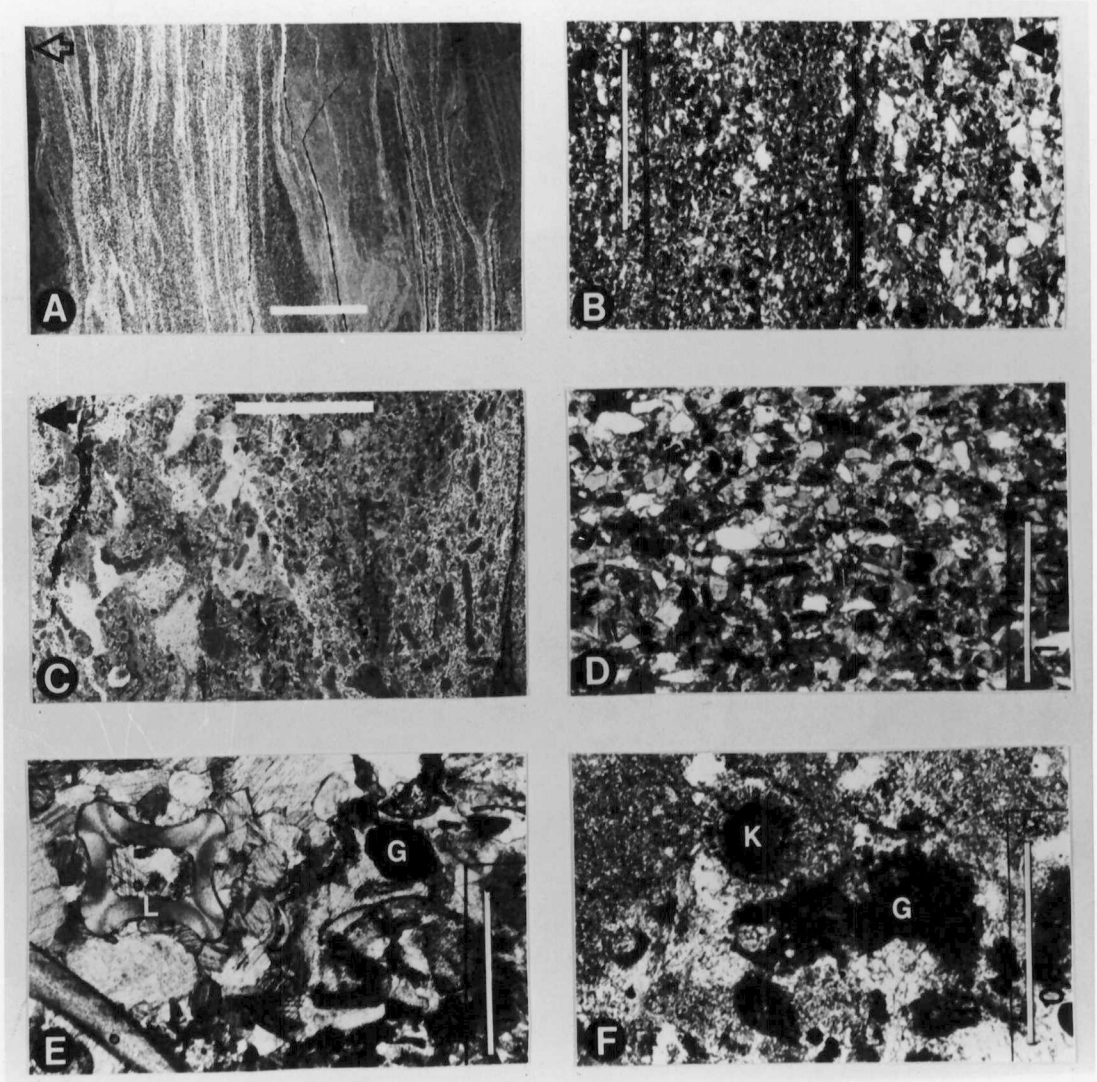


Figure 16.

Skeletal wackestone and packstone interbedded with either cobbly bedded, quartz-rich echinoderm-bryozoan wackestone (Fig. 16C) at LN or laminated, quartz-rich wackestone at HB constitutes lithofacies 2. At HB, medium, wavy bedded, sedlitharenite comprised of fine to very fine sand-sized detrital grains and abraded skeletal debris (Fig. 16D) also occurs as interbeds within this sequence. Quartz-rich wackestone interbeds decrease in frequency and thickness up-section as the skeletal wackestone and packstone beds become very thick to massive towards the top of the unit. The fauna includes ramose bryozoans, brachiopods, echinoderms, ostracodes, sponge spicules, mollusc debris (rare) and trilobites (e.g., Lonchodomas; see Fig. 16E). Most allochems exhibit well-developed micrite envelopes. Algae commonly occur throughout this lithofacies and can constitute up to 15.5% of the rock volume as in sample LN-4 (Fig. 16F). Kazahkstanelia, Hedstroemia, Spongiostroma?, Solenopora:Type P (rare) and Girvanella, observed both as an encrustation on bryozoans and as clumps of tubules, comprise the flora. Girvanella- and Spongiostroma?-encrusted oncolites with nuclei of ramose bryozoans, occur primarily in the quartz-rich, bryozoan wackestone interbeds at LN. These interbeds also contain approximately 10% pelloids by volume and exhibit a slight coarsening-upwards of skeletal grain sizes. Silicified pods of echinoderm packstone, which are bounded by stylolites, have been observed within this lithofacies in the field. Echinoderm grains especially within the packstones of this lithofacies commonly exhibit syntaxial overgrowths of spar while the brachiopods and bryozoans within these packstones typically have

served as the substrate for radiaxial fibrous sparry calcite cement. Zoned, euhedral dolomite rhombs (<0.2 mm) are commonly associated with clay-rich laminae within this lithofacies.

Both lithofacies 1, the cobbly bedded, quartz-rich wackestone, and lithofacies 2, the interbedded skeletal wackestones, packstones and cobbly bedded or laminated, quartz-rich skeletal wackestone are interpreted as representing deposition in a subtidal back-reef lagoon environment. The presence of abundant carbonate and terrigenous clastic mud, a somewhat restricted fauna, well-preserved laminae and the rare occurrence of algae suggest that deposition of lithofacies 1 occurred under quiet water, low energy, deep subtidal (10-20 meters) bottom conditions similar to those proposed for the off-shore lagoon center by Stephenson (1973), Stephenson, Walker and Moore (1973), and Walker (1974b). As indicated by both the sparse flora and fauna and the presence of detrital clay, the water was probably slightly turbid. The small-scale ripple cross-laminae in lithofacies 1 were produced by periodic pulses of higher energy. Within flow depths of approximately 2 meters above the sediment-water interface, current velocities of 30 to 65 cm/sec, as determined by flume studies, produce ripple cross-laminae in very fine sand to coarse silt-sized sediment (Harms et al., 1975). The cobbly bedding which characterizes this lithofacies, resembles the "sedimentary boudinage" described by Wilson (1975, 1978) which he found to be associated with rocks deposited below wave base in shallow water environments and presumed to be the result of differential compaction of clay and lime mudstone. Wanless (1979) suggests

that cobbly bedding can be produced in clayey limestone by nonsutured seam solution in response to stress.

Lithofacies 2, on the other hand, contains abundant algae, a diverse and abundant fauna, abraded and fragmented allochems and rare oncolites. This lithofacies consists primarily of wackestone and packstone and is interpreted as representing deposition in a shallow subtidal, back-reef lagoon subenvironment in close proximity to the skeletal sand banks of the Holston Formation. Deposition occurred under normal marine conditions within the euphotic zone as suggested by the abundance and diversity of the flora and fauna found within this lithofacies. The trilobite Lonchodomas, which in Middle Ordovician rocks in northeast Tennessee is characteristic of deeper subtidal shelf, upper slope and basinal environments with inferred water depths ranging from 40 to 100+ meters (Maitland, 1979; Walker and Benedict, 1980), occurs with algae (Fig. 16E) and/or oncolites in three samples from lithofacies 2 implying either the transportation of algae/ oncolites into deeper water or transport of the abraded spines of Lonchodomas into shallower water. Oncolites, though rare, suggest by analogy with modern environments, maximum water depths of less than 10 meters (Logan et al., 1964). An increase in wave/current activity would be responsible for the formation of oncolites, the removal of mud and the increase in grain-supported fabrics, and also the abrasion and fragmentation of the allochems near the top of the lithofacies. The presence of very fine-grained interbeds of sedlitharenite within this lithofacies at the HB section is indicative of periodic influxes of

terrigenous clastics into this environment due perhaps to the proximity of HB to a terrigenous clastic source area, paleobathymetric differences between HB and LN which could lead to clastic sediment by-passing the LN section or rare storm events. The occurrence of Holston-like grain supported lithologies interbedded with the cobbly bedded, quartz-rich wackestones of the Upper Tongue of the Lenoir Formation in the Knoxville area has been attributed to the activity of storms by Moore (1977) and indicates that these environments were, at least in part, contemporaneous.

Holston Formation

The Holston Formation crops out at both HB and LN. The following three lithofacies have been recognized within the Holston in the Calhoun area. Lithofacies 1, pink-tan interbedded skeletal wackestone and packstone containing occasional "cobbles" of bryozoan boundstone; lithofacies 2, an anastomozing complex of tan-pink skeletal wackestone, packstone, grainstone and red bryozoan boundstone which contains a 1.1 meter thick lense of gray, cobbly bedded, quartz-rich wackestone; and lithofacies 3, blue-gray to pink, quartz-rich skeletal packstone/grainstone. These lithofacies are illustrated in Fig. 15 (p. 65).

All three lithofacies occur at LN while only lithofacies 3 can be recognized at HB. A hummocky stylolite marks the sharp contact between lithofacies 1 and 2 while the contact between lithofacies 2 and 3 if a sharp, irregular, ferromanganese-stained surface. Biotic constituents common to all three lithofacies include ramose and encrusting bryozoans, echinoderms, brachiopods, trilobites, ostracodes, Girvanella and

Hedstroemia. Spongiostroma?, Kazahkstanelia and Solenopora (Fig. 17A) occur only in lithofacies 1 and 2; Vermiporella? occurs only in lithofacies 2. Cephalopods, although rare, occur in both lithofacies 2 and 3.

Compositionally, the skeletal wackestones of lithofacies 1 and 2 are nearly identical. This lithology (Fig. 17B) contains abundant micrite (39.3% by volume). Ramose bryozoans (24.8%) and echinoderms (9.5%) dominate the skeletal component of this rock-type. Algae constitute only 0.5% of the rock by volume and are dominated by Kazahkstanelia and Girvanella. Girvanella-encrusted oncolites are present but rare within these wackestones. The abundance of mud, ramose bryozoans and echinoderms, as well as the presence of well-preserved algae coupled with the lack of abraded skeletal debris, suggest that this lithology represents a shallow, subtidal organic baffle or thicket. The ramose bryozoans and echinoderms, which comprised this baffle/thicket, could effectively baffle currents because of their upright growth forms and thus trap mud in the lee of the thicket in a manner analogous to that proposed by Wilson (1975) for the formation of the Waulsortian mounds of the Lower Carboniferous in Europe and North America. Algae, although absent from typical Waulsortian mounds (Wilson, 1975), are present within the wackestone/bafflestone of the Holston Formation where they may have contributed mud to the wackestone baffle/thicket in the following two ways: first, the Holston algae could produce lime mud by the disintegration of their skeletons upon death as the Recent algae in South Florida do today

Figure 17. Petrographic features of lithofacies 1 and 2 of the Holston Formation.

A. Sample LN-14. The red alga, Solenopora: Type P in lithofacies 1. Crossed polars. Bar scale = 1 mm.

B. Sample LN-15. Ramose bryozoan wackestone/bafflestone from lithofacies 1. Thin-section negative print. Bar scale = 1 cm.

C. Sample LN-27. Bryozoan echinoderm wackestone to packstone from lithofacies 2. Thin-section negative print. Bar scale = 1 cm.

D. Sample LN-21. Bryozoan wackestone/boundstone of lithofacies 2. Thin-section negative print. Bar scale = 1 cm.

E. Sample LN-158. Algal-rich wacke-packstone to bryozoan boundstone. Note the cavity (C) filled with laminated mud at base of sample. Thin-section negative print. Bar scale = 1 cm.

F. Sample LN-21. A clump of Girvanella (G) which also occurs as an encrustation on bryozoans in this wackestone/boundstone from lithofacies 2. Plane light. Bar scale = 0.5 mm.

G. Sample LN-158. The dasyclad alga, Kazahkstanelia (K) from the Holston reef core/flank complex of lithofacies 2. Plane light. Bar scale = 1 mm.

H. Sample LN-18. Stromatactis structure from the base of a bryozoan wackestone/boundstone reef core in lithofacies 2. Thin-section negative print. Bar scale = 1 cm.

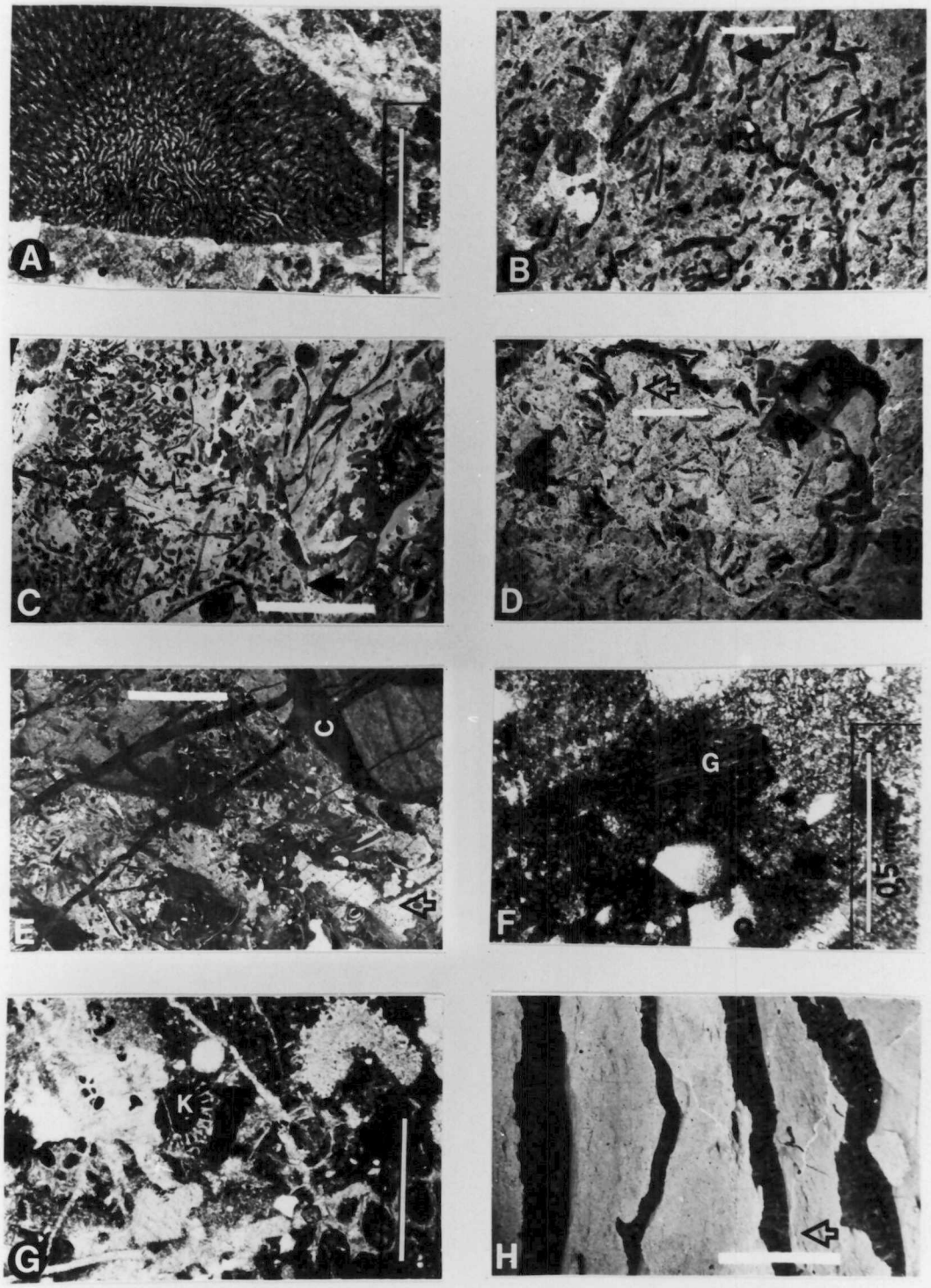


Figure 17.

(Stockman, Ginsburg and Shinn, 1967); and second, the upright growth forms of some Holston algae (e.g., Kazahkstanelia) may have enabled them to baffle currents along with the echinoderms and ramose bryozoans. Walker and Ferrigno (1973) state that echinoderm-bryozoan thickets were associated with the reef flank deposits of the Holston Formation.

The echinoderm-bryozoan packstones (Fig. 17A) of lithofacies 1 and 2 (Fig. 17C) are moderately to poorly sorted. Bryozoans, which comprise 27.7 to 44.8% of the rock volume, are commonly abraded. Echinoderm grains usually exhibit syntaxial overgrowths of sparry calcite and constitute 7.0 to 9.3% of the rock volume. Echinoderm grains occasionally exhibit multiple overgrowths of sparry calcite. Micrite envelopes are well developed on many of the skeletal grains. The presence of moderate to poorly sorted, rounded and abraded allochems within these packstones suggests that current activity was moderate to high. The presence of algae also suggests that deposition occurred within the euphotic zone. Therefore, the echinoderm-bryozoan packstones of lithofacies 1 and 2 are interpreted as representing deposition in a shallow, subtidal, skeletal sand bank subenvironment.

The bryozoan wackestone/boundstone (Fig. 17D, 17E) of lithofacies 2 is characterized by an abundance of mud (55.7%), the dominance of the biota by encrusting bryozoans (25.0 to 27.7%) and the presence of the algae, Girvanella (Fig. 17F) and Kazahkstanelia (Fig. 17G). A single bryozoan boundstone mud mound approximately 1 meter high by 1 meter east-west was observed at the LN section (see Figs. 10C, 10D,

p. 33). This mud mound contains a basal 0.2 meter thick stromatactis structure (Fig. 17H) similar to the Type 3 stromatactis described by Ruppel (1979) from the Holston Formation at the Poor Valley Creek section in northeast Tennessee. The mound has been constructed on a lens of cobbly bedded, quartz-rich wackestone which is similar to that observed in the lithofacies of the Upper Tongue of the Lenoir Formation at the LN section. The stromatactis (Fig. 17H) consists of alternating bands of abiotic red-gray lime mud and radiaxial fibrous calcite which contains scattered anhedral opaques (pyrite?) along the median interference boundary between the calcite crystallites. Cavities within the mud mound have been infilled with laminated mud (Fig. 17E) as well as with packstones/grainstones derived from the reef flank facies.

Bryozoan boundstone mud mounds and associated stromatactis structures comprise the reef core of the Holston Formation elsewhere within East Tennessee (Ferrigno, 1973; Walker and Ferrigno, 1973a,b; Ruppel and Walker, 1982). Algae occur as both a sediment trapper/binder represented by encrusting forms of Girvanella and as a sediment producer, e.g., Girvanella (Fig. 17F) and Kazahkstanelia (Fig. 17G) within the boundstone at LN. The presence of algae suggests that the wackestone/boundstone of the Holston Formation at LN was deposited in a shallow subtidal environment within the euphotic zone. According to Walker and Ferrigno (1973b) and Walker (1977c, 1980b), algae are absent from the "reefy" facies of the Holston Formation at other localities in East Tennessee where this formation has been studied though Cristil (in preparation, 1985) has observed algae within the "reefy" facies of the

Holston at the Rutledge Pike section in northeast Knoxville. Walker and Ferrigno (1973b) have reported the occurrence of bryozoan boundstone cobbles within the flanking grainstones of the Holston Formation within the Knoxville area, and they have cited these occurrences as evidence for the early lithification of the core facies thus, the core facies had the potential to be wave resistant. Therefore, the Holston boundstone, according to Walker and Ferrigno (1973b), represented a reef according to the definition of the Nelson et al. (1962). The occurrence of bryozoan boundstone cobbles within the packstone of lithofacies 1 at LN also suggests that the core facies had undergone early lithification and that the boundstone mud-mounds at LN represent part of a reef core complex. The lens of quartz-rich wackestone within lithofacies 2 appears analogous to the beds of argillaceous limestone which extend into and across buildups in the Middle Ordovician of Virginia and which Grover and Read (1983) have interpreted as representing an incipient drowning event during the growth of the Virginia buildups. This may also be true for the quartz-rich wackestone lens in the Holston Formation. In each case, for the buildups in Virginia and as well as for those in the Holston Formation at the LN section, these beds served as a foundation for subsequent mud-mound growth.

The quartz-rich skeletal packstone/grainstone of lithofacies 3 (Figs. 18A, 18B) contain between 2.2 and 18.3% fine grained subangular to subrounded quartz sand, well sorted echinoderm ossicles and abraded ramose bryozoans. Sulfide content especially that of pyrite (Fig. 18C)

Figure 18. Petrographic features of lithofacies 3 of the Holston Formation.

A. Sample LN-30. Quartz-rich packstone/grainstone. Thin-section negative print. Bar scale = 1 cm.

B. Sample LN-30. Close-up of quartz-rich packstone/grainstone. Crossed polars. Bar scale = 1 mm.

C. Sample HB-F-20. Sulfide (Py) replaced echinoderm grainstone of the Holston Formation. Plane light. Bar scale = 1 mm.

D. Sample HB-21. Sandy bryozoan echinoderm wackestone to packstone. Note shelter cavity (C) filled with "saddle"/"baroque" dolomite. Thin-section negative print. Bar scale = 1 cm.

E. Sample HB-21. The alga Girvanella from the top of the Holston Formation. Crossed polars. Bar scale = 1 mm.

F. Sample LN-35. Algal?-encrusted oncolite (O)/coated grain in quartz-rich echinoderm bryozoan packstone. Crossed polars. Bar scale = 1 mm.

