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Approved by:

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[illegible]

STRATIGRAPHY, TAPHONOMY, AND FAUNAL DISTRIBUTION OF THE CORRYVILLE MEMBER (GRANT LAKE FORMATION, UPPER ORDOVICIAN) IN SOUTHWESTERN OHIO

A Thesis submitted to the

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by

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ABSTRACT

The Corryville Member of the Grant Lake Formation (Upper Ordovician, Cincinnatian Series) in southwestern Ohio represents a transgressive facies deposited along a gentle, storm-influenced intracratonic carbonate ramp. The unit is composed of thick, platy- to flaggy-parted, sparsely fossiliferous shales (63%), and planar-bedded, fossiliferous limestones (37%) and contains a diverse, well-preserved open marine fauna. The purpose of this study was to complete a comprehensive investigation of the paleontology, paleoecology, and stratigraphy of the Corryville Member. Quantitative multivariate analysis, mean shale percentage logs, and comparative taphonomy were utilized to determine the primary depositional mechanisms and the effects of sea level fluctuations on the distribution and preservation of fossil assemblages.

A high resolution stratigraphic investigation at Stonelick Creek, in Clermont County, Ohio, the proposed type section, confirmed that the distribution of lithologies within the Corryville Member is heterogeneous and that these variations are systematic in nature. The vertical section can be subdivided into four laterally persistent "zones" distinguished by marked variations in mean shale percentage, bedding character, and shale and limestone lithology. These zones are recognizable in shale logs and can be used to correlate local and distant field exposures and rock cores throughout the region.

Diagnostic sedimentary structures, macroinvertebrate morphology, and taphonomic indicators suggest that the Corryville Member represents a low energy, deeper water environment that was periodically subjected to high energy storm events. The preservation of fossil assemblages is attributed to a relatively rapid storm-related burial, minimal post-storm reworking by bottom currents or burrowing organisms, and possible early diagenetic cementation. Typical

limestone beds within the Corryville Member are parautochthonous tempestites that display a wide variety of taphonomic signatures, suggesting a remixing of several generations of skeletal materials. Deposits of articulated trilobite and echinoderm specimens are rare and appear to be stratigraphically restricted to the middle and top of the Corryville Member.

A quantitative analysis of faunal distribution within the vertical section revealed that the Corryville Member was essentially a single biofacies and paleocommunity. Corryville fossil assemblages are polytaxic and are dominated by epifaunal and semi-infaunal suspension feeders, primarily *Rafinesquina*, *Zygospira*, pelecypods, ramose bryozoans, that display adaptations for muddy substrates. Although several species of articulate brachiopods were range-restricted to the basal half of the Corryville Member, most assemblages contained variable amounts of the same taxa or taxonomic groups. Trace fossils are abundant and generally restricted to beds with silt-sized sediment, and the Corryville Member appears to belong to the *Cruziana* ichnofacies.

On the basis of faunal distribution, dominant carbonate lithology, bedding style, and the preservation of depositional cycles, the Corryville Member can be subdivided into an "upper" and a "lower" interval. Small-scale cyclic bedding sequences (1-3 m in thickness) present within the "upper" Corryville Member are composed of a proximal "carbonate facies" and a distal "shale facies". The stratigraphically lowest small-scale cycle, situated at the base of the "upper" Corryville Member, represents the first regionally persistent depositional sequence. The base of the shale facies of this cycle is interpreted as the maximum flooding surface, suggesting that the transgression from the underlying Bellevue Member to the Corryville Member was more protracted than has been previously thought. Limestone beds in the upper 3 to 4 meters of the Corryville section displayed taphonomic trends that may be associated with shoaling.

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of Cincinnati Department of Geology. All original field notes, photo negatives, stratigraphic samples, and fossil specimens have been deposited at the Cincinnati Museum of Natural History as stipulated within the University of Cincinnati Museum of Natural History Specimen Acquisition Grant.

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INTRODUCTION

Purpose and Objectives

Within the past decade, researchers have gained significant insight concerning the broad mechanisms responsible for the deposition of the Cincinnatian Series (Meyer et al., 1981; Tobin, 1982; Jennette, 1986; Holland, 1992; Jennette and Pryor, in press). Most recent studies have agreed that episodic storm events were a primary factor in the formation of diagnostic sedimentary structures and in the preservation of fossil assemblages (Tobin, 1982; Brandt, 1986; Jennette, 1986; Diekmeyer, 1990; and others). Limestone and shale facies of several orders of magnitude have been recognized, and their cyclic alteration has been attributed to mechanisms ranging from delta switching to glacial eustacy (Tobin, 1982; Jennette, 1986; Jennette and Pryor, in press). With the larger facies relationships identified, paleontologic research has recently begun to focus on the large- and small-scale response of benthic communities and individual species to variations in paleoenvironmental conditions (Brandt Velbel, 1985; Diekmeyer, 1990; Meyer, 1990; Dattilo, 1992; Diekmeyer, 1992). Several Cincinnatian units have received surprisingly little attention in relation to their supposed stratigraphic importance, and these must be examined to substantiate the validity of the larger stratigraphic trends. The purpose of this study is to complete a modern, high-resolution stratigraphic and paleontologic reassessment of one such interval, the Corryville Member (Grant Lake Formation, Upper Ordovician) in southwestern Ohio.

The Corryville Member, frequently cited for its unusual and abundant fauna (Kerr, 1951; Caster, 1952; Caster and Macke, 1952; Caster et al., 1955; Hinterlong, 1981; Schumacher, 1984), has been described in only general terms, primarily because of its poor surface exposure. Within the past decade, the Corryville Member has been interpreted as a subtidal facies deposited along a gently sloping, west-facing carbonate ramp in a shallow epeiric sea (Tobin, 1982; Tobin and Pryor, 1985). Tobin (1982) first described the Corryville Member as a lower transition zone to upper offshore facies situated at the base of a third-order shoaling-upward cycle, the vertical thickness of which is currently a matter of dispute (see Holland, 1992; Schumacher, 1992). The lower unit contact with the Bellevue Member has been interpreted as an abrupt transgression from a more shallow, turbulent depositional environment to a comparatively quiet, deeper water environment (Tobin, 1982; Tobin and Pryor, 1985). No previous study has adequately assessed the nature of the transgression, and a bed-by-bed analysis would help to determine the intensity and duration of this event. In addition, a fine-scale study might identify the primary controls on Corryville deposition as well as the geometry and lateral continuity of Corryville beds and bedding sequences.

No comprehensive, quantitative taphonomic or faunal distributional survey has been completed for the Corryville interval; much pertinent information concerning the temporal stability of the paleoenvironment can be determined through an examination of fossil distribution patterns and preservational signature. Taphonomy can offer considerable insight into the timing of fossil material accumulation, the energy level of the depositional environment, and the level to which physical, chemical, and diagenetic processes have altered the faunal record. Corryville limestones contain abundant skeletal materials that display a variety of preservational modes and are well-suited for a paleontologic analysis. The presence of exceptionally preserved fossil assemblages (Lagerstätten) is an important feature of the Corryville interval, and their stratigraphic occurrence needs to be resolved. The preservation potential of depositional trends and faunal distributional trends should be improved for a quiet water environment (Aigner, 1985; Speyer and Brett, 1988), and so the Corryville Member should represent an ideal environment for a high-resolution stratigraphic study.

Considering only one approach to stratigraphy can lead to ambiguous conclusions and a loss of valuable comparative data (Brett and Baird, 1986; Brandt, 1989). Therefore, this thesis has been organized as a quantitative, multifaceted approach to stratigraphy that will utilize sedimentology, faunal distribution, and comparative taphonomy. Sedimentology can indicate changes in relative sea level, proximality relationships, and relative rates of deposition, and taphonomy and faunal distributional studies can delineate subtle environmental shifts that may have no sedimentologic signature. Although these three investigative approaches are naturally interdependent, each is presented as a separate chapter, with a comprehensive summary at the end of this report. The following specific objectives are addressed by this investigation:

1. to construct a composite stratigraphic section for the proposed type section of the Corryville Member of the Grant Lake Formation at Stonelick Creek,

2. to define intraformational depositional patterns and cycles based on proximality relationships and to determine whether these patterns can be used for correlation throughout the surface and subsurface of southwestern Ohio,

3. to examine the paleoecology of the Corryville Member using quantitative multivariate analyses for the delineation of macrofossil distribution patterns,

4. to describe the taphonomy of Corryville limestones quantitatively and determine the processes responsible for the formation and preservation of Corryville fossil assemblages,

5. to record and explain the stratigraphic occurrence of fossil Lagerstätten within the vertical section at Stonelick Creek,

6. to reconstruct the Corryville paleoenvironment and propose a mechanism for deposition and cyclic sequences.

History of Nomenclature

The geology of the Cincinnatian Series has been the subject of serious study and debate since the late nineteenth century. Many papers have chronicled the scientific history of these rocks over the past century (Cumings, 1922; Gutstadt, 1958; Peck, 1966; Sweet and Bergström, 1971; Meyer et al., 1981; Tobin, 1982; Meyer et al., 1985; Jennette, 1986; Tobin, 1986; Schumacher, 1992). One source of vigorous contention among past and present Cincinnatian workers has been the criteria used to subdivide the 250 m (820 ft) thick stratigraphic section. Both biostratigraphic (Nickles, 1902; Bassler, 1906; Caster et al., 1955) and lithostratigraphic nomenclatures (Brown and Lineback, 1966; Peck, 1966; Lee, 1974; Ford, 1967; Hay, 1981; Tobin, 1982) have been proposed for the Cincinnatian Series, often with strong disagreement as to the name, number, extent, and boundaries of the various defined units. The Corryville interval, poorly defined from the start, is an apt example of the mutable nature of Cincinnatian stratigraphy.

The Corryville Member initially was recognized by Nickles (1902) from exposures in the Cincinnati area and was named after the community of Corryville, a northern Cincinnati neighborhood within which many of the unit's exposures were once situated. Nickles defined the "Corryville Beds" of the Lorraine Group primarily by the presence and abundance of the characteristic bryozoan *Chiloporella nicholsoni* (James), and by the absence of the bryozoan *Monticulopora modesta* (Nicholson) which delineated the underlying Bellevue beds. The Corryville Beds were simply those in which: "the limestones are thinner and less frequent than in the quarry beds [the Fairview and Bellevue units] and the shales are more yellowish. Blue shale also occurs" (Nickels, 1902. p. 83). Early Cincinnatian workers noted a lack of distinctive character for the Corryville interval, and its position was recognized primarily by means of its position in relation to the overlying and underlying units (Braun, 1916; Fenneman, 1916).

Shortly after Nickles' publication, Bassler (1906, p.10) included the Corryville as a member of the McMillan Formation, which was composed of the Bellevue, Corryville, and Mount Auburn units and named for McMillan Avenue in Cincinnati. Bassler never published a description of the McMillan Formation or its unit boundaries and did not designate a specific type-section for the Corryville. Despite this failure to establish a detailed account of the McMillan Formation, Bassler's nomenclature became the accepted regional stratigraphy for the next half century. Bucher, Caster, and Jones (1939) and then Caster, Dalvé, and Pope (1955) incorporated Bassler's unit names into their biostratigraphic description of the entire Cincinnatian Series.