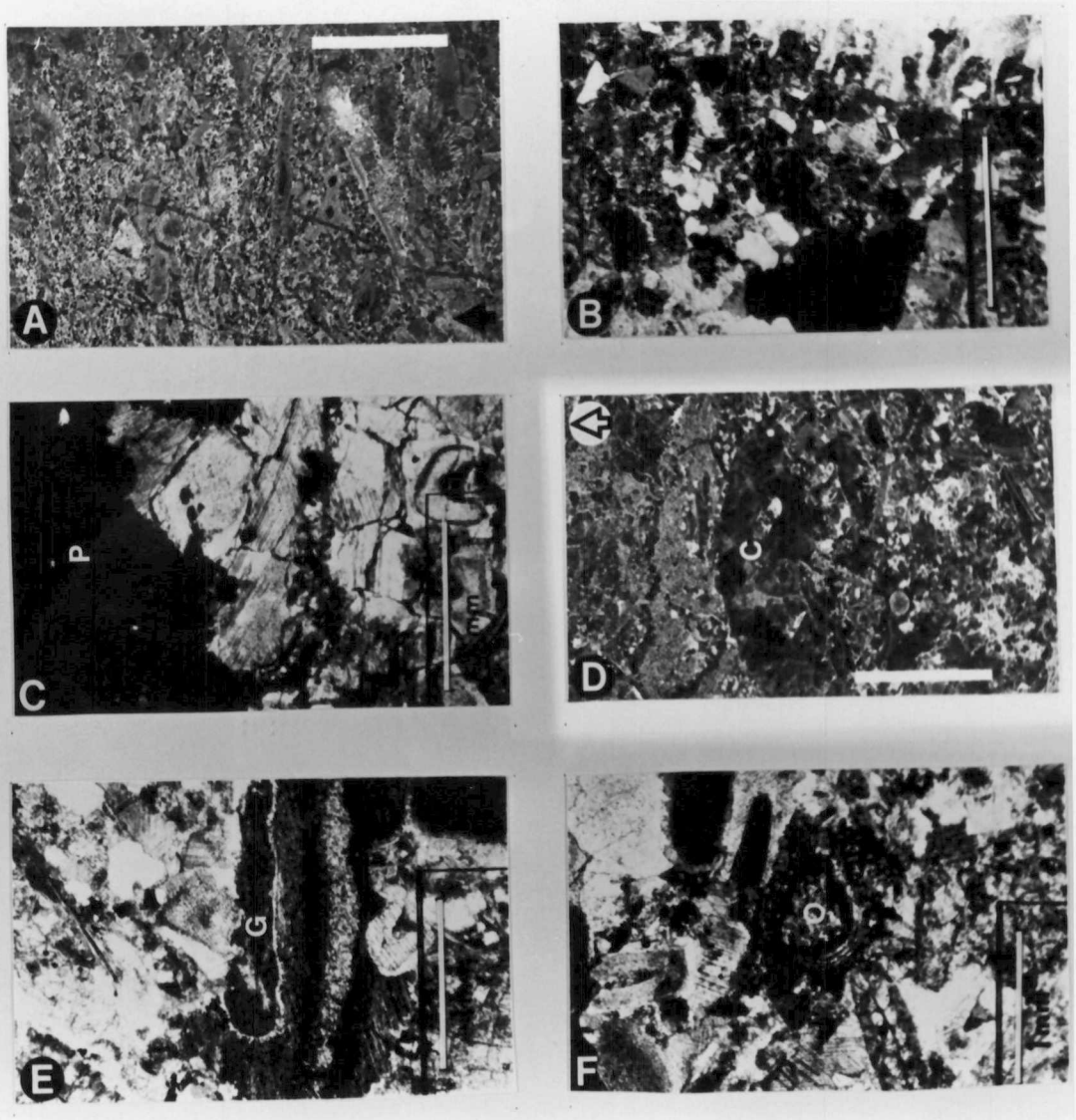


Figure 18.

increases to approximately 2% of the rock by volume within 2 meters of the top of the lithofacies at both HB and LN. The volume percent of micrite increases towards the top of the lithofacies from 5.7% to 17.9% at HB and from 1.1% to 7.6% at LN. Baroque dolomite (Fig. 18D) occurs as a late void-filling cement within the uppermost 2 meters of this lithofacies especially at HB where it constitutes up to 13.4% of the rock volume. Isopachous and radiaxial fibrous calcite cements exhibit a patchy distribution within this lithofacies. Algae, though not abundant, occur throughout this lithofacies at HB. At the LN section, algae including Girvanella (Fig. 18E) and algal?-encrusted oncolites/coated grains (Fig. 18F) have been observed only within samples obtained from the uppermost meter of this lithofacies. The presence of abraded and bored skeletal debris, abraded algae and the grain-supported fabrics in the lithologies of lithofacies 3 suggest deposition under moderate to high energy conditions of a subtidal, reef flank/skeletal sand bank subenvironment. The presence of fine grained detrital quartz within the packstone/grainstone may reflect proximity of the Calhoun area to a terrigenous source during Holston deposition.

The sharp, irregular ferromanganese-stained contact between lithofacies 2 and 3 at LN (see Fig. 10G, p. 33) is interpreted as a corrosion surface similar to those reported by Prokopovich (1955) from upper Middle Ordovician rocks in southeastern Minnesota and by Walker (1977c, 1980b) from the top of the Holston Formation at the Alcoa Highway section in South Knoxville. According to these authors, corrosion surfaces represent periods of slow deposition during which

strong bottom currents are capable of mechanically eroding and chemically dissolving sediment on the sea floor; marine cements and the ferromanganese stains on the corrosion surfaces could be precipitated during this interval (Prokopovich, 1955; Walker, 1977c, 1980b). This surface may have formed as the result of the drowning of the Holston reef core complex coupled with an influx of terrigenous clastics into the environment which could effectively increase the turbidity of the water column, thus, raise the depth of the euphotic zone, decreasing the carbonate production on the reef core complex. According to Schlager (1981), an important factor in the drowning of carbonate platforms is the narrow depth limits of carbonate production. In modern carbonate environments, prolific carbonate production is limited to the euphotic zone, which lies within the upper 50 to 100 meters of the water column, but below 10 to 20 meters depth of water carbonate production drops significantly (Schlager, 1981). The presence of algae directly below the corrosion surface and their absence above this surface which is coupled with a marked increase in detrital quartz supports the conclusion that the drowning of the reef core complex was perhaps attributable not only to a relative rise in sea level but also to an influx of terrigenous clastic sediments onto the shelf edge.

The upper contact between the Holston formation and the overlying "orthocone zone" of the Chapman Ridge formation at both LN and HB is sharp (see Fig. 10A, 10E, p. 33). At HB, this very distinctive contact is marked by an abrupt change in color and lithology from the tan, quartz-rich, echinoderm-bryozoan packstone of the Holston to the

blue-gray, quartz- and cephalopod-rich wackestone-packstone of the "orthocone zone." This contact is also interpreted as representing a corrosion surface. At LN the contact between the Holston and the overlying "orthocone zone" is less obvious than at HB and can be distinguished by the presence of a 0.1 meter thick shaley saprolite overlain by abundant orthocone cephalopods in the basal quartz-rich, blue-gray wackestone-packstone of the "orthocone zone." This surface may also represent a corrosion surface. At both localities, a period of interrupted sedimentation and patchy marine cementation in a subtidal reef-flank/skeletal sand bank environment is recorded at the close of Holston deposition. Mineral (Fe?) stained intraclasts are common within lithofacies 3 at the LN section.

Based on the evidence presented above, lithofacies 1 of the Holston Formation within the study area represents deposition in a moderate to high energy shallow, subtidal skeletal sand bank; lithofacies 2 represents deposition in a moderate to high energy, shallow, subtidal reef core/flank complex; and lithofacies 3 represents deposition in a moderate to high energy, shallow reef flank/skeletal sand bank subjected to influxes of terrigenous clastic sediments, and periodic "drownings." This skeletal sand bank reef core complex was coeval with the deep water shales deposited in the basin to the southeast (see Fig. 6, p. 20, and Fig. 14, p. 63), therefore this complex was deposited in a shelf edge position (Walker, 1977c, 1980b).

Chapman Ridge Formation: "Orthocone Zone"

The "orthocone zone" of the Chapman Ridge Formation is poorly exposed at LN while the exposure at HB is excellent. At both LN and HB, the "orthocone zone" is composed of the two lithofacies described below and illustrated in Fig. 15, p. 65).

Lithofacies 1 is a dark blue-gray, quartz-rich skeletal wackestone/packstone (Figs. 19A, 19B). This lithofacies is characterized by a diverse biota containing abundant cephalopods and also by the occurrence of numerous ferromanganese (Fe/Mn) nodules and, at HB only, ferromanganese pavements (Fig. 19C). Additional biota include echinoderm debris, ramose and encrusting bryozoans, ostracodes, brachiopods, bivalves, gastropods (e.g., Raphistoma sp.), Hedstroemia, Girvanella (Fig. 19D), Receptaculites sp. (Fig. 19E) and Renalcis? oncolites (Fig. 19F). Intraclasts of micrite and pelloidal wackestone/packstone have also been observed within this lithofacies. Mineral impregnated hardgrounds (Figs. 19A, 19B) and intraclasts commonly occur within the lower part of this lithofacies. Extensive bioturbation was observed throughout this unit. Well-developed chamosite ooids are rare in this lithology but chamosite coated-grains/superficial ooids are common.

At both sections, the cephalopods in this lithofacies include actinoceratoid and endoceratoid orthocone cephalopods. In addition, rare coiled nautiloid tarphyceratid cephalopods occur at HB. The cephalopod shells commonly served as a substrate for encrusting bryozoans and have been infilled with sparry calcite and pelleted mud. In addition, a few of the caphalopod shells have been partly replaced by phosphate. Shell-in-shell telescoping can be occasionally observed.

Figure 19. Petrographic features of lithofacies 1 of the "orthocone zone" of the Chapman Ridge Formation.

A. Sample HB-22. Quartz-rich, echinoderm-bryozoan wackestone to packstone. Note the orthocone cephalopod and the mineral impregnated hardground (H). Thin-section negative print. Bar scale = 1 cm.

B. Sample HB-28. Quartz-rich, echinoderm-bryozoan wackestone to packstone. Note the mineralized hardground (H), skeletal debris (S). Thin-section negative print. Bar scale = 1 cm.

C. Sample HB-25. Contact between the sedlitharenite of the overlying "main body" of the Chapman Ridge Formation and a mineralized pavement of the "orthocone zone." Thin-section print. Bar scale = 1 cm.

D. Sample HB-28. Girvanella (G) clump in quartz-rich, echinoderm-bryozoan wackestone to packstone. Crossed polars. Bar scale = 1 mm.

E. Sample LN-F-2. Receptaculites sp. Slab. Bar scale = 2 cm.

F. Sample LN-38. Renalcis? oncolites in a quartz-rich wackestone to packstone. Thin-section negative print. Bar scale = 1 cm.

G. Sample HB-24. Ferromanganese nodule in a quartz-rich, echinoderm-bryozoan wackestone to packstone. Note the mineralized intraclast (I) as the nucleus for the nodule as well as the bryozoans (B) encrusting the nodule. Thin-section print. Bar scale = 1 cm.

H. Sample HB-24. Close-up of the laminae of a ferromanganese nodule. Note the microstromatolitic fabric (S). Crossed polars. Bar scale = 1 mm.

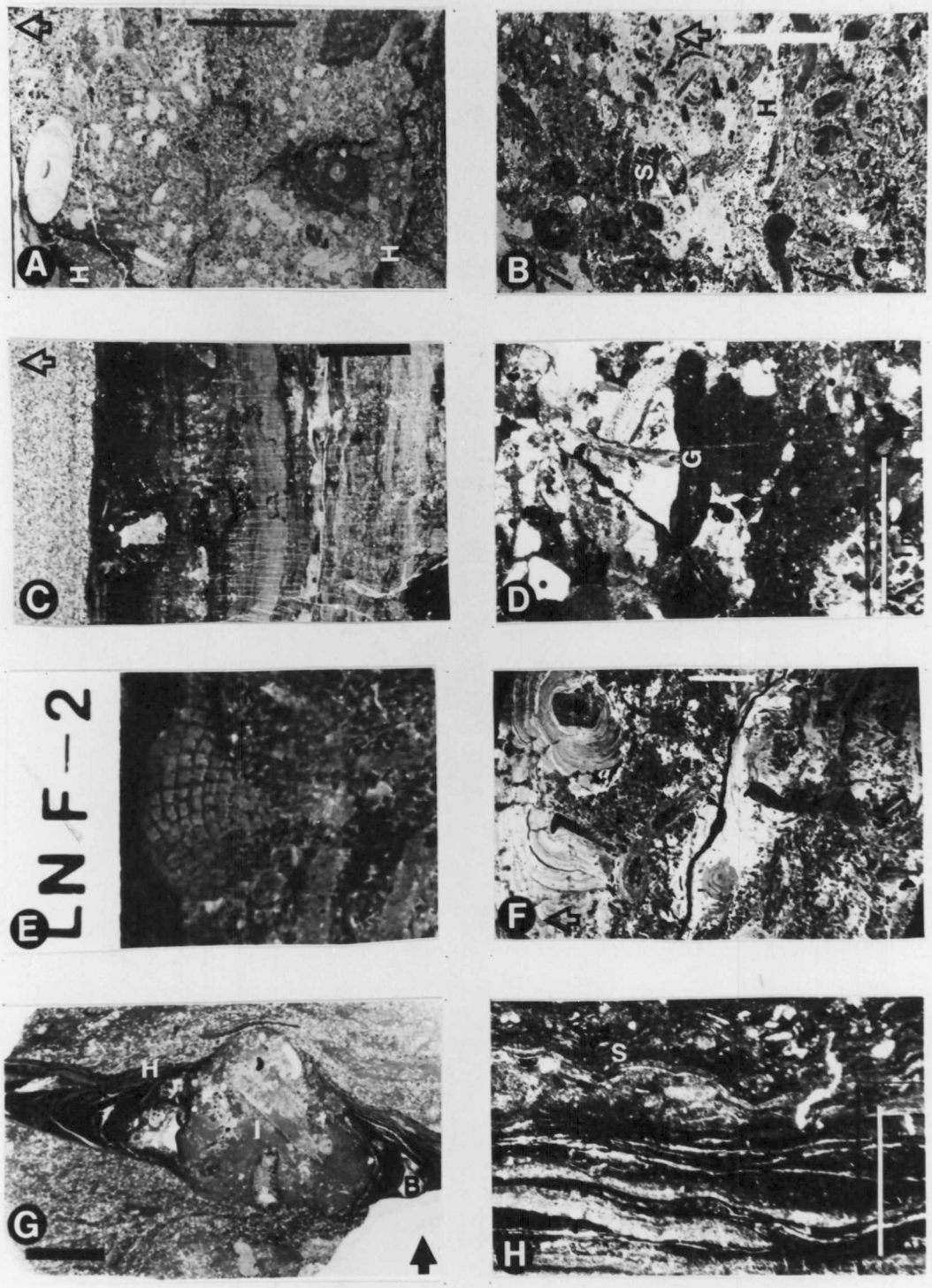


Figure 19.

The ferromanganese nodules (Fig. 19G) of the "orthocone zone" are typically discoidal. They range in size from 5 to 25 cm in long dimension and have been nucleated around either mineral-impregnated intraclasts (Fig. 19G), which may have been derived from the bioerosion of hardgrounds, or cephalopods. These nodules exhibit continuous as well as discontinuous laminae along with a stromatolitic mircofabric (Fig. 19H). The laminae of these nodules consist of chamosite, phosphate, micrite, hematite and limonite which has been reported as a weathering product of chamosite by Phillips and Griffen (1981). Some of the laminae have been encrusted, in part, by bryozoans (Fig. 19G) and frequently contain abundant skeletal and terrigeneous clastic debris (Fig. 19G). Compound nodules, resulting from the coalescence of nodules during growth, and ferromanganese pavements (Fig. 19C) have also been observed within this zone.

The terrigenous clastic component of this lithofacies consists primarily of moderately to poorly sorted, subangular to subrounded, fine to very fine grained quartz sand which constitutes 14.5 to 16.9% of the rock volume. Some coarse and medium grained quartz sand was also observed along with trace amounts of both plagioclase and microcline feldspar, chert, sedimentary and metamorphic rock fragments. There is a significant increase in the volume percentage of terrigenous clastic grains between this unit and the underlying one. At LN, terrigenous clastic grains increase from 2.2% to 14.5% of the rock volume across the contact between the Holston Formation and the "orthocone zone" while at the HB section, the increase is from 5.5 to 16.9% across the same contact.

Stose and Schrader (1923) and Reichert (1942) have reported the occurrence of such manganese-bearing minerals as wad and psilomelane from this stratigraphic interval within the Calhoun area and have referred to this type of mineralization as the "Tellico-Holston" type of manganese deposit. The Calhoun area is included within the Charleston District of these authors.

Lithofacies 2, a silty shale containing ferromanganese nodules, is poorly exposed as a yellow, chippy-weathering, saprolite at the LN section. The contact between lithofacies 1 and 2 at LN is covered. At HB, this lithofacies can not be readily distinguished due to extensive bioturbation but an increase in terrigenous clay to 53.2% of the rock volume was noted near the top of the "orthocone zone" at this section.

The development of hardgrounds, the presence of extensive bioturbation and a large accumulation of cephalopods in addition to the formation of ferromanganese nodules and pavements suggests that the "orthocone zone" may represent a condensed stratigraphic sequence similar to those recognized by Jenkyns (1971) in the Tethyan Jurassic. The presence of abundant mud coupled with the lack of physical sedimentary structures and the abundance of biogenic structures indicates that deposition of the "orthocone zone" sediments probably occurred below effective wave base under moderately deep subtidal conditions. This environment was subjected to periodic increases in current energy which were responsible for the formation of coated grains, mineralized hardgrounds and the inclusion of both terrigenous clastic and bioclastic debris within the ferromanganese nodules found within the

"orthocone zone." Sorem and Fewkes (1977) have reported inclusions of bioclastic and terrigenous clastic debris within the manganese nodules recovered from recent continental margins and seamounts which are characterized by strong currents and high rates of sedimentation when compared to environments where deep sea manganese nodules are found today. According to Prokopovich (1955), Jenkyns (1971) and Scholle et al. (1983), mineralized hardgrounds/corrosion surfaces are also indicative of high current activity. The formation of phosphate is also favored by strong, somewhat persistent upwelling currents (Jarvis, 1980) in shelf-marginal environments in water depths greater than 30 meters (Bromley, 1967; Benedict and Walker, 1978). Porrenga (1973) reported the presence of chamosite in sediments from tropical marine waters typically shallower than 60 meters but deeper than 10 meters. According to this author, chamosite oxidizes to goethite above 10 meters water depth.

The algal grains present in the "orthocone zone" of both sections exhibit some effects of abrasion, which could be due either to intense biogenic activity or to transportation of the algae into the "orthocone zone" environment. The occurrence of oncolites near the base of the "orthocone zone" at LN indicates water depths less than 10 meters and, at least, moderate current activity at that section if they have not been transported. The fauna found within the "orthocone zone" indicates water of normal marine salinity.

In summary, the "orthocone zone" of the Chapman Ridge Formation in the Calhoun area appears to be a condensed sequence. As defined by

Jenkyns (1971, p. 330), ". . . condensed sequences are produced by minimal net sedimentation." The hardgrounds which have been formed within condensed sequences such as the "orthocone zone" are produced ". . . by nil or negative sedimentation" (Jenkyns, 1971, p. 330). Deposition of "orthocone zone" sediments occurred below effective wave base in a moderately deep subtidal environment characterized by periods of strong current activity as indicated by current aligned cephalopods, the formation and mineralization of hardgrounds, the presence of phosphate and the inclusion of debris within the laminae of ferro-manganese nodules. Water depths were probably on the order of 10 to 30 meters based on the presence of phosphate, chamosite and oncolites. The occurrence of algae within the "orthocone zone" suggests that this unit was deposited within or near the euphotic zone. Based on the criteria presented by Stanley and Unrug (1971), the "orthocone zone" probably represents a Middle Ordovician outer shelf-shelf break environment. This environment may have been similar to the off-shore swell environment proposed by Bernoulli and Jenkyns (1974) in which the pisolitic ironstones of Sicily were formed during the Jurassic, and may have resulted from the drowning of the underlying Holston skeletal sand bank possibly due to a relative rise in sea level coupled with a major influx of terrigenous clastic sediments onto the shelf-margin.

Chapman Ridge Formation: "Main Body"

The "main body" of the Chapman Ridge Formation, using the terminology of Cattermole (1958), is incompletely exposed within the

Calhoun area. The best exposure of the "main body" of the Chapman Ridge Formation is at HB while at LN this unit is very poorly exposed and has weathered to a yellow-red sandy saprolite which contains a few small, scattered exposures of unweathered rock. There are three lithofacies recognizable within the "main body" of the Chapman Ridge Formation and they are illustrated in Figure 15 (p. 65).

Lithofacies 1 consists of medium blue-gray, thin wavy-bedded, cross-stratified sedlitharenite (Figs. 20A, 20B) interbedded with blue-gray, laminated, silt-shale (Fig. 20C). The sedlitharenite is composed of 30.8 to 38.5% fine to very fine (rare medium) sand-sized, subangular to subrounded, moderately-sorted, primarily monocrystalline quartz grains. Sedimentary rock fragments, which include shale, siltstone and chert, constitute an additional 7.7 to 12% of the rock volume. The more labile rock fragments (e.g., shale and siltstone) have been squashed during compaction thus producing pseudomatrix which comprises 1.4 to 8.4% of the rock volume. Metamorphic rock fragments are present but rare in this lithology. Other detrital grains include plagioclase and microcline feldspar (up to 3.8%), some of which have undergone alteration to sericite, and trace amounts of mica. The fossil allochems which occur within this lithology are commonly abraded and include echinoderm debris (1.3 to 10.8%) with rare syntaxial overgrowths, brachiopods (to 0.5%) bryozoans (1.4%), and at HB, trace amounts of ostracodes and trilobites. Algae (e.g., Hedstroemia and Girvanella) very rarely occur within this lithofacies. The aforementioned fossil allochems frequently occur in quartz-poor, cross-laminae within the sedlitharenite (see Fig. 20A).

Figure 20. Petrographic features of the "main body" of the Chapman Ridge Formation and the Hiwassee Member of the Ottosee Formation.

"Main Body": Chapman Ridge Formation

A. Sample HB-27. Cross-laminated sedlitharenite from lithofacies 1. Note that the laminae are bioclastic-rich. Thin-section negative print. Bar scale = 1 cm.

B. Sample HB-27. Close-up of the bioclastic-rich laminae within the sedlitharenite. Crossed polars. Bar scale = 1 mm.

C. Sample HB-37. Interbedded sedlitharenite and silty-shale from lithofacies 1. Polished slab. Bar scale = 2 cm.

D. Sample LN-49. Cross-laminated, quartz-rich, bryozoan-echinoderm packstone from lithofacies 3. Thin-section negative print. Bar scale = 1 cm.

E. Sample LN-49. Close-up of quartz-rich packstone. Crossed polars. Bar scale = 1 mm.

Hiwassee Member: Ottosee Formation

F. Sample LN-51. Argillaceous echinoderm wackestone/bafflestone of lithofacies 1. Note the in-situ echinoderm holdfast. Thin-section negative print. Bar scale = 1 cm.