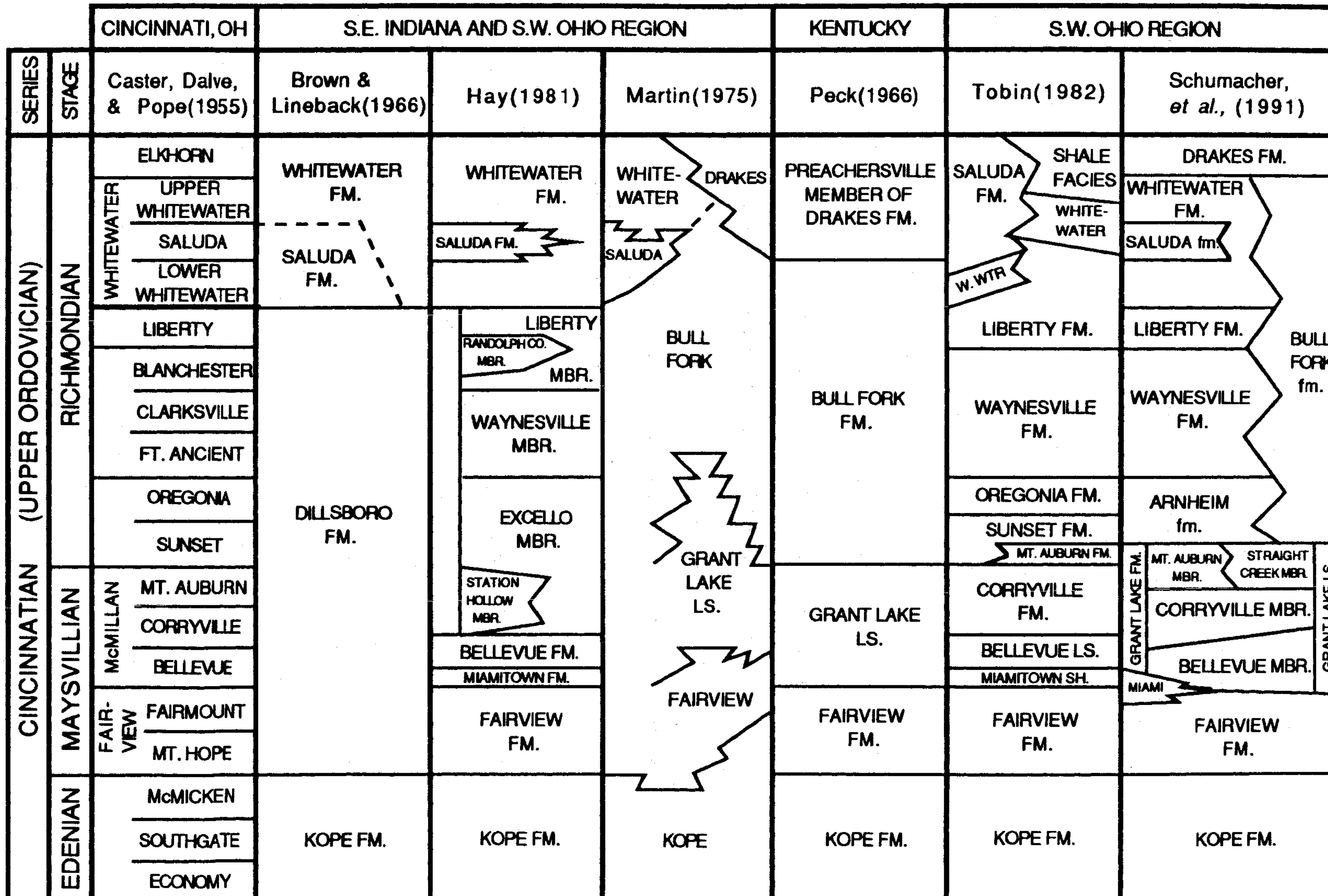
The 1960's and 1970's were a period of reawakened interest in the Cincinnatian Series, marked by a general dissatisfaction with the established stratigraphy and an accompanying desire to redefine the entire Cincinnatian Series using purely lithologic criteria. The original nomenclature of Bassler and Nickles was rejected for what was seen as its biological underpinnings and its lack of sharp, recognizable lithologic unit boundaries. Further, the original nomenclature did not appropriately account for gradational facies changes within the Cincinnatian Series, from the limestone-dominated units of northern Kentucky to the stratigraphically equivalent shale-dominated beds of southeastern Indiana. For these reasons, the name Corryville was abandoned, and its facies was incorporated into larger, undifferentiated lithostratigraphic formations including the Grant Lake Limestone of Kentucky (Peck, 1966; Lee, 1974), and the Dillsboro Formation (Brown and Lineback, 1966; Martin, 1975) and Brookville Formation (Hay, 1981; Hay et al., 1981), both of Indiana. Within the Cincinnati area, Ford (1967, p.934) referred to the entire stratigraphic sequence above the Bellevue as the "unnamed beds", proclaiming that, within the Cincinnati area, there were "no valid lithological criteria" with which to subdivide the interval. Other workers in the Cincinnati area (Osgood, 1970; Hinterlong, 1981; Brandt Velbel, 1985) retained the nomenclature of Caster et al. (1955). In retrospect, the resulting proliferation of unit names was effective for the description of local exposures in the three separate states, but contributed little to an understanding of regional facies relationships. Table 1 compares several of these stratigraphic interpretations for the Cincinnatian Series within the Tri-state region of southeastern Indiana, northern Kentucky, and southwestern Ohio.

In a study of the large-scale depositional dynamics of the Cincinnatian Series in southwestern Ohio, Tobin (1982) concluded that the Cincinnatian strata were a conformable sequence of stacked, genetically-related rock facies. The Corryville interval, according to Tobin, was deposited in a relatively deep water, low energy environment and represented a distinct and mappable facies. In accordance with this reasoning, Tobin (1982, 1986) abandoned the McMillan Formation, and elevated the Corryville to the status of formation. Tobin maintained that Nickles' (1902) "Corryville", while outdated and lacking in detail, remained a valid biostratigraphic and lithostratigraphic identity and so had priority as a rock-stratigraphic unit. Recent geological studies have deferred to this interpretation (Rassmann, 1984; Schumacher, 1984; Meyer, 1990).

This status was brought into question by Schumacher et al. (1991), who documented regional lithostratigraphic variation within the Bellevue, Corryville and Mt. Auburn sequence. Through a combination of bedrock mapping, shale-percentage logs, geophysical logs, and mean percentage of shale, Schumacher et al. recognized that these three lithologic units could be correlated throughout southwestern Ohio, but were not easily mappable at a 1:62,500 map-scale or smaller. In accordance to the guidelines set forth by the 1983 North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), Schumacher et al. reduced these three units to members and placed them within the proposed Grant Lake Formation, a modification of the stratigraphically equivalent, though lithologically disparate, Grant Lake Limestone of Kentucky (Table 1). The older McMillan Formation was regarded as invalid because it lacked a type section and had no defined formational boundaries. Stonelick Creek in Clermont County, Ohio, was proposed as the official type-section for the Corryville Member of the Grant Lake Formation (Schumacher et al., 1991).

The Grant Lake Formation and Grant Lake Limestone of Schumacher et al. (1991) have been adopted by the Ohio Department of Natural Resources (ODNR) Division of Geological Survey and are utilized in this investigation. This nomenclature is favored because: (1) it conforms to the guidelines of the 1983 North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983); (2) it recognizes the Corryville as a distinct, mappable Cincinnatian facies with a unique depositional history; and (3) it can account for lithostratigraphic and faunal variations on both the local and the regional scales. At this time, the general reaction to this stratigraphic nomenclature cannot be assessed. In light of the past debate, future revision in the status of the Corryville interval cannot be entirely dismissed.

Table 1 - Comparison of Cincinnatian stratigraphic nomenclature in southeastern Indiana, southwestern Ohio, and northern Kentucky.


CINCINNATI, OH
S.E. INDIANA AND S.W. OHIO REGION
KENTUCKY
S.W. OHIO REGION
SERIES
STAGE
Caster, Dalve, & Pope(1955)
Brown & Lineback(1966)
Hay(1981)
Martin(1975)
Peck(1966)
Tobin(1982)
Schumacher, et al., (1991)
CINCINNATIAN (UPPER ORDOVICIAN)
RICHMONDIAN
MAYSVILLIAN
EDENIAN
ELKHORN
WHITEWATER
UPPER WHITEWATER
SALUDA
LOWER WHITEWATER
LIBERTY
BLANCHESTER
CLARKSVILLE
FT. ANCIENT
OREGONIA
SUNSET
McMILLAN
MT. AUBURN
CORRYVILLE
BELLEVUE
FAIR-VIEW
FAIRMOUNT
MT. HOPE
McMICKEN
SOUTHGATE
ECONOMY
WHITEWATER FM.
SALUDA FM.
DILLSBORO FM.
KOPE FM.
WHITEWATER FM.
SALUDA FM.
LIBERTY
RANDOLPH CO. MBR.
MBR.
WAYNESVILLE MBR.
EXCELLO MBR.
STATION HOLLOW MBR.
BELLEVUE FM.
MIAMITOWN FM.
FAIRVIEW FM.
KOPE FM.
WHITE-WATER
DRAKES
SALUDA
BULL FORK
GRANT LAKE LS.
FAIRVIEW
KOPE
PREACHERSVILLE MEMBER OF DRAKES FM.
BULL FORK FM.
GRANT LAKE LS.
FAIRVIEW FM.
KOPE FM.
SALUDA FM.
SHALE FACIES
WHITE-WATER
W. WTR
LIBERTY FM.
WAYNESVILLE FM.
OREGONIA FM.
SUNSET FM.
MT. AUBURN FM.
CORRYVILLE FM.
BELLEVUE LS.
MIAMITOWN SH.
FAIRVIEW FM.
KOPE FM.
DRAKES FM.
WHITEWATER FM.
SALUDA fm.
LIBERTY FM.
WAYNESVILLE FM.
ARNHEIM fm.
BULL FORK fm.
GRANT LAKE FM.
MT. AUBURN MBR.
STRAIGHT CREEK MBR.
CORRYVILLE MBR.
BELLEVUE MBR.
GRANT LAKE LS.
MIAMI
FAIRVIEW FM.
KOPE FM.