G. Sample LN-53. Oolitic packstone/grainstone of lithofacies 2 with coarse grained bioclastic laminae. Thin-section negative print. Bar scale = 1 cm.

H. Sample LN-63. Selectively dolomitized ooids in oolitic grainstone of lithofacies 2. Note the abundant radiaxial fibrous cement. Crossed polars. Bar scale = 1 mm.

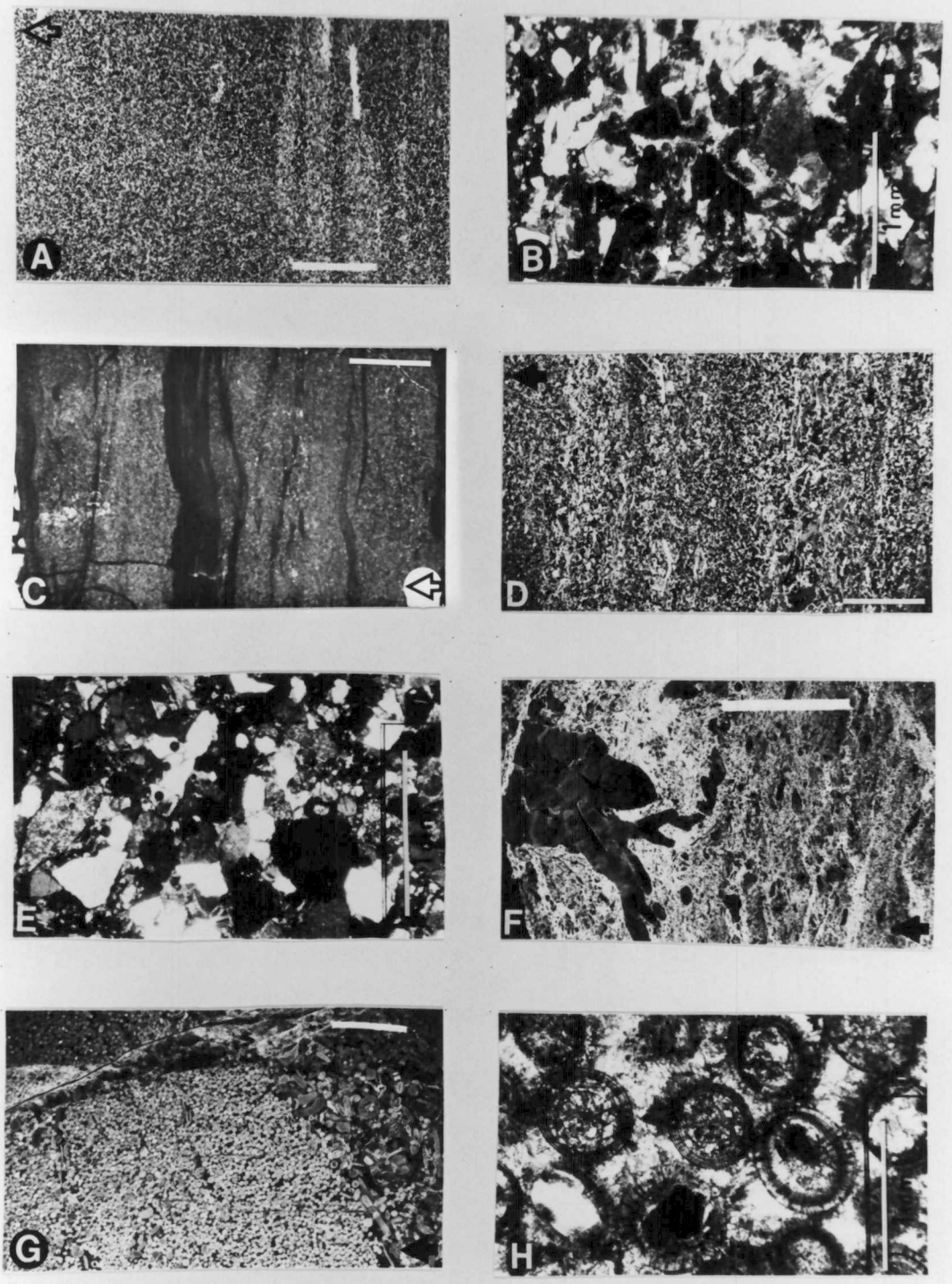


Figure 20.

The silt-shale of lithofacies 1 exhibits wavy to parallel lamination which is continuous except where disrupted by burrowing activities. Laminations alternate between silt-shale and fine-sand laminae. These silt-shales are sharply overlain by sedlitharenite beds which usually contain basal lags of silt-shale clasts (from 7.7 to 23.2% of the rock volume) within them.

Lithofacies 2 consist of sedlitharenites similar to those in lithofacies 1, interbedded with cross-stratified, ferruginous, quartz-rich skeletal packstone. Allochems within the packstone include abraded bryozoans (4.7%), echinoderm ossicles (19.4%), trace amounts of brachiopods, ostracodes, trilobites, ooids, algae and, pelletal and micritic intraclasts some of which have been dolomitized. Grains in the packstone beds are moderately to well sorted; grain-sizes range from fine to medium sand with most grains being subangular to sub-rounded. A few well-rounded, large quartz grains have been observed. Cross-laminae are commonly quartz-poor. Terrigenous clastic grains include both monocrystalline and polycrystalline quartz (31.1%), and plagioclase and microcline feldspar (1.1%). Sedimentary rock fragments, composed of chert and silt-shale, constitute 2.2% of the rock volume of the packstone while metamorphic rock fragments have only been rarely observed within this lithology.

Lithofacies 3 consists of cross-stratified, medium- to thin-bedded sedlitharenites interbedded with ferruginous, quartz-rich packstones (Figs. 20D, 20E) and laminated silt-shales. Silt-shale interbeds increase in occurrence upsection. The framework grains of lithofacies 3 are similar to those noted in the previously described

lithofacies with the one exception being that algae are absent from lithofacies 3 samples. In this lithofacies, however, medium sand-size grains become more common while grain sorting becomes poor to moderate.

The sedimentary structures and fauna observed within all three lithofacies of the "main body" of the Chapman Ridge Formation indicate that deposition of this unit took place under shallow subtidal, current-dominated, normal marine conditions. Cross-stratification is common indicating that the transport of sand-sized sediment occurred by traction processes as ripples and as sand waves in a quartz-rich, sand wave environment similar to that proposed for the Chapman Ridge Formation at the Alcoa Highway section by Walker (1977c, 1980b). Interbeds of discontinuously laminated silt-shale indicate periodic deposition from suspension under lower energy, quiet water conditions characterized by minor biogenic and bottom current reworking. The coarsening-upward lithologic succession observed within the lower half of the "main body" of the Chapman Ridge Formation, as silt-shale interbeds decrease and the thickness of the sedlitharenite/quartz-rich packstone beds increases from lithofacies 1 to lithofacies 2, reflects the progradation of this sequence onto the Middle Ordovician shelf and the reworking of sediments perhaps by storm? waves. The fining-upward lithologic succession indicated by the increase in frequency and thickness of silt-shale interbeds and the decrease in sand bed thickness from lithofacies 2 to 3 reflects the retrogradational nature of the upper part of the "main body" of the Chapman Ridge Formation. Time line 3 (see Fig. 6, p. 20) of Walker (1980a) is based on the progradation-retrogradation of the Chapman Ridge Formation and coeval units.

Lithofacies 1, which is composed of thin wavy bedded sedlitharenites interbedded with laminated silt-shales, is interpreted as representing an initial sand wave phase of deposition during which abundant terrigenous clastic sediment was introduced onto a muddy shelf margin. Periods of higher energy were responsible for the formation of the sharp basal contacts and associated basal lags of silt-shale clasts observed within the sedlitharenite beds of lithofacies 1. Grain separation during the migration of bedforms similar to that reported by Davies (1970) from Shark Bay, Western Australia, may be responsible for the formation of the bioclastic-rich cross-laminae observed in lithofacies 1 (see Fig. 20A). Velocities ranging from 20 to 55 cm/sec within 1 to 2 meters of the sediment-water interface in flume experiments and in natural flows will produce small ripples and sand waves in fine-grained sediment (Harms et al., 1975; Reineck and Singh, 1980). These current velocities may have been generated by storms. During periods of lower energy, deposition of silt- and clay-size particles from suspension formed the silty-shales of this lithofacies. Burrows, which are common in the silt-shale interbeds, indicate a return to this environment by deposit-feeding organisms during these periods of low energy and relative stability of the substrate. The occasional coarse silt-fine sand laminae within the silt-shales may represent episodic increases in energy of sufficient duration to allow currents or waves to rework the sediment. This lithofacies may be analogous to the offshore bars and interbar muddy sediments which Brenner (1980) proposed for shelf sands deposited in North American epicontinental seas during the Jurassic and Cretaceous.

Lithofacies 2, composed of interbedded cross-stratified, thick-bedded sedlitharenite and quartz-rich packstone is interpreted as representing an active, shallow subtidal sand wave environment analogous to the offshore bars of Brenner (1980). The absence of silt-shale interbeds and the presence of cross-stratification suggests deposition under moderate to high energy conditions with current velocities similar to those inferred for the sedlitharenite of lithofacies 1.

Lithofacies 3, consisting of cross-stratified, medium to thin bedded sedlitharenite interbedded with quartz-rich, packstone and laminated, silt-shale, is interpreted as representing the gradual cessation of active sand wave transport and a return to alternating periods of high and low energy similar to that observed in lithofacies 1. This is again analogous to the offshore bars and interbar muddy sediments of Brenner (1980).

Ottosee Formation: Lower Unnamed Shale Member

The contact between the "main body" of the Chapman Ridge Formation and the overlying Lower Unnamed Shale Member of the Ottosee Formation is not exposed within the study area. The only exposure of the Lower Unnamed Shale observed by this author was a very small, discontinuous outcrop along a roadcut approximately 200 meters to the southwest of the HB section. This lithology appeared to be similar to the silt shale observed within the "main body" of the Chapman Ridge Formation and thus may be analogous to the muddy shelf and interbar sediments of Brenner (1980).

Ottosee Formation: Hiwassee Member

Two lithofacies (see Fig. 15, p. 65) have been recognized within the Hiwassee Member of the Ottosee Formation. The contact between the Hiwassee Member and the underlying Lower Unnamed Shale Member of the Ottosee Formation is covered. At LN, the upper part of the Hiwassee Member is poorly exposed as small pinnacle outcrops.

Thick-bedded (massive) mottled gray-brown to pink skeletal wackestone/bafflestone (Fig. 20F) and bryozoan boundstone comprise lithofacies 1. The boundstone, characterized by ramose and encrusting bryozoans which constitute 23.0% of the rock volume, exhibits a patchy distribution within the argillaceous wackestone/bafflestone. The fossil biota of the wackestone/bafflestone is dominated by abundant in situ echinoderm holdfasts, articulated echinoderm columnal segments and echinoderm plates (e.g., Ulrichocystis exima Bassler) which comprise an estimated 10-30% of the rock volume. Brachiopods (1%) including rare inarticulates, sponge spicules (1-15%), ostracodes (2-3%), trilobites (3%), serupulid worm tubes (trace) and the algae, Girvanella and Hedstroemia (trace) comprise the accessory biota within this lithofacies; ooids are rare. Preservation is generally excellent and the articulation of valves and echinoderm plates is quite high. Horizontal burrows, although infrequent, are present within the boundstone Euhedral dolomite rhombs ($\approx$.08 mm) commonly occur within argillaceous laminae. Syntaxial overgrowths of sparry calcite are common on echinoderm grains.

Lithofacies 2 consists of cross-stratified oolitic packstone to grainstone (Figs. 20G, 20H) which has been subdivided into a lower and

an upper part by a poorly exposed interval of wackestone/bafflestone and bryozoan boundstone included in lithofacies 1. The lower part of this unit is composed of well-sorted, well-developed ooids (55.3% of the rock volume) which average ≈0.6 mm in diameter, occasional thin, coarse-grained skeletal interbeds (Fig. 20G) comprised primarily of syntaxially overgrown echinoderm grains (5.9%) and rare abraded grains of the alga Hedstroemia. Radiaxial fibrous calcite cement is pervasive throughout the remainder of this oolite. Several of the detrital quartz grains, which serve as ooid nuclei, exhibit authigenic silica overgrowths which have partially replaced the ooid cortices. Additional ooid nuclei include skeletal debris (e.g., bryozoans and echinoderms), micritic and pelletal intraclasts, chert grains, and sedimentary and metamorphic rock fragments. The upper part of lithofacies 2 is essentially a cross-stratified oolitic grainstone. The ooids, which comprise 57.8% of the rock volume, are well- to very-well-sorted, commonly exhibit thick cortices and average ≈0.6 mm in diameter. The upper part of this lithofacies is sparsely fossiliferous with only echinoderm debris (0.9%) occurring. Radiaxial fibrous sparry calcite cement (Fig. 20H) is ubiquitous and constitutes 40.3% of the rock volume. Many ooids have been selectively dolomitized and contain ≤.05 mm dolomite rhombs within their cortices (Fig. 20H) which could indicate that the ooids were originally composed of high Mg calcite. Compactional features (e.g., spalled ooid cortices) are common within this part of lithofacies 2.

Viewed collectively, the lithofacies of the Hiwassee Member of the Ottosee Formation are interpreted as representative of deposition in a

shallow subtidal, shelf-margin, oolite shoal organic buildup complex. According to Milliman (1974), ooids commonly form in agitated, shallow water (<2 m) environments. Separately, lithofacies 1, an argillaceous echinoderm-bryozoan wackestone/bafflestone with abundant in situ echinoderm holdfasts, clearly represent an "organic buildup" for which the geometry is unknown but presumed to be biostromal (cf. Nelson, 1962). Both echinoderms and ramose bryozoans baffled currents and trapped accumulated mud in their lee in a manner analogous to that proposed by Wilson (1975) for the formation of the Waulsortian mounds, while encrusting bryozoans bound patches of the trapped mud at the sediment-water interface. The lower part of lithofacies 2, an oolitic packstone/grainstone with coarse-grained bioclastic interbeds is interpreted to represent deposition within the mobile fringe of an oolite shoal. Based on the abundance of echinoderm grains within these bioclastic laminae, lithofacies 2 probably was in close proximity to the organic buildup of lithofacies 1. However, the exact relationships between these two lithofacies are not known because the contact between these lithofacies is covered. The upper part of lithofacies 2, a nearly pure oolitic grainstone, is also interpreted to represent deposition within the mobile fringe of an oolite shoal. In the modern oolite shoal environments of the Bahamas, the mobile fringe occurs on the basinward side of the shoal (Harris, 1979). Lithofacies 2 of the Hiwassee Member is similar to lithotype 2 recognized by Cantrell (1982) within an oolite shoal in the Ottosee Formation in the vicinity of Knoxville. Lithofacies 1 is similar to the reef core deposits

recognized by LaFollette (1974) within the Vestal Limestone Member of Ottosee Formation in Knox County, Tennessee.

Ottosee Formation: Middle Unnamed Shale Member

The Middle Unnamed Shale Member of the Ottosee Formation overlies the Hiwassee Member of the Ottosee Formation and is moderately well exposed only at LN. The contact between these two members, though covered, appears to be abrupt.

Two lithofacies have been recognized within the Middle Unnamed Shale Member of the Ottosee Formation and are illustrated in Figure 15 (p. 65). Lithofacies 1 consists of laminated silt-shales with interbeds of very thin to thin, cobbly bedded, quartz-rich wackestone (Figs. 21A, 21B).

Within the outcrop at LN, an eastward thickening wedge of skeletal wackestone to packstone (Fig. 21C) representing lithofacies 2, interfingers with lithofacies 1 thus subdividing it into an upper and lower part.

Overall, lithofacies 1 is poorly fossiliferous; the biota occurs primarily within the coarser grained laminae of the silt shales as well as within the quartz-rich wackestone cobbles and consists of fragmented dendroid graptolites (W. Norton, personal communication) occurring near the base of the unit, sponge spicules (estimated at 1% of the rock volume), ostracode valves (10%), pelloid-size clumps of Girvanella (2%), and echinoderm (2%), rare brachiopod and trilobite debris. Allochem percentages increase slightly at the base of the upper part of lithofacies 1 just above the contact with lithofacies 2, possibly as a

Figure 21. Petrographic features of the Middle Unnamed Shale Member and lithofacies 1 and 2 of the McKnight Member of the Ottosee Formation.

Middle Unnamed Shale Member

A. Sample LN-75. Cross-laminated, quartz-rich wackestone of lithofacies 1. Thin-section negative print. Bar scale = 1 cm.

B. Sample LN-75. Close-up of quartz-rich wackestone. Crossed polars. Bar scale = 1 mm.

C. Sample LN-70. Sandy echinoderm-bryozoan packstone to wackestone of lithofacies 2. Note the fining upwards sequences and increase in mud at the top of the sample. Thin-section negative print. Bar scale = 1 cm.

McKnight Member

D. Sample LN-117. Echinoderm wackestone/boundstone from lithofacies 1. Note cryptalgal laminae (A) at top of sample. Polished slab. Bar scale = 2 cm.

E. Sample LN-125. Quartz-rich echinoderm-sponge wackestone/bafflestone? of lithofacies 1. Note abundant sponges (S). Thin-section negative print. Bar scale = 1 cm.

F. Sample LN-79. Bryozoan wackestone/boundstone from lithofacies 1. Thin-section negative print. Bar scale = 1 cm.

G. Sample LN-82. Cross-laminated, ooid-echinoderm packstone of lithofacies 2. Thin-section negative print. Bar scale = 1 cm.

H. Sample LN-150. Close-up of quartz-rich ooid packstone from lithofacies 2. Crossed polars. Bar scale = 1 mm.

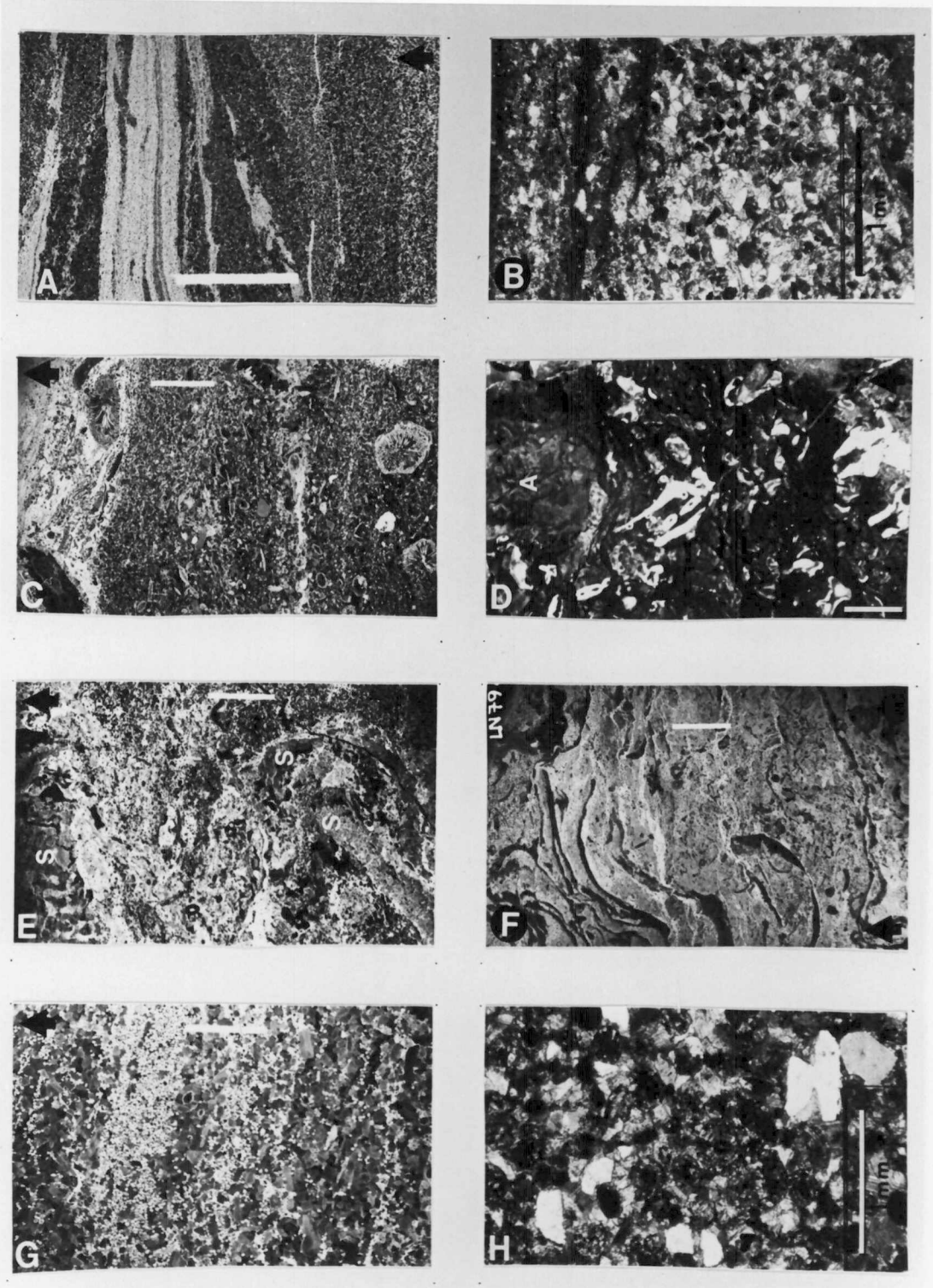


Figure 21.

result of biogenic and/or current reworking of lithofacies 2 allochems into lithofacies 1. Other grains include very fine sand to coarse silt-size grains of quartz, plagioclase, chert, as well as micritic intraclasts and pelloids. Horizontal and vertical burrows are common within mud-rich areas of the lithofacies. Several vertical escape burrows have also been observed in this unit. Laminae within the silt-shales are planar, discontinuous to continuous and occasionally exhibit grading. Ripple cross-laminae have been observed in the quartz-rich interbeds within the lower part of lithofacies 1. Lenticular bedding, starved ripples, swaley cross-stratification, convolute laminations and ripple cross-laminae have been observed in the quartz-rich interbeds above the gradational contact between lithofacies 2 and the upper part of lithofacies 1.

The wackestones and packstones which comprise lithofacies 2 are very fossiliferous. The basal contact between lithofacies 2 and the top of lower part of lithofacies 1 is abrupt. The biota consists of both ramose and encrusting bryozoans (8.6% of the rock by volume), echinoderm debris (11.9%), brachiopods (0.1%) including inarticulate brachiopods, sponge spicules (0.5%), trilobite fragments (5.1%), and trace amounts of Girvanella clumps and fragments of Kazakstanelia?. Allochems (e.g., echinoderms and bryozoans) are commonly silicified. Horizontal burrows have been observed within the mud-rich areas of this lithofacies. Intraclasts, which grade into pelloid-size grains, constitute 4.3% of the rock by volume and exhibit an increase in size and frequency towards the top of the unit. Detrital grains found

within this lithofacies include monocrystalline quartz (0.9%), and trace amounts of plagioclase and chert all of which typically fall within the fine sand-size range; most grains are subangular to subrounded.