Corryville "Type-area"

Although Nickles did not designate a specific type-section for his "Corryville Beds", his original stratigraphic description for the Cincinnati area did cite several localities within the city limits where exposures of the "Corryville Beds" could be examined (1902, p. 83, Pl. 1). These localities, in the Clifton, Avondale, Walnut Hills, Fairview Heights, and Price Hill neighborhoods, are considered to be the informal "type-area" for the Corryville Member. This type-area corresponds to an east-west trending, present-day topographical high that borders on the northern edge of downtown Cincinnati and is the result of downcutting by past and present drainage systems. Most of the Corryville type-area is situated just south of the main campus of the University of Cincinnati (Fig. 1). All of the original exposures within this area have since been demolished or buried (Appendix 1). However, a recent exposure of the upper portion of the Corryville Member in the Corryville community can be seen at the back of an empty lot just west of the intersection of McMillan Street and Vine Street (Fig. 2; Appendix 1).

In the type-area, the contact between the Bellevue and Corryville Members is gradational and can be seen in two partially buried exposures, one atop the cliff located at the southwestern corner of Bellevue Hill Park, and the other at the top of the small Bellevue Member exposure situated just below the transmitting tower above Emming Street (Appendix 1). This contact corresponds roughly to an elevation of 820 feet above sea-level. Although the shales at these exposures are recessed or buried, there exists an obvious transition from irregularly-bedded, brachiopod-rich limestones with randomly oriented fossils (Bellevue Member) to planar-bedded limestones with subhorizontally oriented

Figure 1 - Location of the Corryville "type-area" in Cincinnati, Ohio. The lined area corresponds to elevations between 820 to 865 ft (249.9 to 263.7 m) above sea level. The black rectangle marks the site of the McMillan Street exposure (Appendix 1).

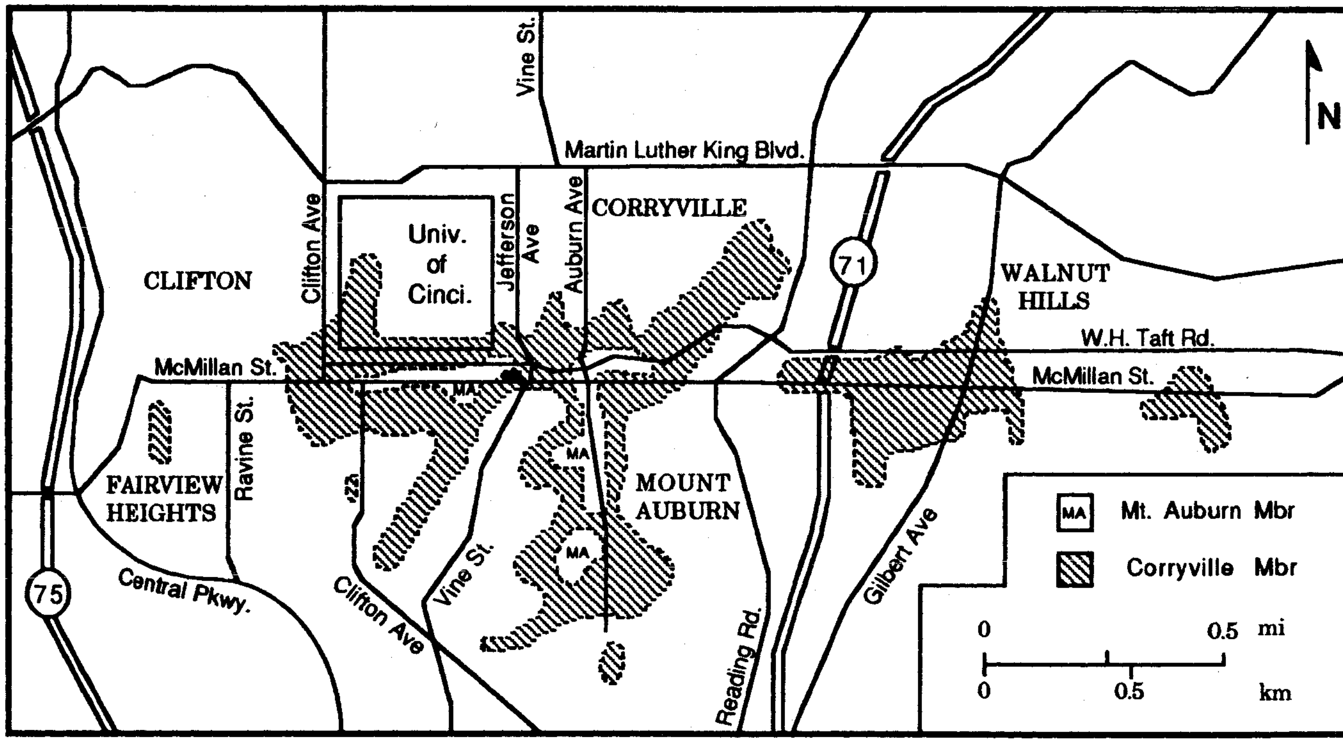

N
Martin Luther King Blvd.
Vine St.
Clifton Ave
Univ. of Cinci.
Jefferson Ave
Auburn Ave
CORRYVILLE
CLIFTON
71
WALNUT HILLS
W.H. Taft Rd.
McMillan St.
McMillan St.
MA
Ravine St.
FAIRVIEW HEIGHTS
MOUNT AUBURN
75
Central Pkwy.
Clifton Ave
Vine St.
Reading Rd.
Gilbert Ave
Mt. Auburn Mbr
Corryville Mbr
0
0.5
mi
0
0.5
km

Figure 2 - A "type" Corryville exposure in an empty, south-facing lot just west of 16 McMillan Street in Cincinnati, Ohio (Appendix 1 - McMillan St.). Horizontal meter stick at center of exposure for scale.

fossils and with a silt cap containing convex-up *Rafinesquina* valves (Corryville Member).

The Mt. Auburn-Corryville contact is covered within the type-area. Given an approximate thickness of 44 ft (15 m) for the type-area (Caster et al., 1955), the expected elevation for this contact should be about 865 feet above sea level. This estimate is corroborated by the comparatively higher elevations of previously existing Mt. Auburn Member exposures. Given boundary elevations and past and present outcrop localities, a bedrock map can be constructed for the prediction of potential Corryville exposures within the type-area (Fig. 1).

Cincinnatian Paleogeography

Just as modern ecological research strives to understand the relationship between geography and the environment, a study of paleoenvironmental and paleoecologic processes must likewise take the paleogeography of its rocks into account. The paleogeography of the Upper Ordovician has been much discussed in the literature (Kreisa, 1981b; Tobin, 1982; Weir et al., 1984; Jennette, 1986; Frey, 1987b; Diekmeyer, 1990; Scotese and McKerrow, 1990) and is briefly summarized here. In the Late Ordovician, southwestern Ohio was the site of a shallow epicontinental sea and was a small part of an elongate, northeast-southwest trending carbonate platform (Tobin, 1982). The Cincinnati Arch, a gentle regional structure, is considered to have existed during the Late Ordovician (Weir et al., 1984). Regional Upper Ordovician lithofacies patterns (Fig. 3) indicate that deeper shelf conditions lay to the northwest and that deltaic and alluvial plains existed in the east and southeast (Tobin, 1982). Clastic material, chiefly terrigenous muds and silts, prograded westward from the

Appalachian basin and were episodically transported into the carbonate-dominated Cincinnati area (Tobin, 1982; Jennette, 1986; Frey, 1987b).

Paleogeographic reconstructions position the Cincinnati Arch in the tropical to subtropical southern hemisphere between 15°-25° south of the equator and rotated 45° clockwise from its present orientation (Kreisa, 1981b; Weir et al., 1984; Scotese and McKerrow, 1990). By assuming past meteorological patterns similar to those existing today, several studies (Kreisa, 1981b; Tobin, 1982; Weir et al., 1984; Jennette, 1986) have inferred that the carbonate ramp was subject to frequent south-southwest-heading tropical storms originating from the westerly-flowing trade winds (Fig. 4). Such storms could have been of hurricane strength and could have been a primary control of deposition.

Figure 3 - Distribution of major North American lithofacies from Late Ordovician time, with inset detailing the environments of the Ohio-Kentucky-Indian region (from Jennette, 1986). Carbonate ramp sloped gently to the W/NW.