The laminated silt-shales and interbedded cobbly quartz-rich wackestones of lithofacies 1 are interpreted to represent deposition within a shallow subtidal, terrigenous clastic-dominated shelf-lagoon. The presence of well-defined burrow walls indicates a firm substrate (Walker, 1974a) in part, whereas convolute lamination originating from the liquifaction of sediment (Reineck and Singh, 1980) indicates that the sediment, at least in places, may have been water-charged. Vertical "escape" burrows and graded laminae were formed by rapid influxes of sediment which were deposited during periods of waning current energy possibly associated with storms. Opposing foreset laminae were produced by oscillatory currents. Ripple cross-laminae which were commonly observed within this lithofacies, form in fine sand-size sediment under flow velocities ranging from 25 to 65 cm/sec within 0.2 to 0.4 meters of the sediment-water interface (Harms et al., 1975; Reineck and Singh, 1980). Lenticular bedding, according to Reineck and Singh (1980), is common in tidal environments where it originates mostly by current activity. Swaley cross-stratification has been observed in sedimentary sequences which have been interpreted by Leckie and Walker (1982) as having been deposited above fair-weather wave base in a storm-dominated environment.

The wackestones and packstones of lithofacies 2 represent a bioclastic accumulation (possibly a skeletal sand bank) within a

subtidal shelf-lagoon environment. Moderate current agitation produced by storm-induced waves may have removed mud and formed the grain-supported fabric commonly observed within this lithofacies in a manner analogous to that proposed for the formation of the skeletal limestone accumulations within the Late Jurassic Redwater Shale Member of the Sundance Formation by Specht and Brenner (1979).

In sum, the Middle Unnamed Shale Member of the Ottosee Formation represents deposition in a shallow subtidal, storm-dominated, carbonate sand/terrigenous mud shelf lagoon.

Ottosee Formation: McKnight Member

The McKnight Member of the Ottosee Formation is moderately well to poorly exposed in the Calhoun area and outcrops only at the LN section. The contact between the McKnight and Middle Unnamed Shale Members of the Ottosee Formation is covered. The five lithofacies recognized within the McKnight Member consist of a complex intergradation of carbonate and terrigenous clastic lithologies which are illustrated in Figure 15 (p. 65). The members of this lithologic complex include argillaceous bryozoan-echinoderm wackestone/bafflestone, bryozoan wackestone/boundstone, skeletal packstone/grainstone, oolitic packstone and grainstone, cross-stratified quartz-rich packstones, and sedlitharenite.

The argillaceous bryozoan-echinoderm wackestone/bafflestone (Fig. 21D, 21E) and bryozoan wackestone/boundstone (Fig. 21F) of lithofacies 1 of the McKnight Member are similar to the bafflestone and boundstone of the Hiwassee Member of the Ottosee Formation but with

four notable differences. These differences are: (1) sponges (Fig. 21E) become an obvious constituent of the lithofacies; (2) cryptalgal laminae (Fig. 21D) observed in one sample from an organic buildup near the top of the McKnight Member indicate that algae may have participated in the trapping and binding of sediment within the buildups; (3) the buildups of the McKnight Member are sharply overlain by units of oolitic packstone (see Figs. 12C, 23E, p. 47) on two occasions and by oolitic sedlitharenite on another occasion, and (4) the buildups appear to be laterally equivalent to cross-stratified, echinoderm-rich (41.5 to 50.0% of the rock volume) packstone which may also contain ooids (0.0 to 27.0%), quartz (0.0 to 4.7%) and clasts of sponges.

The skeletal ooid packstone/grainstone of lithofacies 2 (Figs. 21G, 21H) is moderately- to poorly-sorted and typically contains algae, e.g., Solenopora:Type P, Hedstroemia, and Girvanella which constitute up to 1.3% of the rock volume, rare oncolites, and detrital quartz (0.8+%). Well-developed and superficial ooids occur in nearly subequal amounts within this lithofacies and together comprise 43.9% of the rock volume. The faunal components of this lithofacies include echinoderm debris (6.3%), ramose bryozoans (0.2%), brachiopods (0.3%) and trace amounts of ostracodes, trilobites, cephalopods and sponge spicules. Articulated camerate and inadunate plates from lithofacies 2 include Carabocrinus stellifer?, Paleocrinus sp., Archaeocrinus peculiaris, Cyathocystis sp. and Cliocrinus sp. Micritic and pelloidal intraclasts along with aggregate grains comprise 4.7% of the rock.

Trace amounts of plagioclase and microcline feldspar, and sedimentary and metamorphic rock fragments as well as thick bands of stylocumulate have been observed within this lithofacies.

Lithofacies 3 is composed of well-sorted ooid packstone/grainstone (Fig. 22A) which rarely contains either skeletal debris or quartz. Ooids constitute 58.3% of the rock volume in this lithofacies, are large averaging ≈0.9 mm in diameter, and typically exhibit well-developed cortices. Echinoderm debris (1.4%), ramose bryozoans (0.3%) and unidentified fossil debris (0.3%) comprise the remainder of the faunal elements observed within this lithofacies.

Herringbone and planar cross-stratification are common in both lithofacies 2 as well as in lithofacies 3. Diverse ooid nuclei common to both lithofacies 2 and 3 include micritic and pelloidal intraclasts, fossil allochems, algae and detrital clastic grains. Dolomitization of ooids is common in some samples especially in lithofacies 2 but rarely extends into the matrix of these samples. Deformational and compactional features such as spalled ooid cortices and stylotized grain boundaries are commonly observed within these oolitic lithologies.

The sedlitharenite (Fig. 22B) of lithofacies 4 found within the McKnight is commonly ferruginous, exhibits both trough and herringbone cross-stratification, and contains a sparse, abraded biota. Fossil allochems include ramose bryozoans (0.3% of the rock volume), echinoderms (0.8%), rare ostracodes and unidentified fossil debris (0.5%). Detrital grains include subangular to subrounded, medium to fine sand-sized, monocrystalline and polycrystalline quartz grains (29.3%),

Figure 22. Petrographic features of lithofacies 3, 4 and 5 of the McKnight Member of the Ottosee and lithofacies 1 of the "Bays" Formation.

McKnight Member: Ottosee Formation

A. Sample LN-98. Coarse-grained, oolitic packstone of lithofacies 3. Crossed polars. Bar scale = 1 mm.

B. Sample LN-127. Close-up of oolitic sedlitharenite of lithofacies 4. Crossed polars. Bar scale = 1 mm.

C. Sample LN-136. Quartz-rich, oolitic, echinoderm packstone of lithofacies 5. Note granule size terrigenous clastic grains. Thin-section negative print. Bar scale = 1 cm.

D. Sample LN-136. Close-up of sedimentary rock fragment (quartzarenite) from quartz-rich, oolitic, echinoderm packstone of lithofacies 5. Crossed polars. Bar scale = 1 mm.

E. Sample LN-136. Close-up of polycrystalline (metamorphic) quartz grain from the quartz-rich, oolitic, echinoderm packstone of lithofacies 5. Crossed polars. Bar scale = 1 mm.

"Bays" Formation

F. Sample LN-154. Close-up of a quartz-rich echinoderm-ooid grainstone. Crossed polars. Bar scale = 1 mm.

G. Sample LN-152. Cross-laminated, echinoderm-rich, oolitic sedlitharenite. Polished slab. Bar scale = 2 cm.

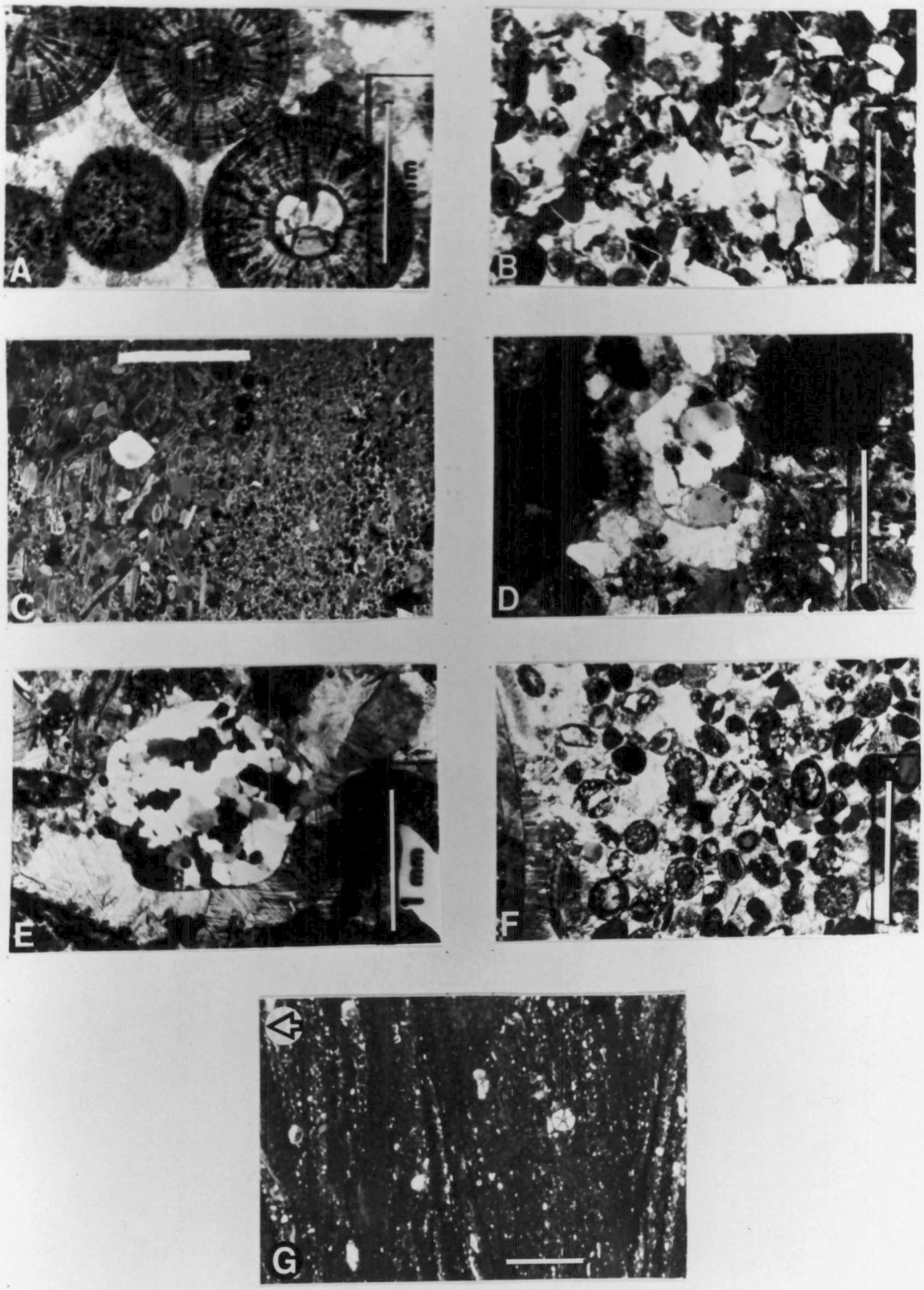


Figure 22.

plagioclase and microcline feldspar (2.1%), sedimentary rock fragments (8.3%) and rare metamorphic rock fragments. Iron-rich ooids (7.0%), which average ≈0.3 mm in diameter, exhibit extensive dolomitization. Subrounded intraclasts of micrite and pelloidal packstone (14.0%) are common within the sedlitharenite. Laterally, this lithology exhibits a sharp erosive contact with the uppermost organic buildup, a bryozoan boundstone reef (cf. Nelson, 1962), within the McKnight Member and contains lithoclasts from the buildup within it (see Fig. 12E, p. 47).

The cross-stratified, quartz-rich packstone (Fig. 22C) of lithofacies 5 is quite similar to previously described packstones in the Ottosee in terms of carbonate components. However, this packstone exhibits several distinctive characteristics which sets it apart from other packstones in the Ottosee Formation. These characteristics are: (1) fossil allochems within the packstone are lineated and imbricated; (2) sharp scour surfaces occur between and within packstone beds (see Fig. 12F, p. 47); (3) the packstone contains poorly defined, thin, quartz-rich laminae; and (4) granule-sized and, rarely, pebble-sized terrigenous clastic grains are common.

The terrigenous clastic grains within this lithology include plagioclase and microcline feldspars (0.2%), sedimentary (Fig. 22D) (1.0%) and rare metamorphic rock fragments and mono- and polycrystalline quartz (Fig. 22E) (24.9% of the rock by volume). Rare blue quartz grains have also been observed in this lithology. Textural inversions occur between large, well-rounded and smaller, subangular grains. Crude normal grading has produced poorly defined fining-upward

sequences which are commonly 0.5 meters thick and sharply overlain by the succeeding unit. Algae (e.g., Solenopora:Type P, Hedstroemia) are common within this lithology, occurring frequently as large rounded clasts. Additional allochems found within this lithology include ooids, which are typically iron-rich, average 0.5 mm in diameter and exhibit superficial and well-developed cortices (11.1% of the rock volume); echinoderm debris (17.1%); bryozoans (9.3%); ostracodes (0.2%); trilobites (0.7%); micritic and pelloidal intraclasts (7.8%). Echinoderm grains typically exhibit syntaxial sparry calcite overgrowths while the bryozoans occasionally served as a substrate for radiaxial fibrous cement.

The intercalated carbonate and terrigenous clastic lithologies of the McKnight Member of the Ottosee Formation are perceived to represent deposition in the subenvironments of a shelf-margin shallow subtidal oolite shoal complex. Without adequate knowledge of the geometry and the orientation of this and body to the Middle Ordovician shelf-margin, determination of a modern analog to the McKnight Member based on the criteria proposed by Ball (1967) or Hine et al. (1981) is difficult. For this reason, the term "shoal complex" has been employed in the present study. The shoal complex consisted of the following subenvironments: organic buildups including one reef (cf. Nelson et al., 1962) composed of argillaceous echinoderm bafflestone and bryozoan boundstone; rare skeletal sand bank/reef flank deposits composed of skeletal grainstones associated with buildups, the mobile fringe of oolite shoals composed of oolitic packstone and grainstone,

which were transected by tidal channels filled with skeletal oolitic packstone/grainstone containing algae and quartz; terrigenous clastic dominated tidal inlets composed of sedlitharenite and quartz-rich packstone; and perhaps stabilized sand flats? similar in lithology to lithofacies 2 but with abundant superficial ooids and thick bands of stylocumulate.

Strong tidal currents and agitated shallow water (<10 meters) conditions are inferred for the shoal complex based on the presence of abundant herringbone cross-bed sets (Reineck and Singh, 1980) and ooids (Milliman, 1974; Bathurst, 1971). Peak current velocities ranging between 50 and 100+ cm/sec are common in Recent oolitic marine sand belts and tidal-bar belts in the Bahamas (Halley, Harris and Hine, 1983). The occurrence of intraclasts within the oolite, the overall lack of mud and the abundance of grain-supported fabrics observed within the lithologies also support a shallow marine, moderate to high energy environmental interpretation for this shoal complex. The sponge-bryozoan-echinoderm organic buildups and the single reef observed within the McKnight shoal complex may be analogous to the sponge-bryozoan bioherms reported by Bliefnick and Gebelein (1978) from the basinward side of Joulters Cay in the Bahamas. The ooid packstone/grainstone of lithofacies 3 indicates formation within an agitated subenvironment such as a mobile fringe which may have formed either on the basinward margin of the shoal complex as in Joulters Cay (Harris, 1979) or on the crests of tidal bars within the shoal complex (Ball, 1967). Where these shoals were dissected by channels, providing avenues for both the transport of sediment and water across the shoal,

an admixture of grains, e.g., intraclasts of micrite and pelloidal wackestone/packstone, ooids and skeletal grains derived from the various subenvironments of the shoal complex (lithofacies 2) occur. The deposition of the quartz-rich packstone lithofacies 5 and sed-litharenite of lithofacies 4 is believed to have occurred in channels and tidal inlets associated with the shoal complex. The presence of a sharp basal scour, and trough and herringbone cross-stratification are characteristic of both deep and shallow water channels within the seaward portions of tidal inlets (Boothroyd, 1978; Hubbard, Oertel, and Nummendal, 1979). According to Boothroyd (1978), trough and herring-bone cross-stratification are produced by migrating cuspate megaripples which are commonly superimposed on the stoss side of high energy sand waves. These cuspate megaripples form under moderate current velocity, are usually three-dimensional and exhibit a sharp scour surface which is localized within the troughs of the megaripples (Boothroyd, 1978; Costello and Southard, 1981). The sharp, scoured intrabed contacts observed within the quartz-rich packstones of the McKnight Member at LN may have been formed by this type of localized scour. According to Boothroyd (1978), the alternation of ebb- and flood-oriented cuspate megaripples also produces herringbone cross beds. The segregation of grains within this lithotype into quartz-rich laminae conceivably was produced by the selective transport of grains in a manner analogous to that observed within migrating megaripples on tidal floor channels in Shark Bay, Western Australia by Davies (1970). The minimum critical velocity for the transport of granule-size grains as determined from

Hjulstrom's diagram is 40 cm/sec. The presence of blue quartz within these packstones indicates that the terrigenous clastic grains which occur within the McKnight Member of the Ottosee were derived from erosion of part of the complex which is now found exposed in the Smoky Mountains specifically within the Ocoee Supergroup.

"Bays" Formation

The "Bays" Formation, which overlies the McKnight Member of the Ottosee Formation, is exposed only at LN. The contact between these lithostratigraphic units is covered. Only the lowermost part of the "Bays" Formation was investigated during this study.

The "Bays" Formation is characterized by one lithofacies (see Fig. 15, p. 65) composed of medium to thick bedded, ferruginous, quartz-rich skeletal oolitic packstone/grainstone (Fig. 22F) and interbeds of echinoderm-rich oolitic sedlitharenite (Fig. 22G) and greenish-gray limy clastic mudstone. The biota within this lithofacies includes echinoderm debris (5.7%), ramose bryozoans (1.2%), brachiopods (0.4%) and trace amounts of trilobite and molluscan debris. Ooids comprise 26.6% of the rock volume while intraclasts of micrite and pelletal wackestone/packstone account for an additional 4.0% of the rock volume. Ooids are small (≈0.3 mm in diameter), primarily superficial, iron-rich and commonly dolomitized. Terrigenous clastic grains include subangular to subrounded, moderately- to poorly-sorted, monocrystalline quartz (15.9%), and trace amount of plagioclase, chert, and sedimentary and metamorphic rock fragments. Grain size of the clastic component ranges from coarse to fine sand.

The lithologies of the "Bays" Formation are interpreted to represent deposition under moderate energy, shallow subtidal conditions at the interface of an oolite shoal complex and a limy terrigenous shelf lagoon/sand and/or mud flat. The cross-laminae, which were observed within this lithofacies, represent periods of moderate to high current energy. A critical flow velocity of 30 cm/sec as determined from Hjulstrom's diagram is necessary for the transportation of coarse-grained sand. According to Harms et al. (1975) and Reineck and Singh (1980), this current velocity is sufficient to produce small ripples and possibly sandwaves in coarse sand-size sediment at flow depths within 20 cm of the sediment-water interface. Periods of lower current energy allowed mud to settle out of suspension to form mudstone interbeds. The coarser grained laminae which occur within the mudstone interbeds possibly represent traction deposits resulting from brief periods of current reworking.

Summary of the Petrology and Depositional Environments of Upper Tongue of the Lenoir, Holston, Chapman Ridge, Ottosee and Lower Bays Formations

1. The Upper Tongue of the Lenoir Formation overlies the Athens Formation and is composed primarily of carbonate sedimentary rocks containing a minor terrigenous clastic component. The two lithofacies recognized within the Lenoir Formation collectively represent a back-reef lagoon occasionally subjected to storm activity.

2. The Holston Formation overlies the Upper Tongue of the Lenoir Formation and interfingers with it. The Holston, like the Upper Tongue

of the Lenoir, is composed primarily of carbonate rocks with a minor terrigenous clastic component. Three lithofacies were recognized within the Holston which collectively represent a shelf-margin skeletal sand bank/reef flank and reef core complex.

3. The Chapman Ridge Formation is separated from the underlying Holston formation by a corrosion surface. The basal member of the Chapman Ridge, the "orthocone zone," contains two lithofacies that represent a condensed sequence of carbonate and terrigenous clastic rocks deposited along the shelf margin. The "main body" of the Chapman Ridge, which sharply overlies the "orthocone zone," is composed of three lithofacies which represent a progradational-retrogradational outer shelf-shelf margin, storm influenced, mixed terrigenous clastic and carbonate sand wave complex.

4. The Ottosee Formation, which is composed of five members, overlies the Chapman Ridge formation. The Lower Unnamed Shale Member is essentially unexposed at both the HB and LN sections. The Hiwassee Member overlies the Lower Unnamed Shale Member and is composed of two lithofacies which represent deposition of carbonate rocks with a minor terrigenous clastic component in a shelf-margin oolite shoal-organic buildup complex. The Middle Unnamed Shale Member abruptly overlies the Hiwassee Member and also contains two lithofacies. These lithofacies are composed of mixed carbonate and terrigenous clastic rocks which represent deposition in a storm/wave dominated, shelf lagoon/mud flat. The contact between the Middle Unnamed Shale and the McKnight Member is covered. The McKnight Member contains five lithofacies and represents

deposition in a shelf-margin oolite shoal-organic buildup complex dissected by tidal inlets and channels which typically contain coarse grained, mixed terrigenous clastic and carbonate rocks. The presence of such coarse grained clastics in shelf margin shallow water carbonate deposits suggests that prior to the deposition of the McKnight Member of the Ottosee Formation the basin between the tectonic upland to the southeast and the western carbonate shelf had been infilled with sediments. Coarse clastics were transported across this infilled basin to a shelf edge which had developed to the east of a successor basin possibly between the Calhoun study area and the Decatur area (Walker et al., 1983). Processes such as "punctuated mixing," "facies mixing," and "in situ mixing" as proposed by Mount (1984) were probably involved in the mixing of the terrigenous clastic and carbonate sediments in the shallow shelf environments of the McKnight Member.

5. The lower "Bays" Formation overlies the Ottosee Formation, but the contact between the two formations is covered. One lithofacies, composed of mixed terrigenous clastic and carbonate rocks, was recognized within the lower "Bays" and represents sediments deposited along the interface of an oolite shoal complex and a shelf lagoon/sand and/or mud flat.

6. Figure 23 summarizes the complex paleoenvironmental array observed through time within the Calhoun study area and surrounding areas in southern East Tennessee.