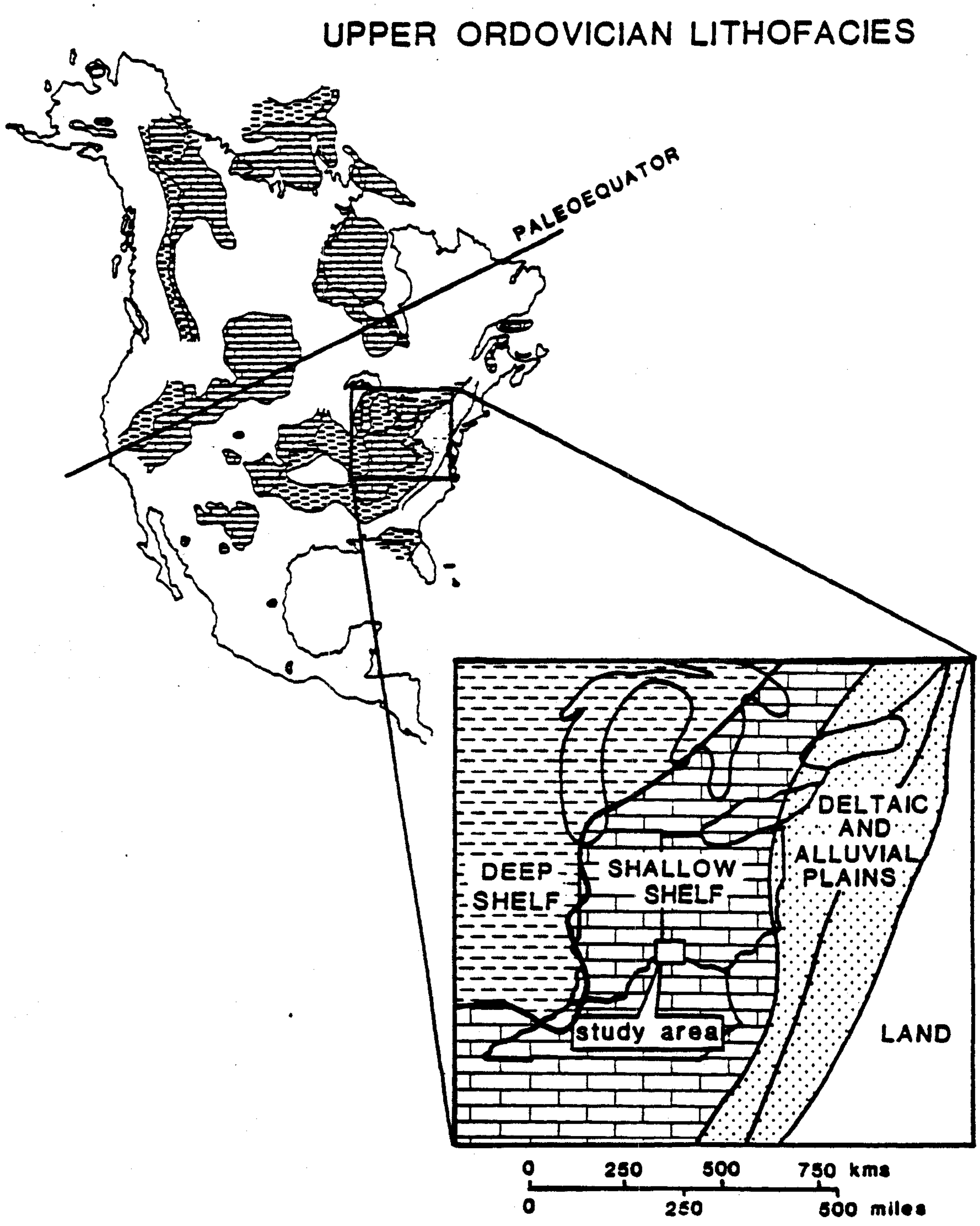
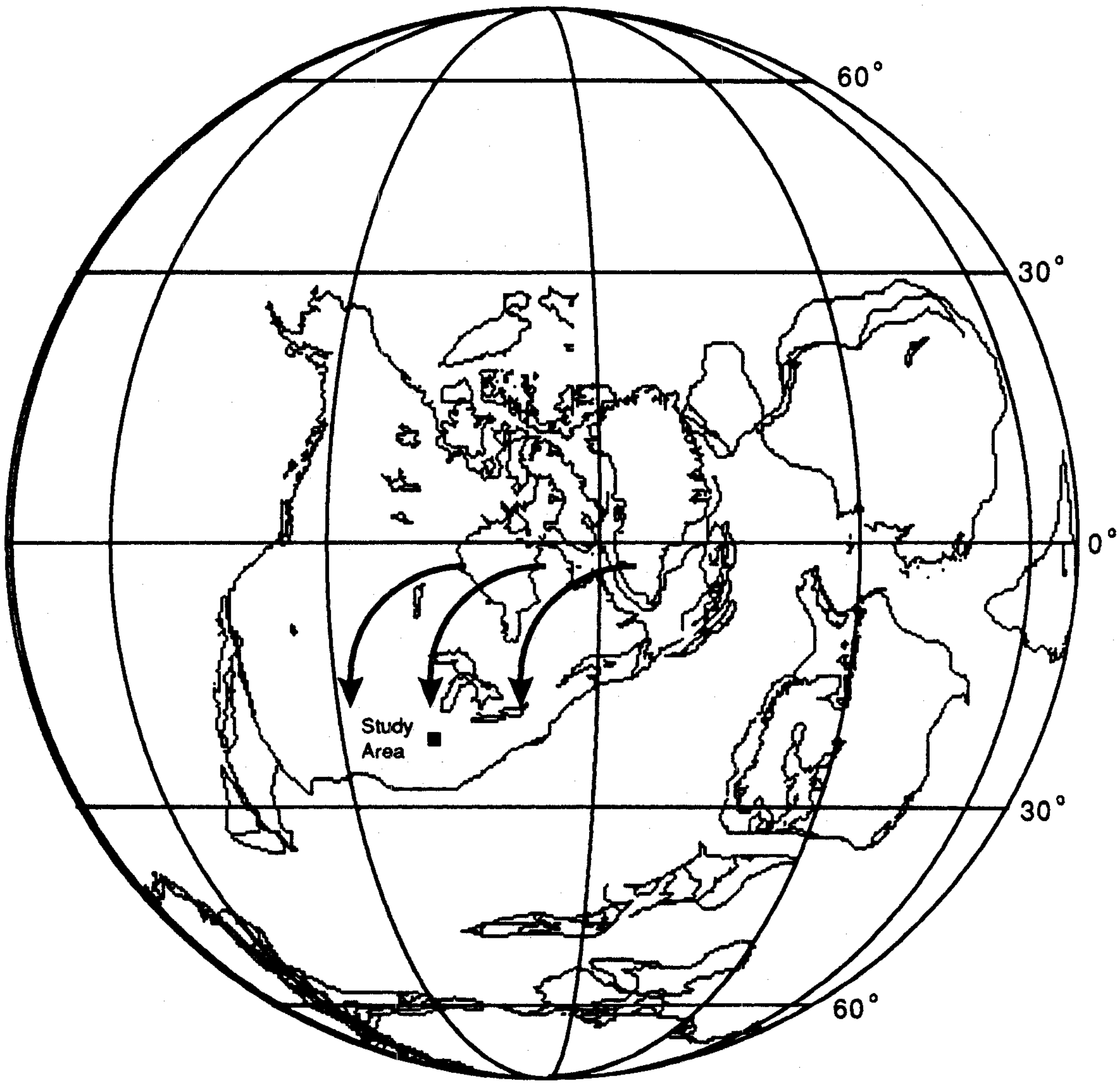

UPPER ORDOVICIAN LITHOFACIES
PALEOEQUATOR
DEEP SHELF
SHALLOW SHELF
DELTAIC AND ALLUVIAL PLAINS
study area
LAND
0 250 500 750 kms
0 250 500 miles

Figure 4 - Paleogeographic reconstruction of southwestern Ohio during the Early Ordovician (modified from Kreisa, 1981b; Scotese and Denham, 1988).


60°
30°
0°
30°
60°
Study Area

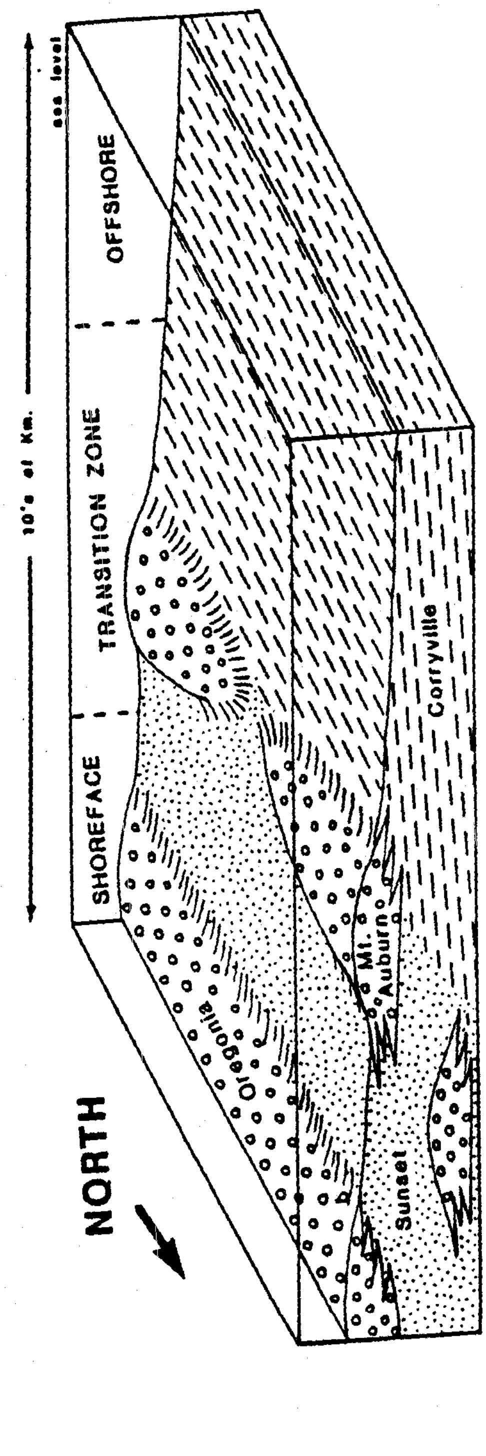
CORRYVILLE SEDIMENTOLOGY AND STRATIGRAPHY

Introduction

The richly fossiliferous Corryville Member of the Grant Lake Formation has always attracted fossil collectors, yet surprisingly little information has been published concerning its local and regional stratigraphy. This lapse is largely attributable to the paucity of Corryville exposures within southwestern Ohio. Situated along local topographic highs, this shale-rich strata has been subjected to prolonged weathering, where even fresh exposures are readily converted to gentle, heavily vegetated hills. Difficulties associated with a study of the Corryville Member include the lack of clean, accessible outcrops, the lack of complete exposures or exposures with identifiable unit boundaries, and the distance between workable field sites. It is no surprise then that many geologic studies have eschewed the Corryville Member in favor of the well-exposed and accessible Kope through Bellevue sequence (e.g. Weiss and Norman, 1960; Scotford, 1965; Weiss et al., 1965; Hofmann, 1966a, 1966b; Ford, 1967; Osborne, 1968; Sweet and Bergström, 1971; Osborne, 1973; Ford, 1974; Tobin and Pryor, 1981; Jennette, 1986; Anstey and Rabbio, 1989; Diekmeyer, 1990; Diekmeyer, 1992; Dattilo, 1992; Jennette and Pryor, in press).

A small number of recent studies have addressed the gross stratigraphy of the Corryville Member and have suggested a storm-generated origin for the unit (Hinterlong, 1981; Tobin, 1982; Schumacher et al., 1991). Tobin (1982; Tobin and Pryor, 1985) interpreted the Corryville strata as having been deposited within a lower transition zone to upper offshore environment along a gently sloping, west-facing carbonate ramp in a shallow epeiric sea (Fig. 5). Tobin (1982) examined the relationships of Cincinnatian depositional facies and

Figure 5 - Paleoenvironmental reconstruction of Corryville by Tobin (1982, Fig. 64). Corryville was defined as a transition zone to offshore facies with the overlying Mt. Auburn, Sunset, and Oregonia lithofacies representative of more shallow water depositional conditions.


sea level
OFFSHORE
TRANSITION ZONE
SHOREFACE
10's of Km.
NORTH
Oregonia
Mt. Auburn
Sunset
Corryville

placed the Corryville beds at the base of a large-scale, shoaling-upward sequence. If this is indeed the case, and the lower Corryville contact signifies an abrupt transgression from a more shallow, turbulent environment to a comparatively deeper water setting, then the nature and tempo of this transgression must be carefully examined. Tobin (1982) relied on partial field exposures for his interpretation of the Corryville interval, and a high resolution analysis of the Corryville interval should be completed for the entire interval. A bed-by-bed analysis can reveal details concerning the intensity of the post-Bellevue transgression, the lithologic homogeneity of the Corryville interval, the presence of intraformational depositional cycles, and the lateral extent of observed lithologic trends. If the Corryville Member does represent a low energy environment below normal wave base (Tobin, 1982), then the preservation potential of valuable stratigraphic information (e.g. event beds and cycles) should be quite high.