Figure 23. Sequential maps illustrating the development of paleoenvironments and lithofacies within the Middle Ordovician of the Calhoun area. SV = Sequatchie Valley, DE = Decatur, P = Prospect, SS = Sweetwater, AT = Athens, MV = Mount Vernon, LN = Louisville and Nashville Railroad, and HB = Henegar Bluff. Area shown is on Figure 13, p. 61. Base maps used are the sediment distribution maps of Walker et al. (1983). Time relationships 1, 2, 3, 4, and 5 are those defined by Benedict and Walker (1978).

Time 0 = Inundation of emergent Knox surface by the Middle Ordovician sea.

Time 1 = *Pygodus serra*-*Pygodus anserinus* Conodont Zonal Boundary.

Time 2 = Base of the *Prioniodus gerdae* Subzone of *Amorphognathus tvaerensis* Conodont Zone.

Time 3 = Based on the progradational and retrogradational sequence of the Chapman Ridge Formation.

Time 3 1/2 = Time halfway between Time 3 and Time 4 during which a successor basin developed on the western carbonate shelf.

Time 4 = Based on the maximum extent of a resurgence of limestone deposition on the western carbonate shelf.

Time 4 1/2 = Time halfway between Time 4 and Time 5.

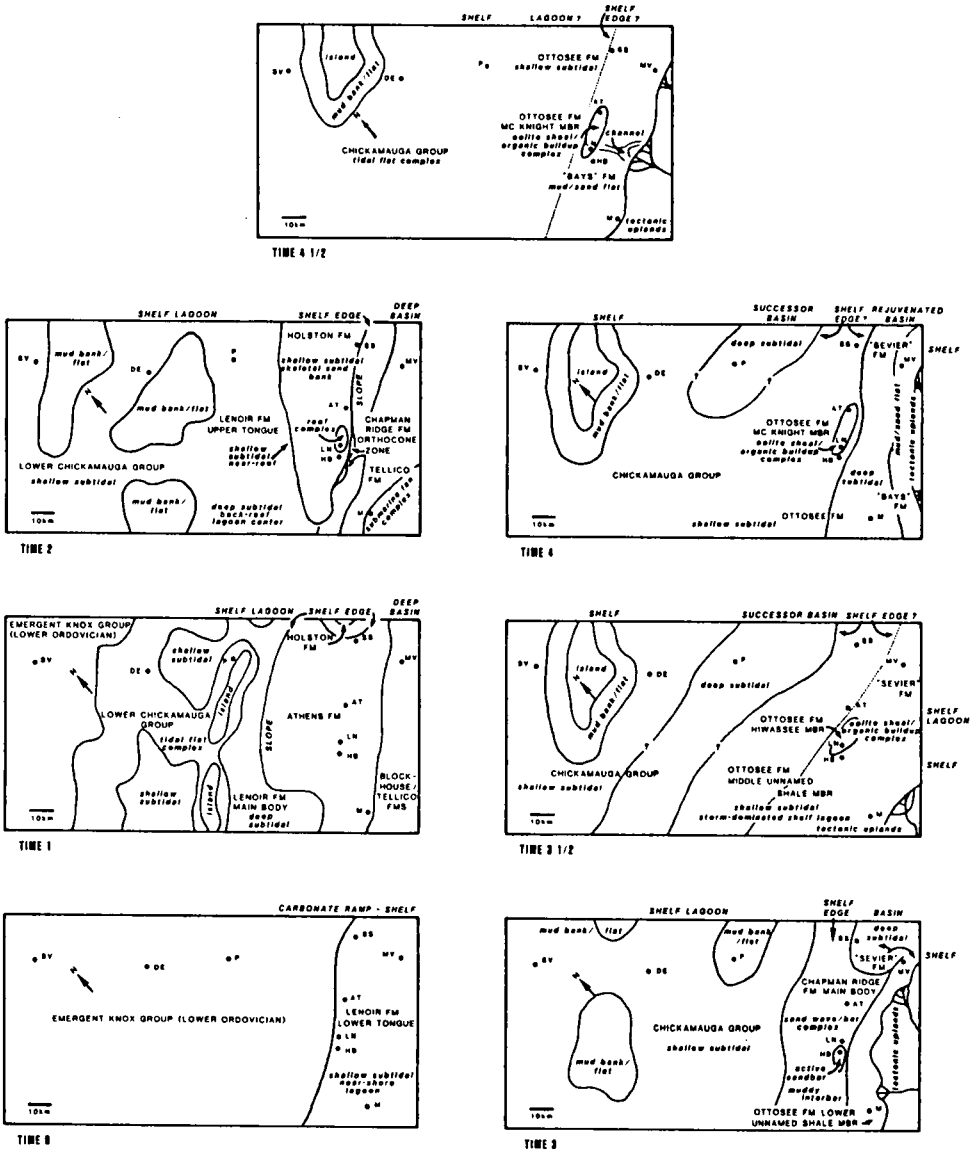

SHELF
LAGOON ?
SHELF EDGE ?
island
mud bank/flat
OTTOSEE FM
shallow subtidal
CHICKAMAUGA GROUP
tidal flat complex
OTTOSEE FM
MC KNIGHT MBR
active shoal/organic buildup complex
channel
"SAYS" FM
mud/sand flat
tectonic uplands
TIME 4 1/2
SHELF LAGOON
SHELF EDGE
DEEP BASIN
HOLSTON FM
shallow subtidal skeletal sand bank
SLOPE
mud bank/flat
LENOIR FM
UPPER TONGUE
reef complex
CHAPMAN RIDGE FM
ORTHOCONE ZONE
shallow subtidal/near-reef
TELLICO FM
LOWER CHICKAMAUGA GROUP
shallow subtidal
deep subtidal back-reef lagoon center
TIME 2
SHELF
SUCCESSOR BASIN
SHELF EDGE ?
REJUVENATED BASIN
deep subtidal
"SEVIER" FM
CHICKAMAUGA GROUP
OTTOSEE FM
TIME 4
EMERGENT KNOX GROUP (LOWER ORDOVICIAN)
LOWER CHICKAMAUGA GROUP
tidal flat complex
ATHENS FM
LENOIR FM
MAIN BODY
deep subtidal
BLOCK-HOUSE/TELLICO FMS
TIME 1
SHELF
SUCCESSOR BASIN
SHELF EDGE ?
"SEVIER" FM
SHELF LAGOON
OTTOSEE FM
HIWASSEE MBR
active shoal/organic buildup complex
CHICKAMAUGA GROUP
shallow subtidal
OTTOSEE FM
MIDDLE UNNAMED SHALE MBR
storm-dominated shelf lagoon
tectonic uplands
TIME 3 1/2
CARBONATE RAMP - SHELF
EMERGENT KNOX GROUP (LOWER ORDOVICIAN)
LENOIR FM
LOWER TONGUE
shallow subtidal near-shore lagoon
TIME 0
SHELF LAGOON
SHELF EDGE
BASIN
mud bank/flat
deep subtidal
"SEVIER" FM
SHELF
CHAPMAN RIDGE FM MAIN BODY
CHICKAMAUGA GROUP
shallow subtidal
sand wave/bar complex
active sandbar
muddy interbar
tectonic uplands
OTTOSEE FM LOWER UNNAMED SHALE MBR
TIME 3

Figure 23.

CHAPTER IV

SUMMARY AND CONCLUSIONS

1. The Middle Ordovician stratigraphic succession above the Athens Formation in the vicinity of Calhoun, Tennessee, was examined in detail at two measured sections, one at Henegar Bluff (HB) in Bradley County and the other at the Louisville and Nashville railroad cut (LN) in McMinn County. The following lithostratigraphic units (from oldest to youngest) are included within this succession: the Upper Tongue of the Lenoir Formation, the Holston Formation, the Chapman Ridge Formation which includes a basal "orthocone zone" overlain by the main body of the Chapman Ridge, the Lower Unnamed Shale, Hiwassee, Middle Unnamed shale and McKnight Members of the Ottosee Formation, and the "Bays" Formation.

2. The Upper Tongue of the Lenoir Formation is comprised of two lithofacies which collectively represent a subtidal, back-reef lagoon environment. The lowermost 1.1 meters of the Upper Tongue of the Lenoir Formation (lithofacies 1) as measured in this study records relatively deep, low energy, subtidal conditions typical of a lagoon center subenvironment in which sediments were commonly burrowed and occasionally reworked by current activity. The upper part of the formation (lithofacies 2) reflects an increase in current/tidal activity which produced thick beds of grain-supported lithologies. Lithofacies 2 represents deposition in a shallow, subtidal back-reef lagoon subenvironment which was in close proximity to the skeletal sand

banks and reef core complex of the Holston Formation. The abundance of algae and the diversity of the fauna suggest that deposition occurred within the euphotic zone under normal marine conditions. The occurrence of Holston-like grain supported lithologies within this lithofacies may be attributed to storm activity during the Middle Ordovician and indicates the contemporaneous nature of these environments. The rare interbeds of sedlitharenite observed within lithofacies 2 may also be the result of storm activity and indicate the proximity of the Calhoun area to a terrigenous clastic sediment source. Based on co-occurrence of specimens of Cahabagnathus sweeti and Prioniodus sp. within the conodont assemblage collected during this study, the Upper Tongue of the Lenoir Formation can be no younger than the Upper Subzone of the Pygodus anserinus Conodont Zone.

3. The Holston Formation in the study area interfingers with the Upper Tongue of the Lenoir Formation. THe Holston represents a shelf-margin, subtidal, skeletal sand bank/reef core complex and contains three lithofacies. Lithofacies 1, represents deposition in a moderate to high energy, shallow subtidal, skeletal sand bank; lithofacies 2, represents deposition in a moderate to high energy, shallow subtidal reef core/flank complex; and lithofacies 3 represents deposition in a moderate to high energy, deep to shallow, reef flank/skeletal sand bank subjected to an influence of terrigenous clastic sediments. Algae, in particular Girvanella, Solenopora, and Kazahkstanelia, occur within all three lithofacies of the Holston but are common in lithofacies 1 and 2 thus suggesting deposition within the euphotic zone. Girvanella may

have acted not only as a sediment producer but also as a sediment binder within the reef-core complex of the Holston. Evidence for disruptions in sedimentation occur in the form of mineral impregnated corrosion surfaces/hardgrounds at the contact between lithofacies 2 and 3 at LN, and also at the contact between the Holston Formation and the overlying "orthocone zone" of the Chapman Ridge Formation particularly at HB. These corrosion surfaces may represent several "drowning" episodes for the Holston during which strong upwelling currents were dominant. The presence of Cahabagnathus sweeti and Prioniodus sp. within samples from the Holston Formation suggest that the base of the formation within the study area lies within the Upper Subzone of the Pygodus anserinus Conodont Zone. The co-occurrence of Cahabagnathus sweeti and Cahabagnathus carnesi in sample HB-14 from Henegar Bluff approximates the Pygodus anserinus-Amorphognathus tvaerensis zonal boundary and thus, allows placement of this zonal boundary at 9.7 meters above the base of the measured section and approximately 244 meters above the post-Knox unconformity at the HB section.

4. The "orthocone zone" of the Chapman Ridge Formation is comprised of two lithofacies which collectively represent a condensed sequence deposited in a shelf-margin environment. Cephalopods, including common actinoceratoid and endoceratoid orthocones and rare tarphyceratid nautiloids, mineral impregnated hardgrounds, ferromanganese nodules and pavements and burrow mottling are common in lithofacies 1. Algae found within this lithofacies includes Renalcis? oncolites and Receptaculites. The ferromanganese nodules, which are

typically nucleated around either cephalopods or mineralized intraclasts, contain laminae of chamosite, hematite, phosphate, micrite and limonite as well as inclusions of carbonate and terrigenous clastic detritus and have been partially encrusted by bryozoans. Lithofacies 2, on the other hand, is a silty shale saprolite containing ferromanganese nodules and is found only at LN. The aforementioned characteristics of the "orthocone zone" indicate that sedimentation rates were low, current activity, particularly by upwelling currents, was high, and water depths were moderate (10-30 m) and probably within the euphotic zone along this shelf-margin environment.

Three lithofacies, which represent a progradational-retrogradational sand wave complex, can be recognized within the "main body" of the Chapman Ridge Formation. The sedimentary structures and fauna observed within all three lithofacies of the "main body" indicate that deposition of this unit took place under shallow, subtidal, current-dominated, normal marine conditions. Lithofacies 1 represents an initial progradational sand wave phase where terrigenous clastic and carbonate sand were transported by traction processes as ripples and sand waves onto a muddy shelf margin. Periods of traction transport of sand, possibly during storms, alternated with periods of quiet water deposition from suspension. Lithofacies 2 represents an active subtidal sand wave environment composed of offshore bars. Lithofacies 3 represents a gradual cessatio of active sand wave migration in the study area and a return to alternating periods of high and low energy similar to those observed in lithofacies 1.

Biostratigraphically important conodonts which have been recovered from the Chapman Ridge Formation include Periodon sp. cf. P. grandis from the "orthocone zone" and Prioniodus sp. and Protopanderodus varicostatus from the "main body." This conodont assemblage suggests that the Chapman Ridge Formation lies within the lower Amorphognathus tvaerensis Conodont Zone near the base of the Prioniodus gerdae Subzone.

5. The Hiwassee Member of the Ottosee Formation consists of two lithofacies which collectively represent a shallow subtidal, shelf margin organic build-up/oolite shoal complex. Lithofacies 1, which is comprised of bryozoan and echinoderm bafflestone and bryozoan boundstone, represents an organic buildup. Lithofacies 2 represents a mobile fringe within an oolite shoal complex interpreted as being deposited in close proximity to the organic buildup of lithofacies 1. The upper part of lithofacies 2 was deposited at some greater distance from the buildups of lithofacies 1. Biostratigraphically significant conodonts have not been recovered from Hiwassee Member samples during this study.

The Middle Shale Member of the Ottosee Formation represents a shelf lagoon complex and abruptly overlies lithofacies 2 of the Hiwassee Member. The Middle Shale Member is composed of two lithofacies. Lithofacies 1 represents a storm-dominated carbonate sand/terrigenous mud shelf lagoon. Sedimentary and biogenic structures are common within the mudrocks (silt shales and wackestones) of lithofacies 1 and include: vertical "escape" burrows, which are indicative

of rapid sedimentation associated with storms; convolute laminations, which originate from the liquifaction of sediment; foreset laminae, produced by oscillatory currents; ripple cross-laminae, common under lower flow regime conditions; lenticular bedding, common in tidal environments; and swaley-cross stratification, which formed above fair-weather wave base in a storm-dominated environment. Lithofacies 2, a lens of bioclastic debris which subdivides lithofacies 1 into an upper and a lower part, represents a skeletal sand bank within the subtidal shelf lagoon environment. Biostratigraphically important conodonts which have been recovered from lithofacies 2 of the Middle Unnamed Shale Member include Prioniodus sp. and Eoplacognathus elongatus which commonly co-occur in the lower part of the Amorphognathus tvaerensis Conodont Zone particularly within the Prioniodus gerdae Subzone.

Five lithofacies can be recognized within the McKnight Member of the Ottosee Formation, which collectively represent a shallow subtidal, shelf margin organic buildup/oolite shoal complex similar to that proposed for the Hiwassee Member. Lithofacies 1 represents shallow water organic buildups and includes a single reef composed of bryozoan and echinoderm bafflestone, and bryozoan boundstone. These buildups are typically overlain by skeletal oolitic packstone (lithofacies 2) which represent channels transecting the mobile fringe of the shoal complex. An oolitic sedlitharenite (lithofacies 4) overlies and scours into the bryozoan boundstone reef of lithofacies 1. The oolitic grainstone of lithofacies 3 represent active shoal margin. The

quartz-rich packstones of lithofacies 5 which commonly contain granule sized terrigenous clastic grains represent channels in a tidal inlet associated with the shoal complex. A single specimen of Proto-panderodus varicostatus was recovered from the McKnight Member and indicates that the McKnight Member is probably no older than the Prioniodus gerdae Subzone of the Amorphognathus tvaerensis Conodont Zone.

Therefore, the Ottosee Formation in the Calhoun area represents a shallow subtidal, shelf margin, oolite shoal/organic buildup/lagoon complex. Conodont evidence suggests that most of Ottosee deposition occurred in the lower Amorphognathus tvaerensis Conodont Zone and probably within the Prioniodus gerdae Subzone.

6. One lithofacies was recognized within the lowermost "Bays" Formation. This lithofacies represents the interface between an oolite shoal and a clastic dominated lagoon/mud flat. Biostratigraphically significant conodonts were not recovered from the "Bays" Formation.

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APPENDIXES

APPENDIX A

MEASURED SECTION DESCRIPTIONS

EXPLANATORY NOTE

The stratigraphic units in the following section have been described in ascending order from oldest to youngest. Cumulative thicknesses of units, as well as sample number locations, have been given with reference to the base of the sections as measured for this study and not in meters above the post-Knox unconformity. Underlined sample numbers have had thin sections prepared from them; twice underlined thin sections have been point counted. Starred sample numbers have been processed for microfossils and sample numbers followed by (P) [e.g., HB-3 (P)] have had acetate peels prepared from them.

Both of these sections, HB and LN, were originally measured and described by Smith (1976) and have been described in a modified form by Walker (1977d,e).

MEASUREMENT CONVENTIONS

The bed thickness reference terms of McKee and Weir (1953), modified by Ingram (1954) and the grain-size terminology standardized by Wentworth (1922) have been utilized in the description of units in this study. Rock nomenclature in this study follows the classification of Dunham (1962) for carbonate lithologies and that of Folk (1968) for terrigenous clastic lithologies.

Bed thickness: [after McKee and Weir (1953) as modified by Ingram (1954)]

Very thick bedded	greater than 1.0 m
Thick bedded	0.3 - 1.0 m
Medium bedded	0.1 - 0.3 m
Thin bedded	0.03 - 0.1 m
Very thin bedded	0.01-0.03 m
Laminated	0.003 - 0.01 m
Thin laminated	less than 0.003 m

Grain size: [after Wentworth (1922)]

Pebbles	4 - 64 mm
Granules	2 - 4 mm
Sand	
Very coarse	1 - 2 mm
Coarse	1/2 - 1 mm
Medium	1/4 - 1/2 mm
Fine	1/8 - 1/4 mm
Very fine	1/16 - 1/8 mm
Silt	1/256 - 1/16 mm
Clay	less than 1/256 mm

HENEGAR BLUFF (HB) SECTION

Approximately 310 meters of Middle Ordovician sedimentary rocks are exposed along with the south side of Upper River Road near Henegar Bluff along the Hiwassee River in Bradley County, Tennessee. This section is located approximately 4 km southeast of Charleston, Tennessee. The part of the HB stratigraphic section measured for this study lies between N35°15'11" and N35°15'14" and W84°43'48" and W84°42'54". The base of the Henegar Bluff section, as measured, described and sampled for this study, is located approximately 232 meters above the post-Knox unconformity in the Upper Tongue of the Lenoir Formation.

Unit Number	Unit Thickness	Cumulative Thickness	Description
1	0.9	0.9	Lenoir Formation: Upper Tongue Next 3 units. Blue-gray, very fine to fine grained, laminated to very thin, wavy and cobbly bedded calcareous siltstone (burrowed argillaceous wackestone). Laminations are commonly wavy and discontinuous and also exhibit normal grading from quartz silt at the base to clay at the top. Cross lamination is vary rare. Weathering produces cobbles of wackestone approximately 3 cm in

			diameter. The sparse fauna includes trilobites, sponge spicules, ostracodes, Girvanella and echinoderm debris. Samples: HB-1, 0.0 m; HB-2, 0.0 m; HB-3*(P), 0.4 m.
2	4.3	5.2	Light to medium blue gray, coarse to fine grained, thin to medium, wavy bedded sandy limestone interbedded with gray, laminated calcareous siltstone and light gray, thin bedded, very fine to fine grained calcareous sandstone. The limestone beds are sandy fossiliferous wackestones and packstones; the sandstone is a very poorly fossiliferous sedlitharenite. Rare cross-laminations were observed in the limestone. fossil debris includes: bryozoans, brachiopods, ostracodes, echinoderms, trilobites, rare hexactine sponge spicules and gastropods. The alga Girvanella occurs as clumps and also as an encrustation especially on bryozoans. Additional algae include Hedstroemia, Kazahstanelia and Solenopora: Type P. Intraclasts are common, some have been burrowed.

			Samples: HB-4, 0.9 m; HB-5, 1.1 m; HB-6*(P), 1.2 m; HB-7*, 1.9 m; HB-8, 2.9 m; HB-10*(P), 3.1 m; HB-9, 3.7 m; HB-11, 5.1 m.
3	0.3	5.5	Medium blue gray, coarse to fine grained, thin, wavy and cobbly bedded, argillaceous limestone. The limestone is a fossiliferous wackestone to packstone containing echinoderm and bryozoan debris. Sample: HB-12-1, 5.3 m.
4	13.4	18.9	Holston Formation: Next 2 Units. Light to medium blue gray, coarse to medium grained, medium to thick bedded fossiliferous limestone. The packstone and grainstone comprising this limestone contain abundant echinoderm and bryozoan debris. Brachiopods, trilobites, ostracodes, and the algae Girvanella and Hedstroemia are also found in this unit. Disseminated grains of very fine grained quartz sand occur within this unit. Samples: HB-12*(P), 5.5 m; HB-13, 7.6 m; HB-14*, 14-1, 9.7 m; HB-15, 11.2 m; HB-16*(P), 13.6 m; HB-17, 16.3 m.

5	6.6	25.6	Light, mottled grayish red, coarse to medium grained, medium to thick bedded limestone. The limestones are grainstones and packstones; lime mud and quartz sand increase at the top of the unit. The upper 2 meters of this unit contains abundant sulfides in "pods" and in the stylocumulate within the limestone which upon weathering imparts a heavy rust colored stain to the outcrop. Bryozoans, brachiopods, echinoderms, trilobites, gastropods, cephalopods and ostracodes comprise the fauna of this unit. Hedstroemia and Girvanella comprise the flora. The upper contact of this unit with the basal "orthocone zone" of the overlying Chapman Ridge Formation is very sharp. Samples: HB-18*(P), 18.9 m; HB-19*, 22.0 m; HB-20*(P), 23.7 m; HB-21* 21-1, 21-2, 21-3*, 25.5 m.
6	3.0	28.6	Chapman Ridge Formation: Orthocone Zone. Medium gray, coarse to fine grained, very thick bedded, bioturbated sandy limestone at the base to sandy

siltstone at the top. The limestones are wackestones to packstones and exhibit numerous mineral impregnated hardgrounds. Actinoceratoid and endoceratoid orthocone cephalopods are abundant; tarphyserid nautiloid and annulate orthocone cephalopods are rare. Some orthocone shells appear to be current lineated. Additional fauna includes trilobites, ostracodes, bryozoans, sponge spicules, brachiopods and echinoderm debris. Algae include Girvanella and Solenopora. The gastropod, Raphistoma sp., was also observed in this unit. Nodules comprised of chamosite, hematite ± limonite are common and form pavements towards the top of the unit. These nodules are nucleated around intraclasts and/or cephalopods and are partially encrusted by bryozoans. Horizontal and vertical burrows are common throughout the unit; intraclasts are commonly mineralized. Samples: HB-22*, 22-1*, 22-2, 25,6 m; HB-55(P), 26.0 m; HB-23*(P), 26.3 m;

			HB-28(P), 26.4 m; HB-24*, 26.6 m; HB-30*, 26.8 m; HB-29(P), 28.4 m; HB-25, 25-1, 25-2, 28.6 m.
7	6.2	34.8	Chapman Ridge Formation: Main Body. Next 4 Units. Light blue-gray, medium to fine grained, thin bedded, cross-stratified calcareous sandstone interbedded with discontinuously laminated silty shales. The base of this unit is in sharp contact with the scoured surface of the orthocone zone below and is marked by a lag of intraclasts in the lowermost bed. The silty shale-calcareous sandstone interbeds attain a maximum thickness of 3 cm and are horizontally burrowed. The calcareous sandstone beds are sedlitharenites which exhibit load structures, sharp scoured bases, rippled? tops and planar and trough? cross-laminae. Abraded skeletal debris occurs as lag within the cross-laminations. Samples: HB-26, 26-1*(P), 28.6 m; HB-27, 28.7 m; HB-37(P), 37-1, 28.9 m; HB-31(P), 29.9 m; HB-32, 32-1, 30.3 m;

			HB-33*(P), 31.0 m; HB-34, 31.4 m; HB-35*(P), 32.8 m; HB-36*, 34.8 m.
	3.0	37.8	Covered Interval
8	3.1	40.9	Light to medium blue-gray, medium to fine grained, very thick to thin bedded, ferruginous, cross-stratified calcareous sandstone (sedlitharenite). Fossils are commonly abraded and include echinoderms, brachiopods, bryozoans, ostracodes, worm tubes, trilobites and Hedstroemia. Samples: HB-47, 38.3 m; HB-48*, 40.8 m.
	7.6	48.5	Discontinuous saprolitic exposures of Unit 8 lithology.
9	1.2	49.7	Light reddish blue-gray, medium to fine grained, medium to thin bedded, cross-stratified, bioturbated, ferruginous sandstone (sedlitharenite). Debris from echinoderms, bryozoans, brachiopods and trilobites is included within relatively quartz-free, fossiliferous laminations observed throughout this unit. Weathering has produced a friable, red, sandy "rind" on the outcrop. Samples: HB-49(P), 48.5 m; HB-50, 49.4 m.

	5.8	55.5	Covered Interval
10	18.4	73.9	Light reddish blue-gray, medium to fine grained very thin to thick bedded, cross-stratified, ferruginous sandstone interbedded with gray, laminated to very thinly bedded, silty shales and/or shaley siltstones which increase in thickness and frequency towards the top of the unit. The sandstones include both sedlitharenites and quartz-rich packstones. Fossils include echinoderms, bryozoans, ostracodes, trilobites and brachiopods. Horizontal burrows are common within the silty shale interbeds. The unit has been folded. Samples: HB-38, 55.5 m; HB-39, 57.7 m; HB-40, 60.3 m; HB-41(P), 61.7 m; HB-42*, 63.4 m; HB-43, 65.0 m; HB-44, 67.5 m; HB-45, 69.7; HB-46, 70.6 m; HB-51, 71.9 m; HB-52*(P), 72.7 m; HB-53(P), 73.8 m; HB-54*, 73.8 m.

LOUISVILLE AND NASHVILLE (L AND N) RAILROAD SECTION

Approximately 780 meters of Middle Ordovician sedimentary rocks are exposed along the L and N Railroad spur between Calhoun and Benton

in a cut just north of Sky Light Road in McMinn County, 2.1 km east-southeast of Calhoun, Tennessee. The section measured in this study lies between W84°41'55" and W84°43'22" and N35°17'15" and N35°17'19". The base of the section, as measured, described and sampled from this study, is located ≅244 meters above the post-Knox unconformity in the Upper Tongue of the Lenoir Formation.

Unit Number	Unit Thickness	Cumulative Thickness	Description
1	1.1	1.1	Lenoir Formation: Upper Tongue: Next 3 Units. Medium blue-gray, fine grained laminated to very thin, wavy to nodular bedded, calcareous siltstone (argillaceous wackestone). The fauna includes brachiopods, bryozoans, ostracodes and trilobites (including Loncodomas). Horizontal burrows are rare. An oncolite, formed by Spongiostroma? encrusting a bryozoan, represents the flora. This unit is similar to Unit 1 at HB. Sample: LN-1(P), 0.2 m.
2	10.0	11.1	Tan to bluish-gray, coarse grained, thin to very thin bedded, fossiliferous limestone (packstone/grainstone) interbedded with gray, fine to coarse grained, thin,

wavy to cobbly bedded calcareous siltstone (argillaceous wackestone). Trilobites including Lonchodomas, bryozoans and echinoderms are common in the packstone-grainstone and ramose bryozoans comprise the most common allochem in the wackestone. Both Girvanella and Spongiostroma? occur as encrustations on ramose bryozoans. Girvanella also occurs as clumps of intertwined tubules within the matrix. Hedstroemia is rare in the packstone-grainstone. Solenopora becomes common at the top of the unit. Silicification of allochems, especially in the packstone-grainstone between 4.8-5.0 meters above the base of the section, is common. The argillaceous wackestone exhibits horizontal burrows, discontinuous laminae and a coarsening upwards of framework grains.

Samples: LN-2*, 1.5 m; LN-3, 2.6 m; LN-4, 4.8 m; LN-5*(P), 5.0 m; LN-6, 5.1 m; LN-7(P), 5.8 m; LN-8*, 6.8 m; LN-9*(P), 8.0 m; LN-10*(P), 9.2 m; LN-11*, 10.1 m.

3	2.5	13.6	Mottled pink and gray, coarse grained, medium bedded, fossiliferous limestone interbedded with gray, fine to coarse grained, thin, wavy to cobbly bedded, calcareous siltstone (argillaceous wackestone). The limestones are packstones-grainstones comprised of ramose bryozoans, brachiopods, echinoderms, ostracodes, trilobiles and algae (Solenopora in the packstones and Spongiostroma oncolites nucleated around fragments of ramose bryozoans in the wackestone). Boundstone "cobbles" occur towards the top of the unit within the packstone-grainstone. Samples: LN-12, 11.1 m; LN-13*, 13-1*, 13.0 m.
4	2.5	16.1	Holston Formation: Next 4 Units. Mottled tan and pink, medium to coarse grained, very thick bedded (massive), fossiliferous limestone (wackestone, packstone and boundstone). The biota includes encrusting and ramose bryozoans, echinoderms, triactine sponge spicules, trilobites, ostracodes,

			Solenopora, Hedstroemia, Spongiostroma? and Girvanella (clumps and oncolites). Traces of quartz sand occur in this unit. Samples: LN-15*, 14.0 m; LN-14*, 14.6 m; LN-16-1*(P), 16-2*, 15.9 m.
5	1.2	17.3	Mottled tan, red and gray, fine to medium grained, very thick bedded (massive) limestone (wackestone-packstone). Encrusting and ramose bryozoans, brachiopods, echinoderms and an orthocone cephalopod comprise the fauna. Contact with the underlying unit is marked by a hummocky stylolite. Samples: No samples taken.
6	8.8-5.2	26.1	Complex intergradations of (1) mottled, medium blue-gray and pink, medium to fine grained, sandy fossiliferous limestone (wackestone-packstone), (2) medium red, fine grained limestone with abundant encrusting bryozoans (boundstone) and (3) mottled pink coarse grained, fossiliferous limestone (packstone) are common within this unit. A lens of gray, fine grained, very thin, wavy to

nodular bedded argillaceous limestone (wackestone) pinching out to the east underlies a small bryozoan lime mud mound (≅1.0 m x 1.0 m) with a 0.2 m thick stromatactis at the base. Encrusting and ramose bryozoans, echinoderms, orthocone cephalopods, sponge spicules, brachiopods, ostracodes, and trilobites make up the fauna. A diverse flora includes Vermiporella?, Kazahkstanelia, Solenopora, Hedstroemia, Spongiostroma?, and Girvanella clumps, oncolites and encrustations. The unit is poorly exposed at the base and thins to the east. The sharp, irregular contact with the overlying unit possibly represents a corrosion surface. Quartz is present in this unit in trace amounts.

Samples: LN-159, 18.8 m; LN-17-1*(P), 17-2, 20.5 m; LN-18, 20.6 m; LN-19*(P), 20.9 m; LN-20, 21.0 m; LN-25, 21.3 m; LN-158, 21.7 m; LN-45, 22.0 m; LN-26*, 22.1 m; LN-27, 27-1, 22.5 m; LN-21, 21-1, 24.1 m; LN-22(P), 25.9 m.

7	8.9-12.5	35.0	Medium blue gray, medium to coarse grained, thin to medium bedded, quartz-rich fossiliferous limestone (packstone-grainstone). Trilobite debris is rare while that of ramose bryozoans, brachiopods and echinoderms is abundant. The algae Solenopora, and Hedstroemia, along with Girvanella oncolites occur at the top of the unit. Mineral stained (Fe?) intraclasts occur throughout this unit but are not common. Horsetail stylolites are common. The packstones-grainstones become sulfide-rich, friable and poorly exposed within a few meters of the top of this unit. Two 0.1 meter thick shales, one at the base and the other at the top of the unit, separate this unit from overlying and underlying units. The unit thickens to 12.5 meters toward the east side of the outcrop. Samples: LN-29, 22.6 m; LN-28*(P), 22.8 m; LN-30*, 24.3 m; LN-31, 25.9 m; LN-23, 26.1 m; LN-24*, 26.5 m; LN-32*(P), 27.1 m; LN-33*, 30.0 m; LN-34, 32.7 m; LN-35*, 33.9; LN-36*, 34.9 m.

8	1.6	36.6	Chapman Ridge Formation: Orthocone Zone. Next 2 Units. Mottled tan-gray, very thin to thin bedded, fine to coarse grained, sandy, orthocone-rich limestone (wackestone-packstone) with boundstone patches. Algae include Girvanella, Hedstroemia, Receptaculites, Spongiostroma? along with Renalcis? oncolites. The fauna is comprised of actinoceratoid and endoceratoid orthocone cephalopods, ramose and encrusting bryozoans, trilobites, brachiopods and ostracodes. The unit is poorly exposed especially towards the top. Mineralized hardgrounds though not as well preserved as at HB were observed from samples obtained from the top of this interval. Samples: LN-37*, 37-1, 35.0 m; LN-38, 35.1 m; LN-39, 35.5; LN-40(P), 36.4 m.
	0.4	37.0	Covered Interval
	0.6	37.6	Gray, coarse grained, cobbly bedded, sandy limestone (wackestone-packstone) similar to previous subunit described. Samples: None collected.
	2.6	40.2	Covered Interval

9	0.9	41.1	Light greenish gray silty shale. Weathers to produce yellow-brown chips. Contains abundant, large single and compound Fe/Mn nodules similar to those found in the HB section. Fauna includes both ramose and encrusting bryozoans, echinoderms, ostracodes and trilobites. Samples: LN-41, 40.2 m; LN-42(P), 41.0 m.
	4.3	45.4	Light tan-yellow sandy saprolite. Weathers to shaley chips as above. Samples: None collected.
10	0.4	45.9	Chapman Ridge Formation: Main Body. Next 3 Units. Mottled tan-gray, fine grained, thin wavy bedded, calcareous sandstone (sedlitharenite) interbedded with thin laminated shaley saprolite. Fossil allochems include echinoderm and bryozoan debris. Siltstone intraclasts are common; ooids are rare. The contact with the underlying shaley saprolite of the orthocone zone is sharp and erosive. Samples: LN-43, 45.4 m; LN-45, 45.6 m.
	9.1	55.0	Covered Interval
11	0.5	55.5	Mottled reddish brown, fine to medium grained, very thin to thin, wavy bedded,

			cross-stratified calcareous sandstone (sedlitharenite) interbedded with silty shaley saprolite and rare quartz-rich packstone. Fossil debris is common in this unit but not readily identifiable. Trace fossils occur along the base of the bed at 55.1 meters. Samples: LN-46, 55.0 m; LN-47, 55.1 m; LN-48, 55.3 m.
	4.0	59.6	Covered Interval
12	3.9	63.4	Medium reddish brown, cross-stratified, fine to coarse grained, thin wavy bedded, quartz-rich, ferruginous fossiliferous limestone (quartz-rich packstone) interbedded with calcareous sandstone (sedlitharenite) and shaley saprolite. Fragmented and abraded brachiopod, bryozoan, echinoderm and trilobite grains are common. Sample: LN-49, 59.5 m.
	97.4	160.8	Covered interval (which includes the upper part of the Chapman Ridge Formation, the entire Lower Unnamed Shale Member of the Ottosee Formation and the base of the Hiwassee Member of the Ottosee Formation).

13	0.5	161.3	Ottosee Formation: Hiwassee Member. Next 5 Units. Mottled gray-tan, fine to coarse grained, thin, wavy to cobbly bedded, argillaceous limestone containing abundant in situ echinoderm holdfasts. In addition, this limestone (an argillaceous wackestone/echinoderm bafflestone) contains abundant echinoderm plates and columnal segments, ramose bryozoans, monaxon sponge spicules, brachiopods, ostracodes, trilobites, a single cephalopod and clumps of Girvanella. Ooids are rare. This lithology weathers to pinnacle outcrops. Samples: LN-51*, 160.9 m; LN-52, 161.2 m.
	1.8	163.1	Covered Interval
14	1.0	164.1	Light gray-brown, coarse to medium grained, thick bedded (massive), fossiliferrous oolitic limestone (echinoderm ooid packstone/grainstone). Fossils commonly occur as lag within cross-laminations and include articulated echinoderm columnal segments,

			ostracodes, trilobites, ramose bryozoans and the algae, Hedstroemia. The majority of the ooids are well developed and exhibit both radial and concentric fabrics. Some superficial ooids were also observed. Weathering of this lithology has produced a pinnacle outcrop.
			Sample: LN-53*, 163.9 m.
	0.1	164.2	Covered Interval
15	0.9	165.1	Mottled reddish-brown gray argillaceous limestone (bryozoan-echinoderm wackestone/bafflestone) similar to Unit 13. The fossil assemblage includes sponge spicules, encrusting and ramose bryozoans, ortracodes and trilobites. In addition, echinoderm debris which includes a plate from the eocrinoid Ulrichocystis eximia Bassler is present. Pinnacle outcrops have been produced by weathering.
			Samples: LN-55, 164.2 m; LN-54 (West), LN-56*(P), 165.0 m.
	0.5	165.6	Covered Interval
16	0.4	166.0	Mottled blue-gray argillaceous limestone. The limestone consists of

			echinoderm wackestone/bafflestone similar to that of Units 13 and 15. Sample: LN-57, 165.8 m.
	0.5	166.5	Covered Interval
	2.0	168.5	Mottled gray argillacous limestone (echinoderm wackestone/bafflestone and echinoderm-bryozoan boundstone). Except for the presence of Girvanella, and abundant encrusting bryozoans, this unit is similar to the units previously described. Samples: LN-58*(P), 166.5 m; LN-59*, 167.5 m; LN-60*(P), 168.4 m.
	16.0	184.5	Covered Interval
17	6.8	191.3	Light tan-gray, coarse to fine grained, thick, wavy bedded oolitic limestone (grainstone). Ooids are usually large (≅0.6 mm in diameter), well developed and exhibit raidal-concentric and concentric fabrics. Smaller, less well developed ooids were also observed. Beds appear to be slightly wedge-shaped and possibly trough cross-bedded. Fossil debris is conspicuously absent from this lithology except as nuclei for ooids.

Samples: LN-61, 184.5 m; LN-62, 185.0 m; LN-63, 187.3 m; LN-64, 189.5 m; LN-65, 191.2 m.

18	8.2	199.5	Ottosee Formation: Middle Unnamed Shale Member. Next 3 Units. Light brownish-gray, very fine grained, laminated, calcareous siltstone (silt shale) with interbeds of cobbly, calcareous sandy siltstone (quartz-rich wackestone). Laminations are commonly planar and discontinuous; cross lamination is rare. Most laminae are normally graded; horizontal and vertical burrows disrupt some of the laminae. Siltstone chips and small cobbles of wackestone generally less than 3 cm in diameter are produced upon weathering of the outcrop. Poorly preserved graptolites including dendroids occur 1.4 meters above the base of the unit. These are the only macrofossils observed in the unit but sponge spicules, ostracode valves and unidentifiable fossil debris can be seen microscopically. At the poorly exposed base of the unit, a small drag fold

			occurs. The contact with the underlying oolitic limestone of the Hiwassee Member though very poorly exposed, appears sharp.
			Samples: LN-66(P), 192.7 m; LN-67(P), 192.8 m.
19	0.6-2.0	201.5	Medium blue-gray, coarse to fine grained, thick to thin bedded, fossiliferous limestone consisting of sandy packstone at the base and wackestone-packstone at the top. Brachiopods, bryozoans, echinoderms and trilobites are abundant; hexactine sponge spicules and clumps of Girvanella are also present. Many fossil allochems have undergone silicification. Some intraclasts have been burrowed. This unit is wedge to lens-shaped, thickening to 2.0 meters at the east end of the outcrop. The basal contact between this unit and the unit below is sharp whereas the upper contact is gradational over an interval of 6 cm.
			Samples: LN-68*, 199.5 m; LN-69*(P), 199.9 m; LN-70*(P), 70-1, 70-2, 70-3*, 201.4 m.

20	5.8	207.3	Interbedded, light blue gray, fine to very fine grained, laminated calcareous siltstone (silt shale) and orange gray, fine to very fine grained, wavy, very thin to thin cobbly-bedded, calcareous, sandy siltstone (quartz-rich wackestone). Subjacent wackestone couplets are separated from each other by ≅8 cm of shale and have sharp upper and lower contacts. Vertical and horizontal burrows occasionally disrupt the laminae in the shale. Vertical "escape" burrows are present within the shales; cross-laminations are present within wackestones. Weathering gives this unit a dimpled, pock-marked appearance. Sponge spicules, trilobites, brachiopods, echinoderms and Girvanella comprise the biota of this unit. Samples: LN-70(P), Float; LN-74(P), 203.8 m; LN-73(P), 204.7 m; LN-75, 206.1 m; LN-76(P), 207.1 m.
	5.8	213.1	Covered Interval
	8.8	221.9	Lithology similar to that of Unit 20. Samples: LN-77(P), 213.9 m; LN-78, 221.5 m.

	19.3	240.1	Covered interval (includes the top of the Unnamed Shale and the base of the McKnight Member).
			Ottosee Formation: McKnight Member. Next 21 units. Note: Due to the very poor, discontinuous (pinnacle) nature of the exposure of the lowermost 35 meters of the McKnight Member along the north side of the railroad, the well exposed outcrop along the south side of the tracks was measured. However, several north side exposures have been projected into this section. Above this 35 meter interval, the exposure along the south side of the exposure becomes very poor and discontinuous. Therefore, the measurement of the section was continued along the much better exposed outcrop on the north side of the railroad. Samples collected from either north or south side outcrops are labeled as such.
21	10.5	250.6	Mottled brownish-pink and gray, coarse to fine grained, thick to medium bedded, fossiliferous oolitic limestone (echinoderm ooid packstone). Echinoderm debris

consists of disarticulated plates and columnals decreasing in abundance ≅4 meters above the base of the unit. A 2.4 meter thick, mottled brownish gray, coarse to fine grained, very thick bedded (massive), argillaceous limestone (echinoderm bafflestone and bryozoan boundstone) is exposed between 240.1 and 242.5 meters above the base of the section along the north side of the traces. Abundant in situ echinoderm holdfasts along with echinoderm debris, ramose and encrusting bryozoans, sponge spicules, worm tubes, ostracodes, trilobites and Girvanella comprise the fauna of the bafflestone and boundstone. A few well developed ooids, exhibiting a radial-concentric fabric, are present in these lithologies which are overlain by a 0.6 meter covered interval which is in turn succeeded by a pinnacle outcrop of oolitic limestone, fossiliferous at the base to nearly pure oolite at the top. Samples: LN-79N, 240.3 m; LN-80N*(P), 241.6 m; LN-81S, 241.6 m.

	0.5	251.1	Covered Interval
22	1.0	252.1	Mottled medium reddish purple gray, coarse to fine grained, thick bedded, cross-stratified oolitic, fossiliferous limestone (ooid-echinoderm packstone-grainstone) interbedded with fossiliferous limestone (echinoderm wackestone/bafflestone and oolitic wackestone to packstone). The oolitic grainstone appears to have a sharp erosive basal contact with the underlying wackestone-packstone. The fauna includes a sponge clast, and bryozoan, trilobite and echinoderm debris in the packstone-grainstone while in situ echinoderm holdfasts, plates, and columnal segments, ramose and encrusting bryozoans, ostracodes, sponge spicules and trilobites comprise the fauna in the wackestone/bafflestone. The contact with the overlying unit is marked by a stylolite. Along the north side of the cut between 250.1-254.0 m is a 3.9 meter thick, mottled reddish brown-gray, coarse to fine grained, medium to thick

			bedded, argillaceous, fossiliferous limestone (echinoderm wackestone/ bafflestone). In situ echinoderm holdfasts and ramose and encrusting bryozoans are abundant; trilobites, ostracodes, sponge spicules, the alga Girvanella, and ooids also occur within this lithology. The contact with the overlying oolite is sharp. Samples: LN-82S, 251.1 m; LN-83S(P), 252.0 m; LN-92N, 253.4 m.
23	9.7	261.8	Mottled brownish blue-gray, coarse to fine grained, herringbone cross-bedded oolitic limestone (echinoderm ooid packstones and grainstones). Brachiopods, articulated echinoderm columnal segments and plates representing Archaeocrinus pecularis and unidentified camerates and inadunates, ramose bryozoans and trilobites comprise the major fossil allochems. Samples: LN-84S*, 252.4 m; LN-85S*, 256.4 m; LN-86S, 256.7 m; LN-87S, 261.1 m; LN-88S, 261.3 m; LN-89S*(P), 261.4 m.