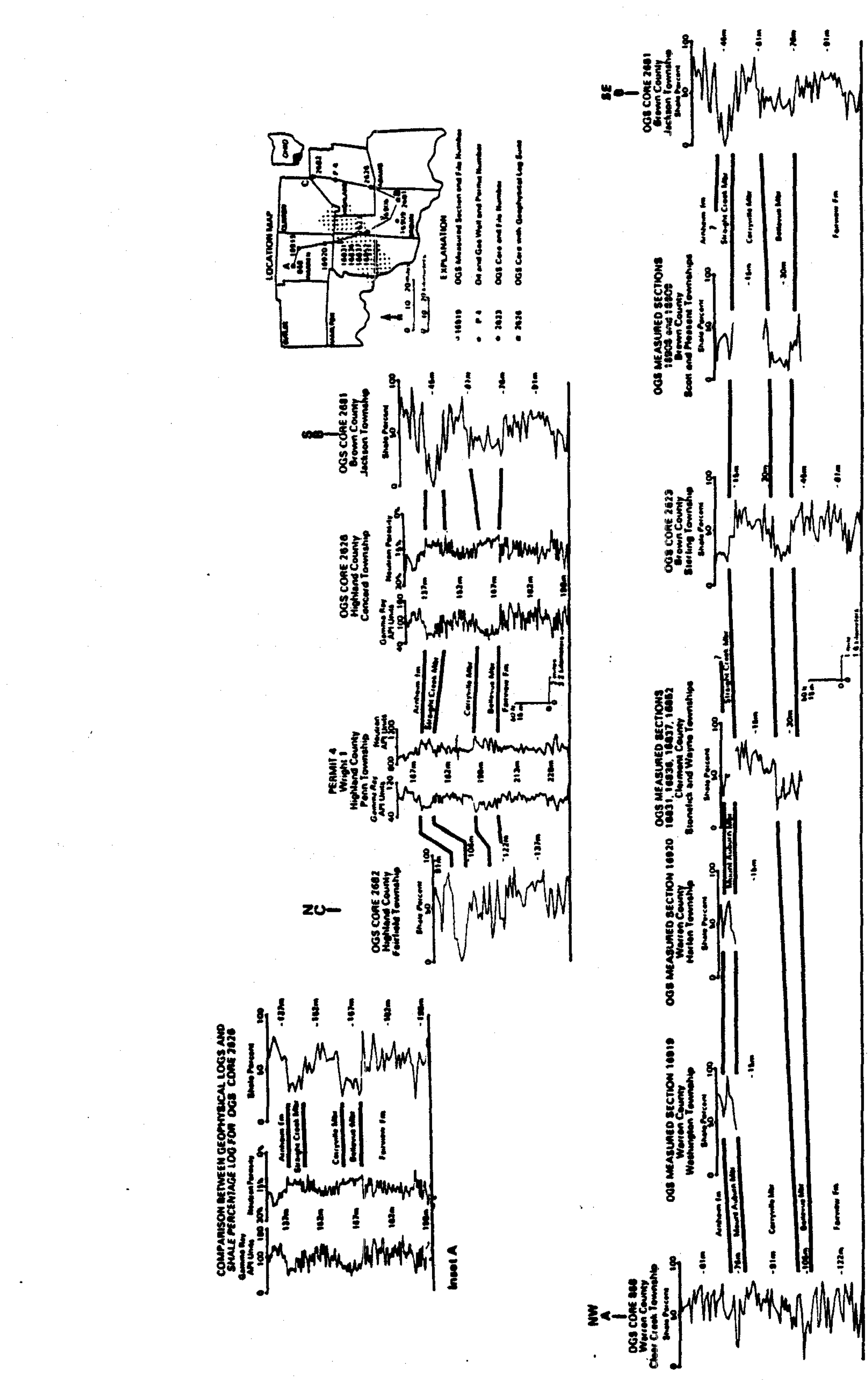
Many new stratigraphic concepts and tools are at hand for a high resolution lithostratigraphic analysis of the Corryville Member. This study has incorporated aspects of dynamic stratigraphy and event stratigraphy to explain variations in Corryville depositional dynamics and has used mean shale percentage logs to examine the extent of depositional trends throughout the area of southwestern Ohio. Dynamic stratigraphy, a process-oriented analysis of sedimentary sequences, applies proximality relationships to explain the mechanisms responsible for all scales of deposition (Aigner, 1985; Seilacher and Aigner, 1991). Event stratigraphy, the stratigraphy of specific event deposits, is a similar concept that has been used for basin analysis and local chronostratigraphic correlation (Seilacher, 1982; Jennette, 1986; Miller et al., 1988; Dattilo, 1992; Jennette and Pryor, in press). Shale logs, which can objectively measure the relative amount of shale and limestone in a field exposure or rock core, have been used effectively to resolve subtle facies variations (Schumacher et al., 1991; Dattilo, 1992). Schumacher et al. (1991) mapped regional facies changes in the Bellevue through Corryville sequence through the use of shale logs (Fig. 6).

Storm Deposition

Storm related processes and episodic sedimentation were a primary depositional mechanism for many Upper Ordovician epicontinental sequences (Kreisa, 1981a, 1981b; Tobin, 1982; Marsaglia and Klein, 1983; Brandt, 1986; Lehman and Pope, 1989; Jennette and Pryor, in press; and others) and in similar Phanerozoic strata (Ager, 1974; Aigner, 1982; Fürsich, 1982; Gray and Benton, 1982; Brett, 1983; Marsaglia and Klein, 1983; Brett and Baird, 1985; Norris, 1986; and others). Recent studies of modern storm-dominated environments and storm-generated sedimentary structures have helped to develop actualistic depositional models used to interpret ancient storm-deposited strata (Kreisa, 1981b; Aigner, 1985). Actualistic studies have necessarily focused on the larger, preservable storm-related trends and have documented lithologic, sedimentologic, and taphonomic patterns that grade systematically between "proximal" (nearshore, shallow) and "distal" (offshore, deeper water) settings. Identification of storm-related strata is especially critical for the comprehension of many ancient depositional settings (e.g. epeiric seas) that lack an ideal modern analog.

In southwestern Ohio, deposition of carbonate and clastic sediments occurred along a shallow, gently-sloping, storm-dominated carbonate ramp (Tobin, 1982; Jennette, 1986; Jennette and Pryor, in press). Epeiric sea carbonate ramps consisted of several coexisting, depth-related, open-marine

Figure 6 - Correlation of Grant Lake Formation and Grant Lake Limestone in southwestern Ohio through mean shale percentage logs from cores and measured sections (from Schumacher et al., 1991).



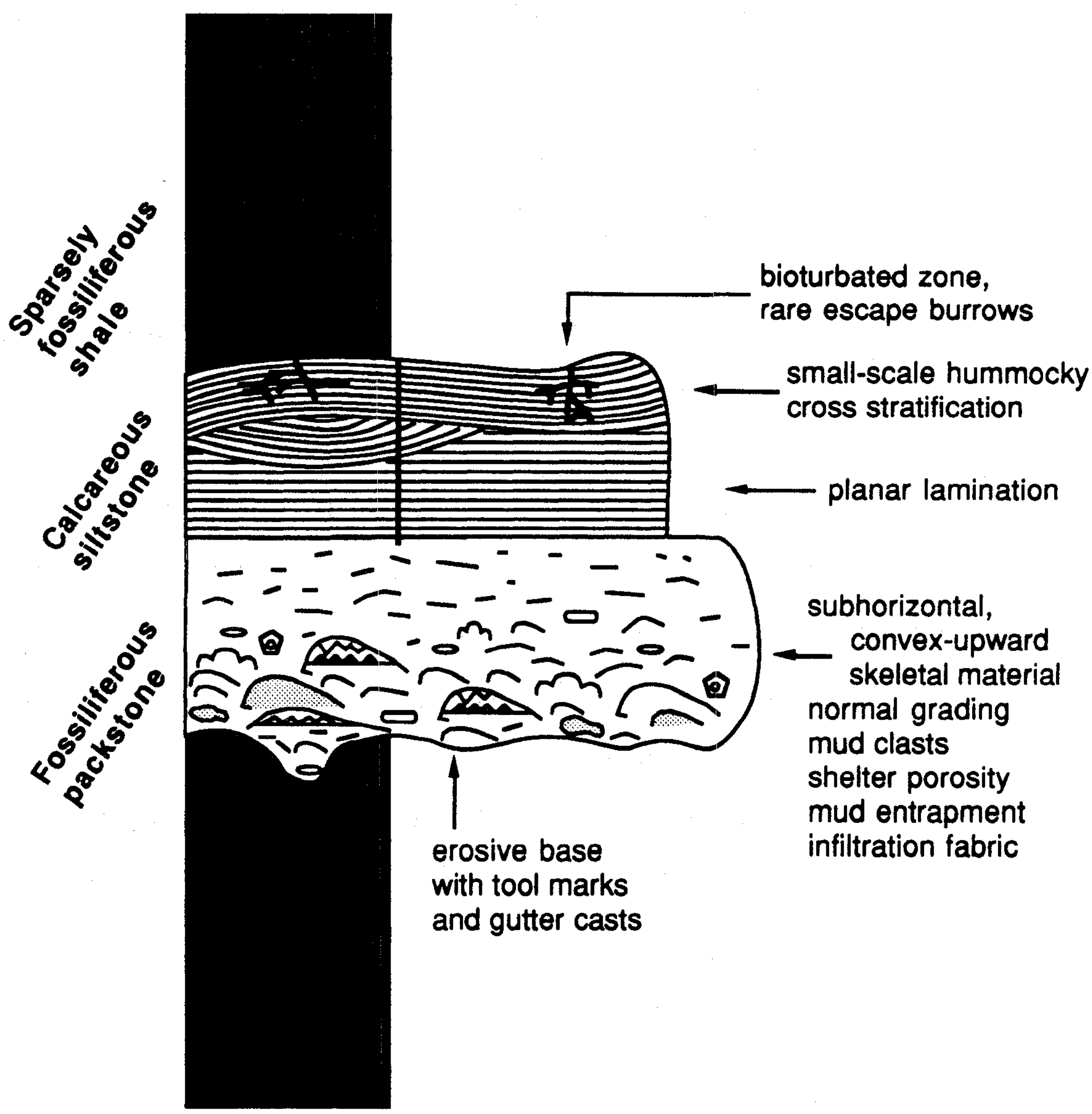
LOCATION MAP
EXPLANATION
Inset A

facies that each displayed a different biological, chemical, and physical character (Irwin, 1965). A singular feature of these ramp environments is their lack of protective reef belts or sharp breaks in slope (Irwin, 1965, Fig. 1; Read, 1985); the entire Cincinnatian Sea ramp would have been exposed to storm effects, and storm-related proximality gradients would likely be evident in the Cincinnatian strata of Ohio (Jennette and Pryor, in press). Modern studies cannot duplicate this depositional system, but the study of modern hurricanes in similar environments (e.g. the Bahamian shelf) can help to explain the intensity and duration of similar ancient storms. Modern hurricanes generally originate in the Tropics and have high wind circulations (170-250 km/h) and large areas of coverage (average 330-420 kms in diameter) (Tobin, 1982). Harrison and Mahan (1981) estimated a Cincinnatian hurricane rate of 160 storms/1000 years, but this rate was based upon the number of recent storms affecting south Florida and therefore may not be an adequate analogy for subequatorial epicontinental seas.