24	2.4	264.2	Mottled brownish blue-gray, coarse to fine grained, herringbone cross-bedded oolitic limestone (ooid grainstone). Fossil debris is rare in this unit and exclusively echinoderm in origin. Samples: LN-90S, 261.8 m; LN-91S(P), 264.3 m.
	4.9	269.1	Covered Interval Note: Continued measurement of the section along the north side of the railroad cut.
25	39.4	307.5	Mottled blue-gray, coarse to fine grained, medium to thick bedded oolitic limestone (ooid packstone/grainstone) containing lenses of coarse to fine grained fossil debris, oncolites, cephalopods, bryozoans, brachiopods and echinoderm. This unit is cross-bedded in part. Samples: LN-93, 270.8 m; LN-94, 273.2 m; LN-95, 278.8 m; LN-96, 287.0 m; LN-97, 293.4 m; LN-98, 290.8 m; LN-99, 307.1 m.
26	3.1	310.6	Medium pink, coarse to fine grained, medium to thick bedded oolitic limestone

			(ooid packstone/grainstone) with thin lenses of coarse to fine grained fossil debris consisting primarily of echinoderm columnal segments. Samples: LN-100, 100-1, 310.6 m.
	31.0	341.6	Covered Interval
27	1.0	342.6	Mottled blue-gray, coarse to fine grained, thick bedded, cross-stratified oolitic limestone (ooid packstone/grainstone). Cross-laminae are particularly echinoderm-rich. Hummocky stylolites in this unit contain ≅2 cm thick stylocumulate bands. Sample: LN-101, 341.6 m.
	1.1	343.7	Covered Interval
	1.9	345.6	Gray, oolitic limestone (oolitic packstone/grainstone). Similar to lithology previously described. Sample: LN-109(P), 345.5 m.
	0.9	346.5	Covered Interval
	2.7	348.2	Gray, oolitic limestone (oolitic packstone/grainstone). Similar to lithology previously described. Sample: LN-103, 348.0 m.
	0.3	348.5	Covered Interval

28	5.9	354.4	Mottled tan-pink-gray, coarse to fine grained, thick bedded, fossiliferous oolitic limestone (ooid packstone/ grainstone). This unit contains abundant ramose bryozoans, echinoderm debris and Solenopora. Sample: LN-104, 354.3 m.
29	4.4	358.8	Mottled gray-brown, coarse to fine grained, medium to thick bedded fossiliferous oolitic limestone (ooid packstone to grainstone). Echinoderm columnal segments and plates are abundant; brachiopods and ostracodes are also represented in the fauna. A lens of very coarse quartz sand occurs in the upper half of the unit (356.1 meters above the base of the section). Samples: LN-105*, 356.1 m; LN-106, 356.6 m; LN-107(P), 357.6 m.
	2.2	361.0	Covered Interval
30	1.6	362.6	Mottled blue-gray-brown, fine to medium grained, very thick bedded, calcareous oolitic sandstone (sedlitharenite). Herringbone cross-beds are common. Echinoderm debris includes an

			unidentified camerate plate. Thick stylocumulate can be observed. Sample: LN-108, 361.9 m.
31	1.7	364.3	Mottled gray-brown, fine to coarse grained, very thick bedded, cross-stratified sandy, fossiliferous limestone (ooid packstone and grainstone). Granule to pebble size metamorphic and sedimentary rock fragments and chert occur with coarse quartz sand as lag within cross laminations. The terrigenous clastic component of this unit exhibits a textural inversion with large grains being well rounded and smaller grains being subangular. This unit also contains abundant articulated echinoderm plates and columnal segments. Trilobites, brachiopods, ramose bryozoans and rare ostracode comprise the rest of the fauna. Abraded and rounded fragments of the algae Solenopora and Hedstroemia are also present. Ooids observed exhibit well developed as well as superficial cortices.

			Samples: LN-111*(P), 362.9 m; LN-109, 363.2 m; LN-110, 363,3 m; LN-112*, 363.7; LN-113, 364.3 m.
	28.9	392.3	Covered Interval
32	1.3	393.6	Mottled gray-red, coarse to fine grained, very thick bedded (massive), argillaceous fossiliferous limestone (sponge-echinoderm-bryozoan wackestone/ bafflestone). In situ echinoderm holdfasts have been observed along with trilobite debris, sponge spicules, encrusting and ramose bryozoans and the alga Kazahkstanelia. Sample: LN-114*, 392.5 m.
	0.4	394.0	Covered Interval
33	1.4	395.4	Medium red, coarse to fine grained, very thick bedded, oolitic, fossiliferous limestone (ooid bryozoan echinoderm packstone). Subrounded to subangular clasts of Solenopora and sponges occur along with trilobites, ramose bryozoans, and articulated echinoderm columnal segments. A single orthocone cephalopod was observed in this unit. Ooids exhibit both radial and radial-concentric structure.

			Sample: LN-115(P), 392.5 m.
	0.4	395.8	Covered Interval
34	2.7	398.5	Intercolated reddish gray, coarse to fine grained, cross-stratified, sandy fossiliferous limestone (echinoderm packstone) and mottled red, argillaceous, fossilferous limestone (echinoderm-bryozoan wackestone/bafflestone and boundstone). Fossil allochems in the packstone include echinoderm plates and columnal segments, brachiopods, trilobites, Solenopora and Hedstroemia. The meter-thick wackestone/bafflestone and boundstone lithology contains abundant in situ echinoderm holdfasts, ramose and encrusting bryozoans, sponge spicules, brachiopods, ostracodes and some possible cryptalgal laminations. Samples: LN-116(P), 396.0 m; LN-117(P), 396.8 m; LN-118*(P), 397.3 m; LN-119*, 398.0 m; LN-120, 398.5 m.
	1.0	399.5	Covered Interval
35	2.2	402.7	Medium gray, fine to coarse grained, thin to thick bedded, cross-stratified, sandy, fossiliferous, oolitic limestone

			(oolitic packstone). Granule sized chert and sedimentary and metamorphic rock fragments occur 1.2 meters above the base of the unit, increase in abundance towards the top of the unit and along with bryozoan and echinoderm debris commonly forms lag deposits within cross laminae. Samples: LN-121, 399.9 m; LN-122, 402.3 m.
36	7.5-4.4	410.2	Mottled grayish red and brown, coarse to fine grained, very thick bedded (massive), argillaceous, fossiliferous limestone (sponge-rich wackestone/ bafflestone, sponge-rich ooid packstone and echinoderm-bryozoan bafflestone to boundstone). Allochems include trilobites, ostracodes, ramose and encrusting bryozoans, sponges, echinoderm holdfasts in growth position and echinoderm debris which includes plates of Cyanthocystis sp. and unidentified camerates. Several short covered intervals occur within this unit. The unit thins abruptly to the east where it has been cut into and filled by Unit 37.

			Samples: LN-123, 404.5 m; LN-124*, 405.3 m; LN-125, 406.1 m; LN-126(P), 409.7 m.
37	4.4-7.6	414.6	Medium reddish brown, fine grained, very thick bedded, oolitic sandstone (sed-litharenite). Bidirectional and trough cross laminae are present. This unit is fossiliferous in places with camerate, paracrinoid, and Archaeocrinus peculiaris plates, echinoderm debris and ramose bryozoans present. Large intra-clasts of bryozoan boundstone apparently derived from Unit 36 are contained within this lithology near the contact between the two units. This unit thins to the west over Unit 36. Samples: LN-128, 409.7 m; LN-127, 410.0 m; LN-129, 129-1, 413.7 m.
38	0.2	414.8	Medium mottled gray and brownish red, fine to coarse grained, thin to medium bedded, quartz-rich oolitic limestone (ooid packstone to grainstone). Super-ficial and well developed ooids are both present in this lithology. Ramose bryozoans, echinoderms and brachiopods

			are the common allochems. A thick, quartz-rich hummocky stylolite was observed.
			Sample: LN-131(P), 414.7 m.
39	18.1	432.9	Medium red and white mottled, coarse to fine grained, thick to very thick bedded, oolitic, quartz-rich, cross-stratified fossiliferous limestone (bryozoan wackestone and packstone) and medium sand to pebble (rare) size, ferruginous, fossiliferous sandstone (echinoderm-bryozoan sedlitharenite). The contact with the underlying oolite of Unit 38 is sharp and represents a scour surface. Individual beds usually exhibit basal scour surfaces, cross laminae which are either bioclastic-rich or quartz-rich, imbrication of fossil allochems, and poorly defined grading which appears to fine upwards. A few pebble-size terrigenous clastic grains occur near the top of the unit. Chert, sedimentary and metamorphic rock fragments and blue quartz are represented within the terrigenous clastic component

			of this unit. Allochems represented in this unit include brachiopods, ramose bryozoans, echinoderm plates from Cleiocrinus sp., trilobites, Hedstroemia and rounded clasts of Solenopora. Both superficial and well-developed ooids with ferruginous laminae are common. A covered interval of 2 meters lies between 429.7 and 431.1 m. Samples: LN-130, 130-1, 130-2, 418.8 m; LN-132*, 414.9 m; LN-133(P), 416.8 m; LN-134(P), 416.9; LN-135, 417.7 m; LN-136*, 417.8 m; LN-137(P), 418.5 m; LN-138(P), 420.5 m; LN-139(P), 421.2 m; LN-140, 429.3 m; LN-156, 429.6 m.
	0.5	433.4	Covered Interval
40	27.8	461.2	Medium blue-gray, coarse to fine grained, very thick bedded, cross-stratified quartz-rich, fossiliferous oolitic limestone (ooid packstone). This unit contains rounded mudstone/ shale intraclasts, brachiopods, ramose bryozoans and echinoderms which commonly occur as lag within cross-laminae. Ooids observed include radial, concentric and superficial types.

			Samples: LN-141, 433.5 m; LN-142, 435.7 m; LN-143, 438.2 m; LN-144*(P), 439.5 m; LN-145*(P), 445.5 m; LN-146, 461.1 m.
41	7.6	468.8	Mottled bluish gray and brown, coarse grained, thick bedded, fossiliferous, oolitic limestone (ooid packstone and grainstone) which becomes interbedded with fine grained, quartz-rich oolitic limestone (packstone and grainstone) 3.4 meters above the base of this unit. Bidirectional cross-laminae are common 4.7 meters above the base of the unit. The allochems include: Solenopora, Hedstroemia, Girvanella, articulated echinoderm columnal segments, plates from the eocrinoid Ulrichocystis eximia, Archaeocrinces peculiaris, Cyathocystis sp., Carabocrinus sp. cf. C. stellifer, and ? Paleocrinus sp., ostracodes, trilobites, brachiopods, ramose bryozoans and rare cephalopods. Occasional pebbles were observed within this unit. Samples: LN-147*, 461.2 m; LN-148*, 461.9 m; LN-149*, 462.2 m; LN-150*, 466.2 m; LN-157, 468.7 m.

	0.9	469.7	Covered Interval
42	1.5	471.2	Mottled brownish blue-gray, fine to coarse grained, very thick bedded, cross laminated, quartz-rich, fossiliferous oolitic limestone. Cross laminae are bidirectional. This unit contains some rounded mudstone/shale intraclasts along with fine grained fossil debris. Sample: LN-151, 470.8 m.
	35.0	506.2	Covered interval (which includes the upper part of the McKnight Member of the Ottosee Formation and the lower part of the "Bays" Formation).
43	2.8	509.0	"Bays" Formation. Mottled grayish red, coarse to fine grained, medium to thick bedded, quartz-rich, ferruginous, oolitic limestone (oolitic packstone/ grainstone) interbedded with laminated greenish gray calcareous shale/mudstone and oolitic sandstone (sedlitharenite). This unit contains abundant echinoderm debris, ramose bryozoans and trilobites. Ooids exhibit concentric, radial and superficial fabrics, ooid laminae are typically ferruginous.

Samples: LN-152*(P), 506.2 m;

LN-153*(P), 507.4 m; LN-154, 508.4 m;

LN-155F*(P), 508.6 m.

APPENDIX B

POINT COUNT DATA

Table 1. Point Count Data for the Henegar Bluff (HB) Section, Bradley County, Tennessee.

	Lenoir Fm.: Up. Tongue	Holston Formation			Chapman Ridge Formation				
					Orthocone Zone		Main Body		
Sample Number:	HB-4	HB-15	HB-21-3b	HB-21t	HB-22-1	HB-29	HB-26-1	HB-27	HB-45
Micrite	33.3	5.7	11.1	17.9	32.5	15.8	7.7	5.7	-
Intraclasts	3.5	0.3	4.4	1.5	3.8	1.7	8.3	7.7	14.6
Spar	10.4	29.5	24.1	38.6	3.8	0.3	16.4	8.0	2.5
Peloids	Tr.	Tr.	Tr.	Tr.	Tr.	-	-	-	-
Ooids	-	-	-	-	Tr.	-	-	-	Tr.
Coated grains	Tr.	-	-	-	-	-	-	-	-
Algae	15.3	Tr.	Tr.	Tr.	-	-	Tr.	Tr.	-
Sponge spicules	Tr.	-	-	-	Tr.	-	-	-	-
Brachiopods	0.3	0.3	Tr.	0.5	Tr.	Tr.	0.5	Tr.	-
Bryozoans	9.3	10.3	15.5	9.3	13.0	0.6	1.4	1.4	4.7
Mollusks	Tr.	-	Tr.	0.2	8.2	-	-	-	-
Echinoderms	8.4	33.4	33.6	14.1	11.5	1.1	10.8	10.6	19.4
Ostracodes	0.8	3.5	0.3	1.2	0.5	-	Tr.	Tr.	Tr.
Trilobites	1.9	1.1	0.8	1.5	1.2	0.3	Tr.	Tr.	Tr.
Unidentified fossil debris	3.5	4.0	2.7	1.5	4.3	0.9	2.7	3.1	2.8
Dolomite	Tr.	1.1	1.1	13.4	0.5	-	Tr.	-	-
Quartz	10.4	5.4	5.5	Tr.	16.9	20.7	30.8	37.7	31.1
Stylocumulate	1.3	4.9	0.3	0.2	0.9	-	-	-	-
Opaques	1.6	0.3	Tr.	0.2	2.6	3.2	-	-	-
Feldspar	Tr.	Tr.	Tr.	Tr.	Tr.	0.3	2.5	3.7	1.1
Fe-rich mud	-	-	-	-	-	-	-	-	21.3
Sedimentary rock fragments	Tr.	Tr.	-	-	Tr.	1.7	7.7	12.0	2.2
Pseudomatrix	-	-	-	-	-	-	1.4	1.4	-
Terrigenous clay	-	-	-	-	-	53.2	9.4	8.6	-
MM rock fragments	-	-	-	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Burrows	Tr.	-	-	-	Tr.	Tr.	Tr.	-	-

Table 2. Point Count Data for the Louisville and Nashville (LN) Railroad Section, McMinn County, Tennessee.

									Chapman Ridge Fm.			Ottosee Formation											
	Lenoir Fm.: Up. Tongue		Holston Formation						O.Z. Main Body			Hiwassee Member			Unnamed Mid. Shale	McKnight Member							"Bays" Fm.
Sample Number:	LN-2	LN-13	LN-15	LN-158	LN-26	LN-21-1	LN-33	LN-36	LN-37	LN-43	LN-49	LN-53	LN-59	LN-63	LN-68	LN-79	LN-82S	LN-98	LN-119	LN-127	LN-136	LN-147	LN-154
Micrite	8.7	19.1	39.3	39.0	8.8	55.7	1.1	7.6	8.7	1.3	0.5	2.4	21.2	-	23.2	32.4	3.6	5.8	2.9	-	4.3	0.3	0.2
Spar	36.7	11.3	10.5	8.2	20.7	2.9	3.4	38.3	14.2	0.3	18.1	34.0	2.4	40.3	17.2	3.3	18.4	26.9	19.5	26.7	15.9	32.2	26.9
Intraclasts	0.5	0.3	Tr.	Tr.	0.5	0.2	0.8	0.5	5.5	23.2	1.0	Tr.	Tr.	-	4.3	0.3	0.5	1.1	3.9	14.0	7.8	4.7	4.0
Peloids	Tr.	1.1	0.2	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	-	-	-	-	Tr.	Tr.	-	-	Tr.	Tr.	Tr.	Tr.	-
Ooids	-	-	-	-	-	-	-	-	-	Tr.	Tr.	55.3	Tr.	57.8	Tr.	0.5	27.0	58.3	-	7.0	11.1	43.9	26.6
Coated grains	-	-	Tr.	Tr.	-	-	-	Tr.	2.9	-	-	Tr.	-	-	-	-	-	-	-	-	-	Tr.	-
Algae	0.2	Tr.	0.5	Tr.	1.4	0.5	-	Tr.	Tr.	-	-	Tr.	-	Tr.	-	-	-	-	-	-	-	1.3	-
Sponge spicules	-	-	-	-	-	0.3	-	-	-	-	-	-	1.8	-	0.5	4.4	Tr.	-	-	-	-	-	-
Brachiopods	1.5	Tr.	0.2	0.3	Tr.	0.2	0.8	1.7	0.2	Tr.	2.3	-	-	-	0.1	Tr.	-	-	-	-	Tr.	0.3	0.4
Bryozoans	3.8	36.1	24.8	27.7	44.8	25.0	30.4	24.2	31.0	1.3	9.2	1.7	23.0	-	8.6	15.9	1.4	0.3	9.2	0.2	9.3	1.0	1.2
Mollusks	-	-	-	2.5	0.6	0.3	-	3.1	1.0	-	Tr.	-	Tr.	-	Tr.	0.3	-	-	-	-	-	0.3	-
Echinoderms	25.4	11.3	9.5	9.3	7.0	1.4	37.7	17.4	12.9	1.3	18.4	5.9	16.9	0.9	11.9	9.0	41.5	1.4	50.0	0.8	17.1	6.3	5.7
Ostracodes	4.6	1.4	1.3	0.6	2.2	0.2	-	-	1.0	-	0.3	Tr.	Tr.	-	3.8	1.9	Tr.	-	0.2	Tr.	0.7	-	-
Trilobites	11.5	1.4	1.8	0.5	0.2	0.3	1.1	1.4	1.8	-	2.0	0.3	1.2	-	5.1	0.3	Tr.	-	0.5	-	0.7	Tr.	Tr.
Unidentified fossil debris	3.3	4.0	5.5	2.2	0.2	-	2.2	1.1	2.1	0.5	4.0	-	5.4	-	4.0	3.8	-	0.3	1.6	0.5	2.5	0.5	1.4
Dolomite	1.0	0.3	1.3	1.4	16.2	2.0	0.3	-	1.0	0.3	Tr.	-	Tr.	-	0.2	Tr.	-	-	5.3	2.3	1.0	0.5	3.1
Quartz	0.7	6.9	2.9	2.2	Tr.	8.6	18.3	2.2	14.5	38.5	19.3	0.3	9.7	Tr.	0.9	1.9	Tr.	4.7	4.7	29.3	24.9	0.8	12.8
Stylocumulate	0.5	-	-	0.8	0.2	2.3	3.6	-	-	-	-	-	-	0.9	0.5	0.3	7.2	1.1	2.1	0.5	0.7	7.8	15.9
Opaques	1.0	1.4	-	-	-	0.3	2.2	2.9	-	-	-	-	-	-	0.5	0.3	Tr.	-	-	5.2	3.0	-	1.4
Feldspar	-	0.3	-	-	-	Tr.	Tr.	-	Tr.	3.8	0.6	-	Tr.	-	Tr.	-	-	-	-	2.1	0.2	-	Tr.
Fe-rich mud	-	-	1.8	1.9	-	-	-	-	-	15.5	12.3	-	-	-	2.3	25.2	-	-	-	-	-	-	-
Sedimentary rock fragments	-	0.3	-	-	-	Tr.	Tr.	Tr.	Tr.	8.4	Tr.	Tr.	1.2	Tr.	Tr.	Tr.	-	-	Tr.	8.3	1.0	-	Tr.
Pseudomatrix	-	-	-	-	-	-	-	-	-	6.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrigenous clay	-	4.6	-	-	-	-	-	-	-	-	-	-	16.9	-	-	-	-	-	2.8	-	-	-	-
MM rock fragments	-	-	-	-	-	-	-	-	-	-	Tr.	Tr.	-	-	-	-	-	-	Tr.	Tr.	Tr.	-	Tr.
Burrows	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.3	-	-	-	-	-	-	-	-

APPENDIX C

STRATIGRAPHIC DISTRIBUTION OF CONODONT ELEMENTS

Table 3. Conodont Elements Recovered per Sample: Henegar Bluff (HB), Bradley County, Tennessee.