Storm conditions provide high waves with longer periods than normal that effectively lower the wave base and affect the muddy substratum that is commonly away from the coastal areas and below normal wave base (Kreisa, 1981b; Meyer et al., 1981). With a deepening of wave base, the shallow sea floor is eroded, sediment is suspended by wave surge, and fine sands, muds, and silts are transported offshore by wave-driven unidirectional bottom currents (refer to Kreisa, 1981b; Aigner, 1985; or Jennette, 1986 for more detailed treatments of this process). Similar unidirectional currents have been estimated from the Triassic Upper Muschelkalk in southwest Germany at 1-20 cm/s in distal settings and 20-60 cm/s in more proximal settings (Aigner, 1985, p. 94). A coarse shell lag may be left in place or the exposed, indurated sea bottom may be scoured (Goldring and Aigner, 1982; Kreisa and Bambach, 1982). After the storm has passed, suspended sediments settle out rapidly into a storm event bed, or "tempestite", that reflects the entire storm event, from the rapid early erosion to the post-storm waning flow regime (Reineck and Singh, 1972; Ager, 1974; Kreisa, 1981b; Aigner, 1982; Tobin, 1982; Kreisa and Bambach, 1982; and others). Turbidites are not the equivalent of tempestites, and although the two share some characteristics, they can be distinguished on the basis of their sedimentary structures, biofabrics, and stratigraphic context (Gray and Benton, 1982; Einsele and Seilacher, 1991).

Tempestites have been previously recognized within the Corryville Member (see "Bouma sequences" in Hinterlong, 1981) and other Cincinnatian strata (Brandt, 1986; Jennette, 1986; Frey, 1987b; Jennette and Pryor, in press; and others). The ideal tempestite (Fig. 7) consists of a couplet of a basal fossiliferous limestone, or "shell bed", and a planar laminated to hummocky cross-stratified calcareous siltstone (Kreisa, 1981b; Marsaglia and Klein, 1983; "graded-skeletal sheets" in Aigner, 1985; and others). The diagnostic sedimentary structures associated with this type of storm deposit suggest the effects of both unidirectional and oscillatory (wave) currents and may indicate paleodepth (Aigner, 1982). The fossiliferous limestone records the high-energy storm phase and represents reworked, disturbed parautochthonous material that has been winnowed in place (Kreisa and Bambach, 1982). The base of this limestone is erosional, with aligned gutter casts, scour marks, and tool marks, and infiltration fabrics, intraclasts, and normal grading are seen within the limestone (Kreisa, 1981b; Aigner, 1982; Kreisa and Bambach, 1982; Marsaglia and Klein, 1983). The upper siltstone is recognized as the result of waning-energy deposition and a return to dominantly oscillatory water flow (Kreisa and Bambach, 1982; Aigner, 1985). These siltstones frequently show an upward increase in mud matrix and weakening of laminae as wave-

Figure 7 - Idealized storm event bed with limestone and siltstone couplet (modified from Ager, 1974; Kreisa, 1981b; Brandt, 1986).

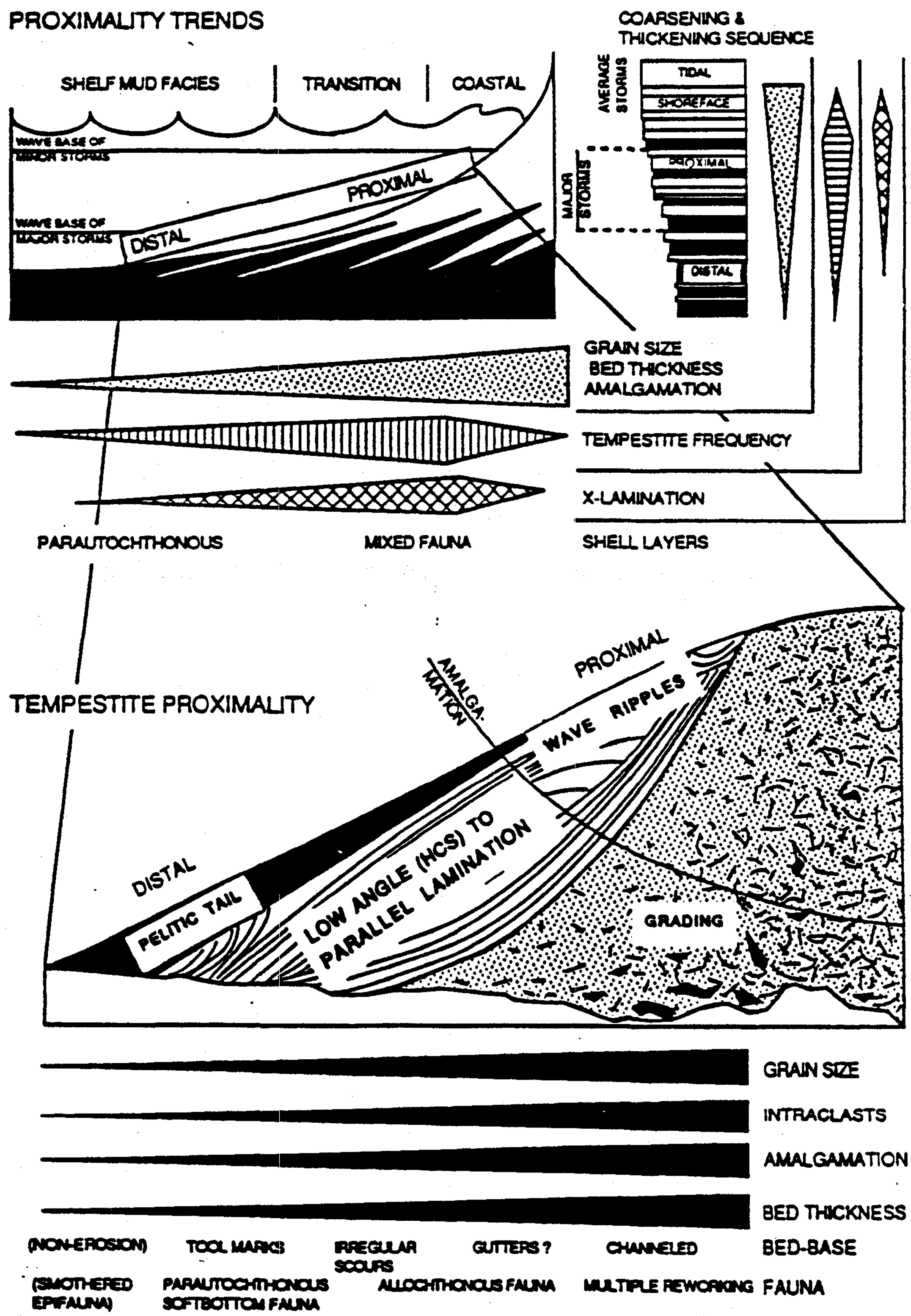

Sparsely fossiliferous shale
Calcareous siltstone
Fossiliferous packstone
bioturbated zone, rare escape burrows
small-scale hummocky cross stratification
planar lamination
subhorizontal, convex-upward skeletal material
normal grading
mud clasts
shelter porosity
mud entrapment
infiltration fabric
erosive base with tool marks and gutter casts

generated currents dissipated (Reineck and Singh, 1972). The upper surface of this siltstone can be diffusely or highly burrowed and may contain escape traces (Kreisa, 1981b; Aigner, 1982).

The "proximality concept", developed by Aigner (1982, 1985), details the gradational change in lithology, paleontology, ichnology, and sedimentary structures from proximal (marginal or nearshore) settings to more distal (basinal or offshore) settings (Fig. 8). Proximality gradients can help to explain the vertical and lateral facies sequences in storm-dominated shelf environments and can indicate paleobathymetric trends and relative sea level changes (Aigner, 1982; Norris, 1986). Tempestite character will vary with proximality to the sediment source, and the distribution of tempestites is likely to be controlled by a combination of water depth and environmental energy (Aigner, 1982, 1985; Kidwell et al., 1986; Norris, 1986; Westrop, 1986; Jennette and Pryor, in press). In proximal settings, storm events are more frequent, and storm layers are more often amalgamated and "cannibalized", that is, resuspended and incorporated into other tempestites (Aigner, 1985). Onshore to offshore proximality trends include: (1) a decrease in the number of storm events that have the energy to rework the deeper sediments; (2) a decrease in the thickness and frequency of grainstones, packstones, and tempestites; (3) a decrease in the degree of amalgamation of beds; (4) a decrease in the level of current reworking of bottom sediments; (5) an increase in the amount and preservation of bioturbation; and (6) an increase in the abundance of siltstones and mudstones (Kreisa, 1981b; Aigner, 1982; Brett, 1983; Kidwell et al., 1986; Norris, 1986; Frey, 1987b). In storm-dominated environments, siltstones would represent deep water, offshore deposition of the most distal portion of a tempestite (Aigner, 1985, p. 88).

Figure 8 - Model of vertical and lateral depositional trends associated with tempestite deposition along a proximal-distal transect (from Aigner, 1985).

PROXIMALITY CONCEPT



Cyclicity

Cycles are defined as recurring sequences of lithologically distinctive strata. They imply recurrent depositional or environmental conditions and allow insight into stratigraphic age and accumulation rate on all scales (Einsele, 1982). These may occur on a wide variety of scales from lake varves to orbital cycles to global sea level variations. Einsele et al. (1991) summarized cycles as belonging to either autocyclic sequences, those controlled by processes that occur within the same sedimentary regime (e.g. lobe switching on a subsiding delta plain, migration of fluvial systems), or allocyclic sequences, those caused by variations external to the considered sedimentary system (e.g. global sea level variations, climactic change, tectonism). By their nature, allocyclic sequences have a larger lateral continuity and may be correlatable for greater distances (Einsele et al., 1991).

Anstey and Fowler (1969, p. 679) were the first to recognize large-scale Cincinnatian facies patterns, and they attributed these sedimentary cycles to major changes in sea level (Anstey and Fowler, 1969). Tobin (1982) investigated several scales of cyclicity in the Cincinnatian Series and described a hierarchical arrangement of three orders of cycles: (1) storm cycles that were thin, graded bedding sequences deposited mechanically from suspension by storm activity, (2) megacycles, moderately thick (0.4-4.0 m) sequences with a carbonate hemicycle overlain by a shale hemicycle, (3) and large-scale shoaling-upward shelf cycles. Each large-scale shoaling cycle was asymmetrical, with a thinning shale hemicycle and an upper thickening limestone hemicycle (Tobin and Pryor, 1981; Tobin, 1982). Based upon lithofacies relationships, more recent studies have recognized five "third-order" (as in Goldhammer et al., 1990) shoaling-upward cycles within the Cincinnatian

Series of Ohio and Kentucky (Holland, 1992; Schumacher, 1992). Shoaling cycles have been attributed to sea level changes by local or regional tectonics, basin sedimentation patterns, a Late Ordovician glaciation, or some combination of these mechanisms (Tobin, 1982; Jennette, 1986; Jennette and Pryor, in press).

As described, Tobin's (1982) transgressive megacycles graded upward from a thick grainstone base to a shale- and siltstone-rich interval. The cyclic bedding represented clear water carbonate sedimentation and biological productivity that was episodically interrupted by terrigenous sedimentation (Tobin and Pryor, 1981; Tobin, 1982; Meyer et al., 1985; Tobin and Pryor, 1985). Tobin (1982) proposed several possible mechanisms for these cycles, including delta switching, lateral changes in the sediment supply, and tectonic and/or volcanic activity (Tobin, 1982). In a subsequent examination, Jennette (1986) and Jennette and Pryor (in press) determined that the megacycles of the Kope and Fairview Formations displayed a regressive signature that corresponded well with the "proximality concept" of Aigner (1982, 1985). These coarsening-upward cycles were attributed to a relatively rapid transgression related to glacio-eustatic sea level rise, where the cycle base was the transgressive shale facies and the overlying carbonate facies represented progressively shallower water and higher energy environmental conditions (Jennette, 1986; Jennette and Pryor, in press). Previous workers (Scotford, 1965; Anstey and Fowler, 1969; Tobin and Pryor, 1981; Tobin, 1982) had not believed that the small-scale cycles were laterally continuous, but Jennette (1986) and Jennette and Pryor (in press) proved otherwise, using isochronous event beds to trace cycles laterally and to establish a chronostratigraphic framework for the southwestern Ohio and northern Kentucky area.

Previous Stratigraphic Work

Early stratigraphic studies offer relatively little detail concerning the Corryville interval (Bassler, 1906; Braun, 1916; Fenneman, 1916; Forsyth, 1946; Kerr, 1951). Estimations of the vertical thickness of the Corryville Member have ranged from 13.4 or 15.2 m (Fenneman, 1916; Kerr, 1951; Caster et al., 1955; Gutstadt, 1958) to 18.3 m (Nickles, 1902; Forsyth, 1946). Recent measurements from cores and from the extrapolation of incomplete field exposures have shown that the thickness of the Corryville Member varies throughout southwestern Ohio (Tobin, 1982; Schumacher et al., 1991) (Fig. 9). The Corryville Member may attain a maximum thickness of more than 20 m in central Warren County, Ohio, and from there thins westward, eastward, and southeastward. The Corryville Member is thinnest in the Grant Lake Limestone at Maysville, where it has been measured at less than 6 m (Schumacher et al., 1991). Shale content and average shale thickness decrease southward and eastward with a concomitant increase in the abundance of grainstones (Tobin, 1982; Schumacher et al., 1991). Schumacher et al. (1991) demonstrated that mean shale percentage within the Corryville Member varies geographically (Fig. 10).

Both the upper and lower contacts of the Corryville Member in the southwestern Ohio area vary from sharp to gradational and are differentiated by a change in the mean percentage of shale, limestone bedding style, shale parting characteristics, and the fossil content of the shales. The underlying Bellevue Member contains a comparatively low mean shale percentage (17-47%), irregular- to wavy-bedded limestone, and fissile-parted, fossiliferous shale (Schumacher et al., 1991). Shale beds are predominantly discontinuous and individual beds within the Bellevue interval can be difficult to distinguish.

Figure 9 - Isopach map of the Corryville Member in southwestern Ohio (modified from Schumacher et al., 1991). Rock cores and field exposures of this study are represented.

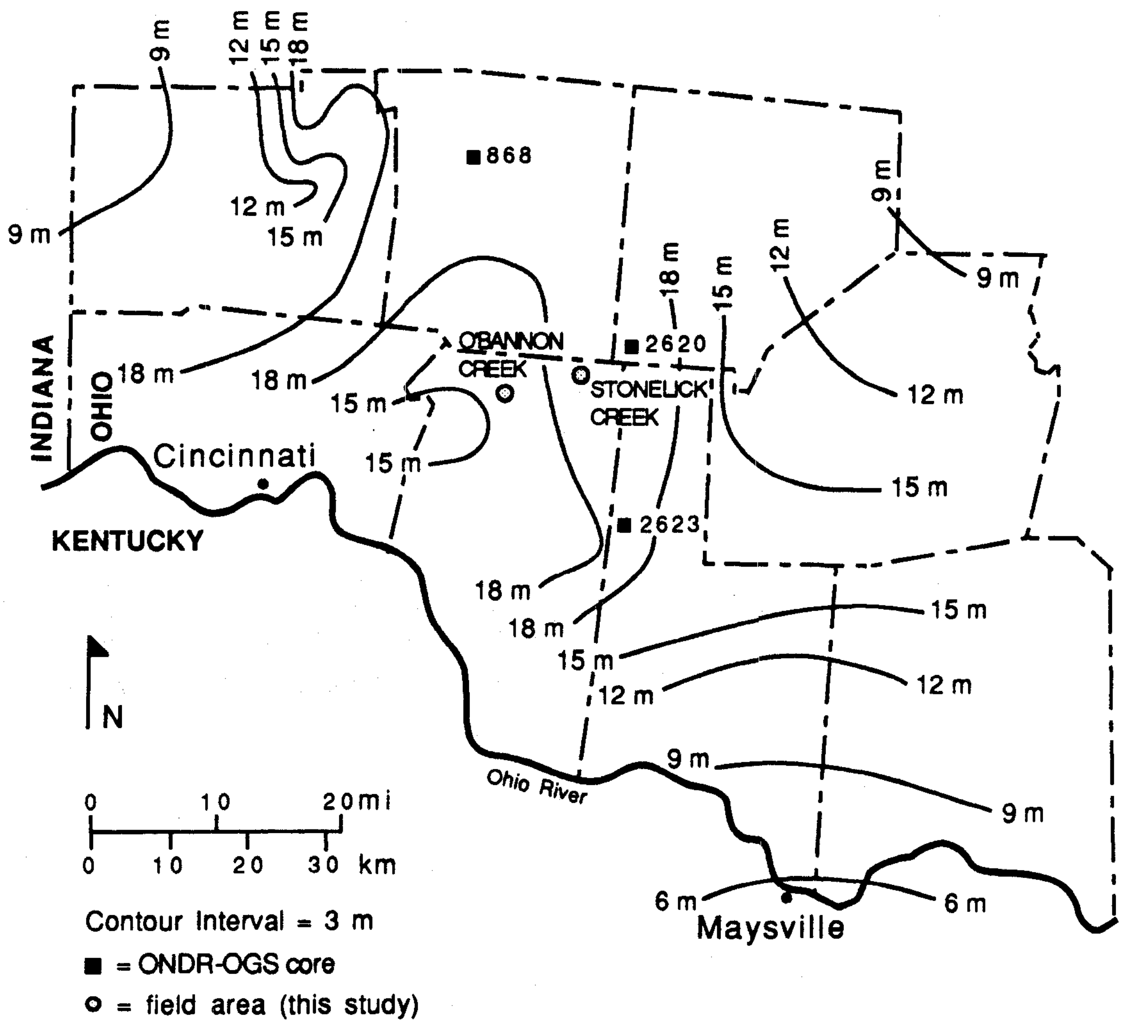
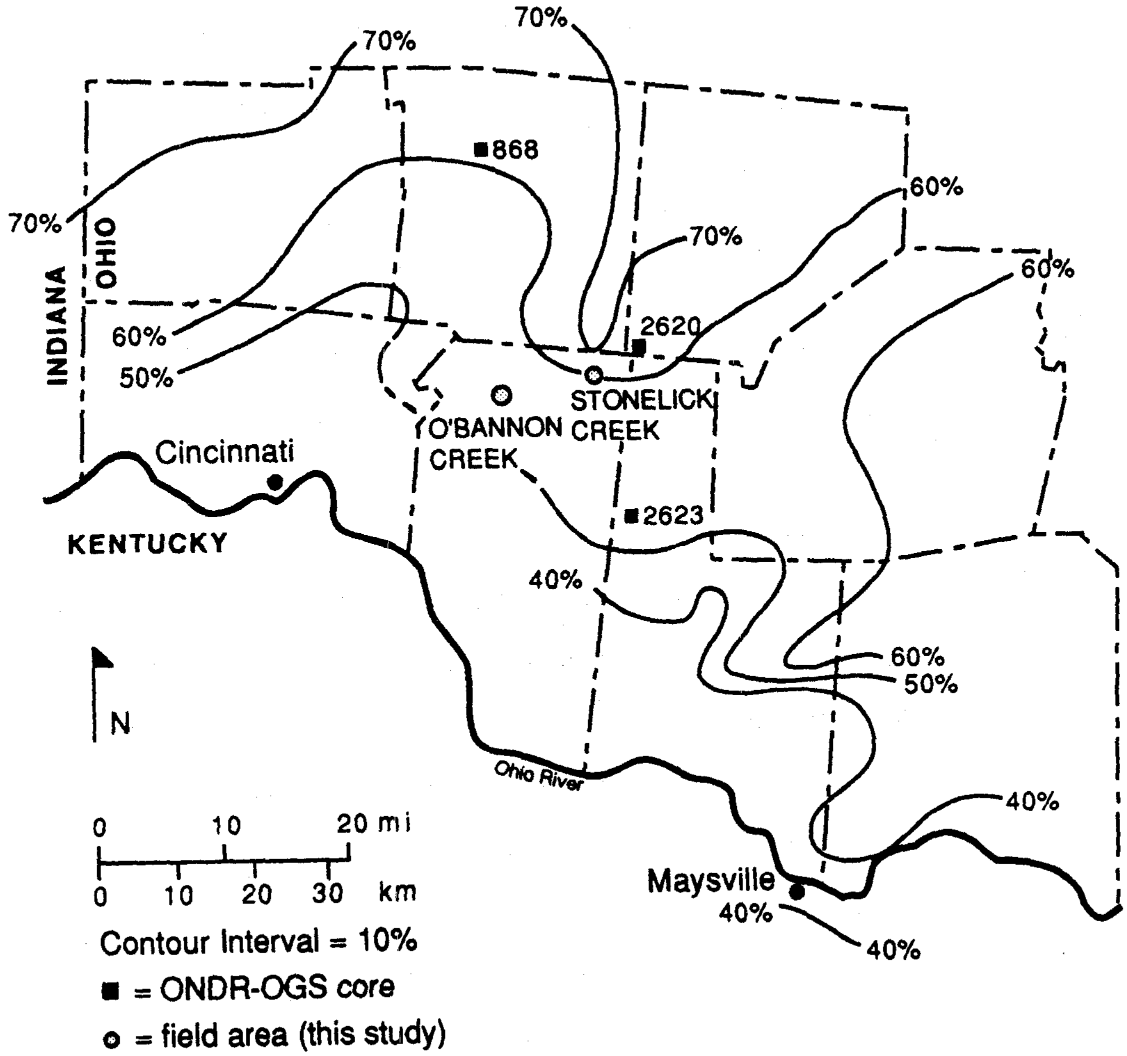

9 m
12 m
15 m
18 m
868
OBANNON CREEK
STONELICK CREEK
2620
2623
INDIANA
OHIO
KENTUCKY
Cincinnati
Maysville
Ohio River
N
0 10 20 mi
0 10 20 30 km
Contour Interval = 3 m
■ = ONDR-OGS core
○ = field area (this study)

Figure 10 - Regional variation in the mean shale percentage of the Corryville Member in southwestern Ohio (modified from Schumacher et al., 1991). Rock cores and field exposures of this study are represented.