	Lenoir Formation: Upper Tongue				Holston Formation				Chapman Ridge Formation: OZ	Chapman Ridge Formation: Main Body		
Sample Number (HB)	6	7	10	12	14	16	18	21	22	26	33	52
Sample Weight (kg)	1.0	2.0	1.0	1.0	2.0	2.0	1.0	4.0	4.0	2.8	1.8	1.0
Meters Above Base (M)	1.2	1.9	3.1	5.5	9.7	13.6	18.9	25.5	25.6	28.6	31.0	72.7
"Acodus" mutatus (Branson & Mehl)												
ACO	--	--	--	--	--	--	--	--	1	--	--	--
Appalachignathus delicatulus (Bergström et al.)												
OZ	--	--	--	--	1	--	--	--	--	--	--	--
Belodella n. sp. A of Bergström (1971)												
OE-a	--	--	--	--	3	--	--	--	--	--	--	--
Cahabagnathus sweeti (Bergström)												
POLP	--	--	1	--	--	--	--	--	--	--	--	--
AMB	--	--	--	--	1	--	--	--	--	--	--	--
Cahabagnathus carnesi (Bergström)												
AMB	--	--	--	--	2	1	--	--	--	--	--	--
Chirognathus sp.	--	1	--	--	--	--	--	--	--	1	--	--
Drepanoistodus n. sp. of Carnes (1975)												
DR Form B	--	1	--	--	--	--	--	--	--	--	--	--
Drepanoistodus suberectus (Branson & Mehl)												
HO Form A	1	1	1	--	1	--	--	--	--	--	--	--
HO Form B	--	1	--	--	--	--	--	--	1	--	--	--
HO Form C	--	2	--	--	1	--	--	1	--	--	--	--
SU	--	--	1	--	1	--	--	--	--	--	--	--
I	--	2	--	--	--	--	--	--	1	--	--	--
Erismodus sp. 1 of Carnes (1975)												
T-s	--	1	--	--	--	--	--	--	--	--	--	--
"Oistodus" pseudoabundans (Schopf)	1	--	--	--	--	--	--	--	--	--	--	--
Paltodus? sp. of Carnes (1975)												
PAL Form B	1	--	--	--	--	--	--	--	--	--	--	--
ACO	--	--	--	--	--	1	--	--	--	--	--	--
Panderodus sp. cf. *P. gracilis* (Stauffer)	15	9	4	--	1	--	--	--	1	--	--	--
Panderodus sp. cf. *P. panderi* (Stauffer)	11	5	7	--	4	--	--	--	--	--	1	--
Periodon sp. cf. *P. grandis* (Ethington)												
P	--	--	--	--	--	--	--	--	1	--	--	--
Phragmodus sp. cf. *P. inflexus* (Stauffer)												
D	--	--	--	--	--	--	--	--	1	--	--	--
Plectodina n. sp. of Carnes (1975)												
F	--	3	--	--	--	--	--	--	--	--	--	--
O	--	--	6	--	--	--	--	--	--	--	--	--
E	--	1	--	--	--	--	--	--	1	--	--	--
C	1	3	1	--	4	--	--	--	--	--	--	--
OZ	2	--	--	--	--	--	--	--	--	--	--	--
T-s	1	1	1	--	1	--	--	--	--	--	--	--
T-as	2	--	1	--	2	--	--	--	--	--	--	--
Z	--	1	--	--	--	--	--	--	--	--	--	--
D	--	3	2	--	4	--	--	--	--	--	--	--
Plectodina sp.												
CY	1	--	--	--	--	--	--	--	--	--	--	--
T	--	--	--	--	--	--	--	--	1	1	--	--
Z	--	--	--	--	--	--	--	--	--	--	--	--
C	--	--	--	--	--	--	--	--	--	1	--	1
OZ	--	--	--	--	--	--	--	1	--	--	--	--
Prioniodus sp.												
B	--	1	--	--	--	--	--	--	--	--	--	--
PS	--	2	--	--	--	--	--	--	--	4	2	--
TP	--	--	--	--	--	--	--	--	--	1	--	--
Protopanderodus variocostatus (Sweet & Bergström)												
V	--	--	--	--	--	--	--	--	--	1	--	--
Scalopodus insculptus (Branson & Mehl)	--	--	--	--	--	1	--	--	--	--	--	--
Triangulodus sp. cf. *T. brevibasis* (Sergeeva)												
O	--	2	--	--	--	--	--	--	--	--	--	--
DR	--	--	--	1	--	--	--	--	--	--	--	--
SC	--	--	--	--	--	1	--	--	--	--	--	--
Co-s	--	--	1	--	--	--	1	--	--	--	--	--

Note: The following samples from Henegar Bluff (HB) proved barren when processed for conodonts:

Sample No.	Wt. (kg)	Meters Above Base	
HB-3	0.5	0.4	Lenoir Formation: Upper Tongue
HB-19	1.0	22.0	Holston Formation
HB-20	1.0	23.7	
HB-23	1.0	26.3	
HB-24	1.0	26.6	Chapman Ridge Formation: Orthocone Zone
HB-30	1.0	26.8	
HB-35	1.0	32.8	
HB-36	1.0	34.8	
HB-48	1.0	40.8	Chapman Ridge Formation: Main Body
HB-47	1.0	63.4	
HB-54	0.5	73.8	

Table 4. Conodont Elements Recovered per Sample: Louisville and Nashville (L&N) Section, McMinn County, Tennessee.

	Lenoir Formation: Upper Tongue					Bolston Formation						Ottosee Formations															"Baya" Formation	
												Hiwassee Member					Middle Unnamed Shale Member			McKnight Member								
Sample Number (L&N)	2	9	10	11	13	15	14	16	17	19	38	51	56	58	59	60	68	69	70	80	84A	112	116	119	124	144	145	149	150	153
Sample Weight (kg)	27	1.0	2.0	1.0	2.5	2.0	3.0	3.0	1.0	3.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	4.3	1.0	1.0	1.0	7.0	1.0	1.0	1.0	1.0	1.5	4.0	2.0
Meters Above Base (M)	1.5	8.0	9.2	10.1	13.0	14.0	14.6	15.9	20.5	20.9	22.8	160.9	165.0	166.5	167.5	168.4	199.5	199.9	201.4	241.6	252.4	363.7	396.0	398.0	405.3	439.5	443.0	462.2	466.2	507.4
"Acontiodus" sp. cf. A. curvatus (Hamm)																														
AC0	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Appalachignathus delicatulus (Bergström et al.)																														
OZ	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	1	1	3	--	--	--	--	--	--	17	--	--	--	--
T	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	17	--	--	--	--
Belodella nevadensis (Ethington & Schumacher)																														
OE-d	1	--	--	--	--	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Belodella n. sp. A of Bergström (1971)																														
OE-a	--	--	--	--	4	10	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
OE-d	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
BDEL-bi-a	--	--	2	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
BDVL-t-d	--	--	--	--	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Belodina compressa (Ethington & Schumacher)																														
ES	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MA	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M	--	--	--	--	1	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Belodina sp.																														
ES	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--
Bryantodina typicalis (Stauffer)																														
BR	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
OZ	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	17	--	17	--
Cahabagnathus sweeti (Bergström)																														
POLP	3	--	--	--	3	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
AMB	2	--	--	--	1	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chirognathus sp.	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	1	4	--	--	--	--	--	--	--	--	--	--	--
Curtognathus sp.																														
CA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
CUR	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TR	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	1	--
"Distacodus" n. sp. of Carnes (1975)																														
ACDH	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	2	--
"Distacodus" sp.																														
I	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Drepanoistodus suberectus (Branson & Mehl)																														
MO Form A	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	2	--	5	--	--	--	--	--	--	--	--	--	--	--
MO Form B	--	--	--	--	--	--	--	--	--	--	--	3	1	--	--	--	2	3	12	1	--	--	--	--	--	--	--	--	--	--
MO Form C	2	--	1	--	--	--	--	--	--	--	--	1	--	--	--	--	1	2	7	--	--	--	--	--	--	--	--	--	--	--
SU	1	--	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--	2	2	--	--	--	--	--	--	--	--	--	--	--
I	2	--	--	--	--	2	--	--	1	--	--	1	--	--	--	--	1	1	4	--	--	--	--	--	--	--	--	--	--	--
Eoplacognathus elongatus (Bergström)																														
APB	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	2	2	--	--	--	--	--	--	--	--	--	--	--
POLP	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	7	--	--	--	--	--	--	--	--	--	--	--
Eriomodus sp. 1 of Carnes (1975)																														
T-s	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	1
T-a	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
PR	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
E	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
F	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Z	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Oistodus sp. cf. "O". pseudoabundans (Stauffer)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	1	--	--	--	--	--	--	--
Oistodus sp. cf. "O". venustus (Stauffer)	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paltodus? sp. of Carnes (1975)																														
PAL	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paltodus n. sp. (Bergström)	--	--	--	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Panderodus sp. cf. P. gracilis (Stauffer)	9	--	3	--	26	37	3	--	2	1	1	2	2	1	--	1	2	3	1	--	--	--	--	--	--	--	--	--	--	--
Panderodus sp. cf. P. panderi (Stauffer)	5	--	1	1	12	35	4	7	1	2	--	--	4	--	2	2	4	1	4	1	1	--	--	--	--	--	--	1	1	--

Table 4 (continued)

	Lenoir Formation: Upper Tongue					Bolston Formation						Ottosee Formations																		
												Hixsonese Member					Middle Unnamed Shale Member			McKnight Member									"Reyn" Formation	
Sample Number (LN)	2	9	10	11	13	15	14	16	17	19	18	51	56	58	59	60	68	69	70	80	848	112	116	119	124	144	145	149	150	153
Sample Weight (kg)	27	1.0	2.0	1.0	2.5	2.0	3.0	3.0	1.0	3.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	4.3	1.0	1.0	1.0	7.0	1.0	1.0	1.0	1.0	1.5	4.0	2.0
Meters Above Base (M)	1.5	8.0	9.2	10.1	13.0	14.0	14.6	15.9	20.5	20.9	22.8	160.9	165.0	166.5	167.5	168.4	199.5	199.9	201.4	241.6	252.4	363.7	396.0	398.0	405.3	439.5	445.0	447.2	466.2	507.4
Paraprioniodus sp. cf. *P. costatus* (Ethington & Clark)																														
T	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Phragmodus flexuosus (Moskalenko)																														
P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	61	--	--	--	--	--	--	--	--	--	--	--
CY	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11	53	--	--	--	--	--	--	--	--	--	--	--
Phragmodus sp. cf. *P. inflexus* (Stauffer)																														
P	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
CY	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Plectodina aculeata (Stauffer)																														
CZ	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--
D	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	3	--	--	--	--	--	--	--	--	--	--	--
Plectodina n. sp. of Carnes (1975)																														
F	--	1	--	--	--	--	3	--	--	1	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
C	1	--	--	--	1	6	--	--	--	--	--	3	--	--	--	1	6	6	29	--	--	--	--	--	--	--	--	--	--	1
M	--	--	1	--	1	2	1	--	1	--	--	--	--	--	--	--	1	--	6	--	--	--	--	--	--	--	--	--	--	--
C	1	--	3	--	10	13	2	2	1	2	--	4	--	--	--	1	9	13	112	--	--	--	--	--	--	--	--	--	--	--
CZ	4	--	--	--	6	6	2	2	1	--	--	1	--	1	--	--	--	3	8	--	--	--	--	1	--	--	--	--	--	--
Fe	--	--	--	--	7	3	2	--	--	--	--	1	--	--	--	--	1	4	31	--	--	--	--	--	--	--	--	--	--	--
T-a	2	--	--	--	--	7	--	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Z	--	--	--	--	6	7	1	1	--	--	--	1	--	--	--	1	1	2	9	--	--	--	--	--	--	--	--	--	--	1
B	4	--	3	--	11	3	2	4	1	--	--	1	--	--	--	2	4	14	61	--	--	--	--	--	--	--	--	--	--	--
Plectodina sp.																														
CY	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	1	--	--	--	--
T	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Z	--	--	--	1	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
C	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CZ	--	--	--	--	--	8	4	--	--	--	1	--	--	--	--	--	--	2	4	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	2	--	25	--	--	--	--	--	--	--	--	--	--	--
Polycaulodus sp.																														
CA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
TR	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	2	--	--	--	1	--	--	1	--	--	3	--
Prioniodus sp.																														
B	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
PS	3	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	1	2	--	--	--	--	--	--	--	--	--	--	--
TP	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--
RB	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Protopanderodus varicostatus (Sweet & Bergström)																														
V-s	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--
Pygodus sp. *P. anserinus* (Lamont & Lindström)																														
BA	1	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pygodus serra (Hadding)																														
PY	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Scalopodus sp.																														
S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Triangulodus sp. cf. *T. brevibasis* (Sergeeva)																														
O	--	--	--	--	--	--	--	--	--	--	--	3	--	--	--	--	--	1	2	--	--	--	--	--	--	--	--	--	--	--
DR	--	--	--	1	--	--	1	--	--	--	--	--	1	--	--	--	--	--	1	--	--	--	--	--	--	--	1	--	--	--
SC	2	--	--	--	1	--	1	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
CO-a	1	--	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	2	--	--	--	--	--	--	--	1	--	--	--
CO-as	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Walliserodus sp. cf. *W. trigonis* (Schopf)																														
CU	1	--	--	--	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DTS	3	2	2	--	1	5	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--
MU	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
U	1	--	2	--	1	2	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 4 (continued)

Note: The following samples from the Louisville and Nashville (LN) section proved barren when processed for conodonts:

Sample No.	Wt. (kg)	Meters Above Base	
LN-5	1.0	5.0	Lenoir Formation: Upper Tongue
LN-8	1.0	6.8	
LN-26	2.0	22.1	
LN-30	1.0	24.3	
LN-24	1.0	26.5	
LN-32	1.0	27.1	Holston Formation
LN-33	1.0	30.0	
LN-35	1.0	33.9	
LN-36	1.0	34.9	
LN-37	1.0	35.0	Chapman Ridge Formation: Orthoconе Zone
LN-53	1.0	163.9	Ottosee Formation: Hiwassee Member
LN-85S	1.0	256.4	
LN-89S	1.0	261.4	
LN-105	1.0	356.1	
LN-111	1.0	362.9	
LN-114	1.0	392.5	Ottosee Formation: McKnight Member
LN-118	1.0	397.3	
LN-132	1.0	414.9	
LN-136	1.0	417.8	
LN-147	1.0	461.2	
LN-148	1.0	461.9	
LN-152	1.0	506.2	"Bays" Formation
LN-155	1.0	508.6	

CODE FOR COMPARABLE ELEMENTS UTILIZED IN TABLES 3 AND 4

ACOD = acodontiform
ACON = acontiodontiform
AMB = ambalodontiform
B = belodontiform
BDEL = belodelliform
BR = bryantodiniform
C = cordylodontiform
CA = cardiodelliform
CO = costate elements
CU = curvatiform
CUR = curtognathiform
CY = crytoniodontiform
D = dichognathiform
DR = drepanodontiform
DYS = dyscritiform
E = eoligonodiniform
EB = eobelodiniform
F = falodontiform
HA = haddingodontiform
HB = hibbardelliform
HO = homocurvatiform
I = inclinatiform
M = monitorensiform
MA = marginatiform
MU = multicostatiform
O = oistodontiform
OE = oepikodontiform
OZ = ozarkodiniform
P = phragmodontiform
PAL = paltodontiform
POLP = polyplacognathiform
PR = prioniodiniform
PS = prioniodontiform
PY = pygodiform
S = spathognathodontiform
SC = scandodontiform
SU = suberectiform
T = trichonodelliform
TP = tetraprioniodiform
TR = trucherognathiform
U = unicostatiform
V = varicostatiform
Z = zygognathiform
a = adenticulate
as = asymmetrical
bi = biconvex
d = denticulate
s = symmetrical

APPENDIX D

FIELD UNITS AND THEIR CORRESPONDING LITHOFACIES

Appendix D relates field units from both the Henegar Bluff and LN sections (as described in Appendix A) to their corresponding lithofacies (as described in Chapter III of the text).

Henegar Bluff

Field Unit	Lithofacies	Formation Name
1	1	Lenoir:Upper Tongue
2	2	Lenoir:Upper Tongue
3	2	Lenoir:Upper Tongue
4	3	Holston
5	3	Holston
6	1	Chapman Ridge:Orthocone Zone
7	1	Chapman Ridge:Main Body
8	2	Chapman Ridge:Main Body
9	2	Chapman Ridge:Main Body
10	3	Chapman Ridge:Main Body

LN

1	1	Lenoir:Upper Tongue
2	2	Lenoir:Upper Tongue
3	2	Lenoir:Upper Tongue
4	1	Holston
5	2	Holston
6	2	Holston
7	3	Holston
8	1	Chapman Ridge:Orthocone Zone
9	2	Chapman Ridge:Orthocone Zone
10	1	Chapman Ridge:Main Body
11	2	Chapman Ridge:Main Body
12	2	Chapman Ridge:Main Body
13	1	Ottosee:Hiwassee Member
14	2	Ottosee:Hiwassee Member
15	1	Ottosee:Hiwassee Member
16	1	Ottosee:Hiwassee Member
17	2	Ottosee:Hiwassee Member
18	1	Ottosee:Middle Unnamed Shale Member
19	2	Ottosee:Middle Unnamed Shale Member
20	1	Ottosee:Middle Unnamed Shale Member

LN (continued)

Field Unit	Lithofacies	Formation Name
	3 ⇌ 2 ↑	
21	1 ⇌ 2	Ottosee:McKnight Member
22	1 ⇌ 2	Ottosee:McKnight Member
23	2	Ottosee:McKnight Member
24	3	Ottosee:McKnight Member
25	3 ⇌ 2	Ottosee:McKnight Member
26	3 ⇌ 2	Ottosee:McKnight Member
27	3	Ottosee:McKnight Member
28	2	Ottosee:McKnight Member
	2 ⇌ 4 ↑	
29	2	Ottosee:McKnight Member
30	4	Ottosee:McKnight Member
31	3 ⇌ 5 ↑	Ottosee:McKnight Member
32	1	Ottosee:McKnight Member
33	1 b+f	Ottosee:McKnight Member
34	1 b+f	Ottosee:McKnight Member
35	3 ⇌ 5	Ottosee:McKnight Member
36	1	Ottosee:McKnight Member
37	4	Ottosee:McKnight Member
38	5	Ottosee:McKnight Member
39	5	Ottosee:McKnight Member
40	2 ⇌ 5	Ottosee:McKnight Member
	2 ⇌ 5 ↑	
41	2	Ottosee:McKnight Member
42	2	Ottosee:McKnight Member
43	1	"Bays"

Note: b = buildup; f = flank; ⇌ = interbedded lithofacies.

APPENDIX E

PLATE

Plate 1. Conodonts from the Calhoun Area.

A. Paraprioniodus sp. cf. P. costatus (Ethington and Clark)
Triconodelliform element. x96. L and N sample LN-153. "Bays" Formation.

B. Erismodus sp. 1 of Carnes (1975)
Triconodelliform element. x112. L and N sample LN-153. "Bays" Formation.

C. Periodon sp. cf. P. grandis (Ethington)
Falodontiform element. x126. Henegar Bluff sample HB-22. Chapman Ridge Formation: "Orthocone Zone."

D. Eoplacognathus elongatus (Bergström)
Polyplacognathiform element. x128. L and N sample LN-70. Ottosee Formation: Middle Unnamed Shale Member.

E. Protopanderodus varicostatus (Sweet and Bergström)
Varicostatiform element. x112. L and N sample LN-124. Ottosee Formation: McKnight Member.

F. Cahabagnathus sweeti (Bergström)
Ambalodontiform element. x114. Henegar Bluff sample HB-14. Holston Formation.

G. Pygodus sp. P. serra (Hadding)
Pygodontiform element. x126. L and N sample LN-19. Holston Formation.

H. Cahabagnathus carnesi (Bergström)
Ambalodontiform element. x125. Henegar Bluff sample HB-14. Holston Formation.

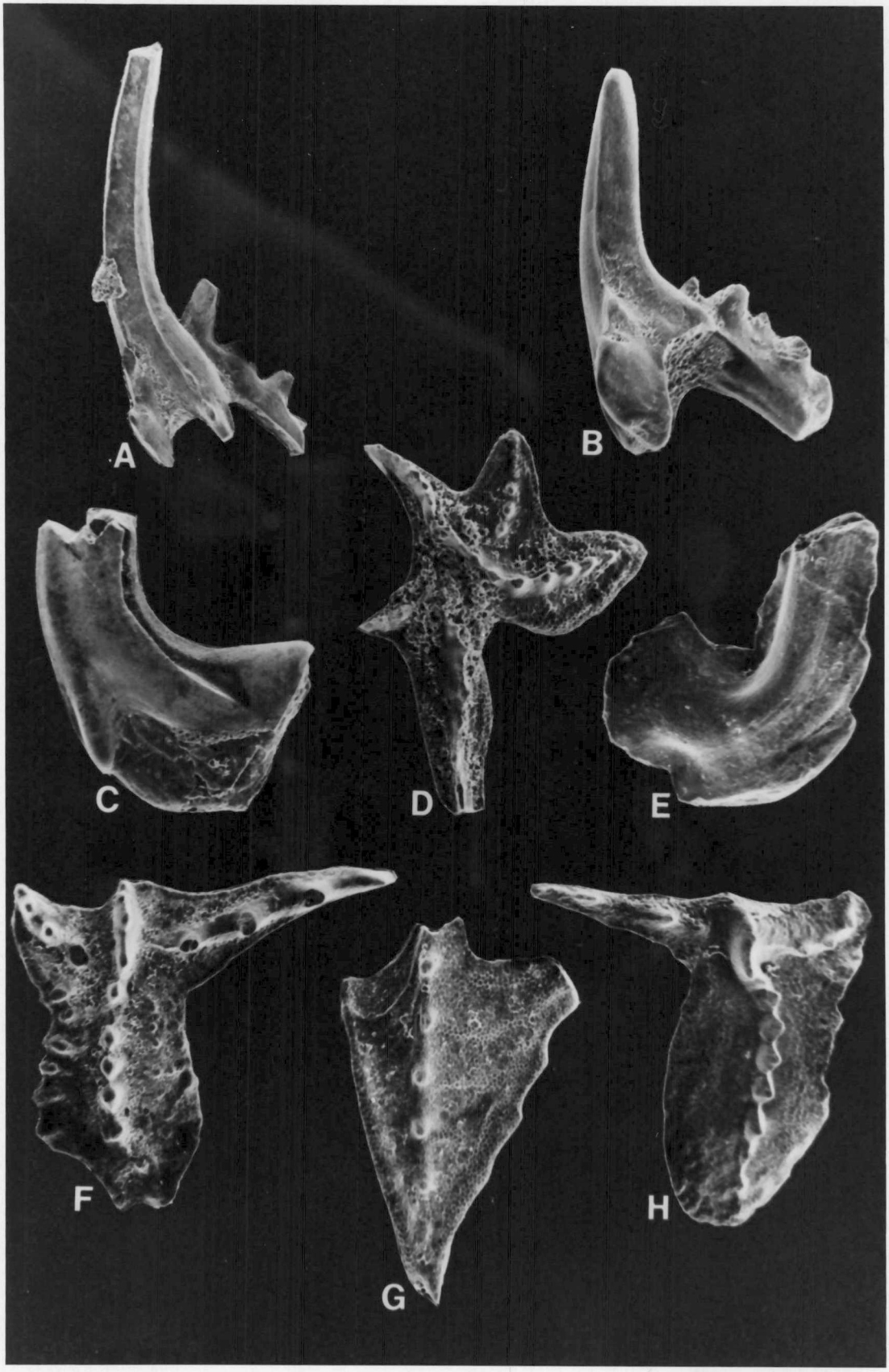


Plate 1.

VITA

Robert Charles Asreen, Jr., was born in Brooklyn, New York, on November 25, 1948. Upon graduation from Nazareth High School in 1966, he attended Kingsborough Community College in Brooklyn where he completed as Associate of Arts degree in 1968. Robert completed his undergraduate education at Hunter College in New York City where he received a Bachelor of Arts degree in 1971 with a major in geography. Robert continued his education by attending Hunter College (1972-1973) and Washington State University (1973) as a part-time student. From February 1974 to February 1975, Robert was a research assistant at the Institute of Archeology and Anthropology at the University of South Carolina where he was responsible for assessing the environmental impact of construction projects upon cultural resources. Between 1975 and 1979, he served as an archaeological consultant to projects in Delaware, Louisiana, Maryland, Washington, and Tennessee. He married Judith Marie Canonico in 1978.

Robert entered The University of Tennessee, Knoxville, as a nondegree graduate student in geology in January 1979 and became a candidate for a Master of Science degree in the fall of 1980. He served as a graduate teaching assistant in geology at The University of Tennessee from September 1980 to June 1981 and from September to December 1983. During the summer of 1981, he was employed as a geologist by the Minerals Division of Getty Oil Company. Michael Domenic was born during the summer of 1981 and Daniel was born during

the summer of 1983. He received his Master of Science degree in March 1985.

The author is a member of the American Association of Petroleum Geologists and at this writing, Bob is employed as a production geologist in the Field Studies Group with the Midcontinent Division of Exxon Company U.S.A. in Midland, Texas.