70%
70%
70%
70%
868
60%
60%
OHIO
INDIANA
60%
50%
2620
STONELICK CREEK
O'BANNON CREEK
Cincinnati
KENTUCKY
2623
40%
60%
50%
N
Ohio River
0 10 20 mi
0 10 20 30 km
40%
Maysville
40%
40%
Contour Interval = 10%
■ = ONDR-OGS core
o = field area (this study)

Where the Bellevue-Corryville transition is gradational, the accepted procedure is to place the contact arbitrarily midway between the typical unit lithologies (Schumacher et al., 1991). The Bellevue interval has been interpreted as a shallow inner ramp to carbonate sand-shoal facies (Tobin, 1982; Jennette, 1986; Jennette and Pryor, in press)

The overlying Mount Auburn Member of the Grant lake Formation is composed of fissile, fossiliferous shale (50%) and nodular-bedded limestones (Schumacher et al., 1991, Appendix 3). The shales contain small, fossiliferous limestone nodules and a very fine fossil detritus that imparts a gritty, peppery texture to the weathered beds (Fig. 11). The Mt. Auburn Member grades to the east, southeast, and south into the Straight Creek Member of the Grant Lake Limestone, a limestone-dominated laterally equivalent facies (Schumacher et al., 1991). The Corryville-Mt. Auburn contact is commonly gradational and may be placed at the top of the highest typical Corryville limestone bed or at the base of the lowest typical Mt. Auburn shale bed (Fig. 12). The best examples of this interval occur in small stream exposures at the Hunts Creek, Second Creek, and Lick Run localities (Appendix 1). The large, globose, and thick-shelled brachiopod *Platystrophia ponderosa* var. *auburnensis*, known colloquially as the "double-headed Dutchman", is restricted to the Mt. Auburn Member, and its initial appearance can assist in the placement of the upper Corryville contact. The brachiopod *Leptaena richmondensis* makes its first appearance in the Mt. Auburn Member (Meyer et al., 1981, p. 68). This interval has been described as a shoreface environment (Holland, 1992).

A single study (Hinterlong, unpublished Master's Thesis, 1981) examined the Corryville Member in detail at Stonelick Creek. On the basis of field observations of sedimentology and paleontology, Hinterlong constructed a stratigraphic column and subdivided the interval into seven distinct lithofacies

Figure 11 - Field exposure of nodular-bedded Mt. Auburn Member at Lick Run, Harlan Township, Warren County, Ohio. Staff at center of exposure is 1 m in length.

Figure 12 - Field exposure with Corryville-Mt. Auburn contact at Lick Run, Harlan Township, Warren County, Ohio. Contact is gradational, but is marked by a shift from planar bedding and thick, sparsely fossiliferous shales to nodular and wavy-bedded limestones and thin, fossiliferous shales. Meter-length staff at center of exposure marks the approximate unit contact.

as defined by Hay (1975) for the Cincinnatian Series (1981, Appendix; see also Meyer et al., 1981, Fig. 35). Hinterlong suggested that the lower Corryville Member recorded a transgression, followed by a stillstand at the center of the unit, and a final regression in the upper one-third of the section. No details were presented concerning the regional or local persistence of these trends or the manner in which Hinterlong had constructed his single composite stratigraphic column. Hinterlong (1981, p. 61-62, Fig. 20) did recognize the abundance of individual storm beds , but made no mention of larger storm-related cyclicity.

At localities other than Stonelick Creek, Tobin (1982) observed megacycles within the Corryville Member. He estimated the presence of 21 Corryville megacycles that averaged a thickness of 1.09 m, with a 0.38 m carbonate hemicycle and a 0.71 m shale hemicycle. The shale content of the carbonate hemicycle was 18%, the highest of any Cincinnatian formation, and the shale content of the shale hemicycle was 74%. Tobin's measured exposures, however, were all within the upper portion of the Corryville Member, and his estimate of 21 cycles appears to have been based upon an extrapolation of cycle thickness and estimated unit thickness rather than a direct physical verification.

To the south and east of the Grant Lake Formation is the laterally equivalent Grant Lake Limestone of Kentucky and southernmost Ohio (Peck, 1966; Lee, 1974; Schumacher et al., 1991). Within the middle Grant Lake Limestone, the Corryville Member appears as predominantly irregular- to wavy-bedded, argillaceous, fossiliferous limestone and interbedded calcareous, fossiliferous shale (Peck, 1966). Limestone represents 70-90% of the unit, and lesser amounts of planar-bedded, argillaceous, fossiliferous limestone and calcareous, sparsely fossiliferous shale increase in abundance in a northwestward direction from Maysville, KY (Schumacher et al., 1991). Road cuts and stream exposures are accessible (Appendix 1). The original type section was designated from a series of road cuts located along KY Route 1449, approximately 2 km (1.2 mi) south of Maysville, KY (Peck, 1966). The type section for the Straight Creek Member was designated more recently from exposures along the West Fork of Straight Creek, Franklin Township, Brown County, Ohio (Schumacher et al., 1991). Unique bryozoan reef mounds have been reported from the upper Corryville Member of the Grant Lake Limestone in north-central Kentucky (Cuffey, 1992).

Methods

Two field areas in southwestern Ohio were chosen for this investigation (Fig. 13). All field work was completed in the summer and fall of 1990. The primary study site was at Stonelick Creek in Stonelick Township, Clermont County, Ohio, located about 2.2 km (1.3 mi) west from the center of Newtonsville and roughly 15.5 km (9.3 mi) east of the city limits of Milford (Fig. 14). At Stonelick Creek, the entire Corryville Member is present as a series of discontinuous streamcuts upstream and downstream from the Ohio State Route 131 bridge (84°6'43"W, 39°10'40"N; Newtonsville, Ohio 7.5-minute quadrangle). This study was restricted to a 2.3 km stretch of the creek south of the S.R. 131 bridge, where exposures containing Corryville strata were of maximum height and abundance. Eight of the largest stream cuts were described and measured to the nearest cm using a hand level and Jacob's staff. All beds greater than 1 cm of thickness were described. The faunal content and sedimentology of each shale and carbonate bed was noted, and a representative hand sample was collected from each carbonate bed. A composite section of the Corryville Member was constructed from the correlation of all eight measured sections.

The second study site was a single stream cut at O'Bannon Creek, north of the town of Goshen in Goshen Township, Clermont County, Ohio (84°1'03"W; 39°14'07"N; Goshen, Ohio 7.5-minute quadrangle), approximately 13 km (8 miles) to the west-northwest of Stonelick Creek (Fig. 13). The 8.3-meter-thick section was located along the west side of the creek in an east-facing gully approximately 366 m south of the Gaynor Farm Road bridge. As at Stonelick Creek, this exposure was described and measured to the nearest cm using a hand level and Jacob's staff, and a representative hand sample was collected

Figure 13 - Location map of field sites and cores.

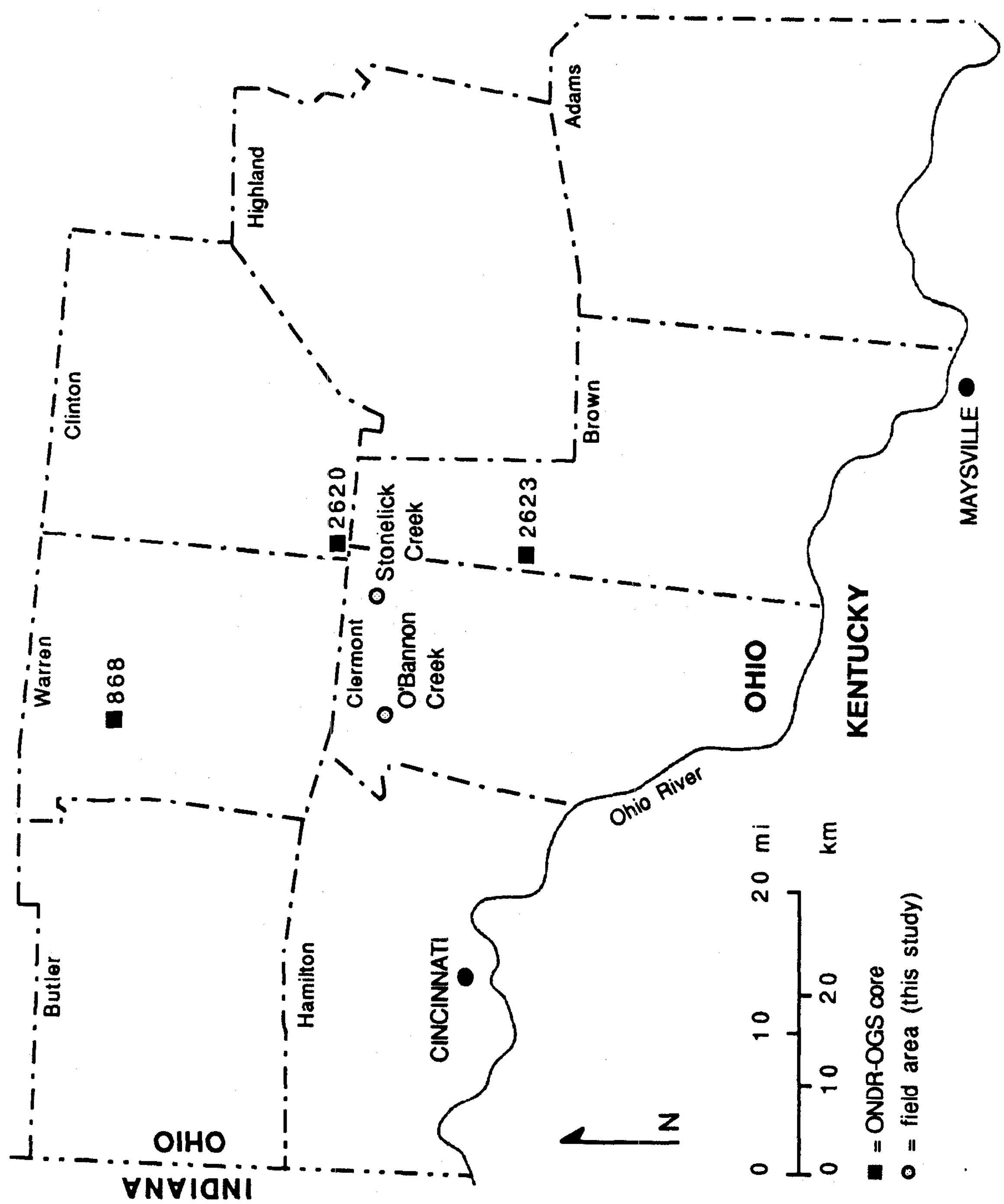
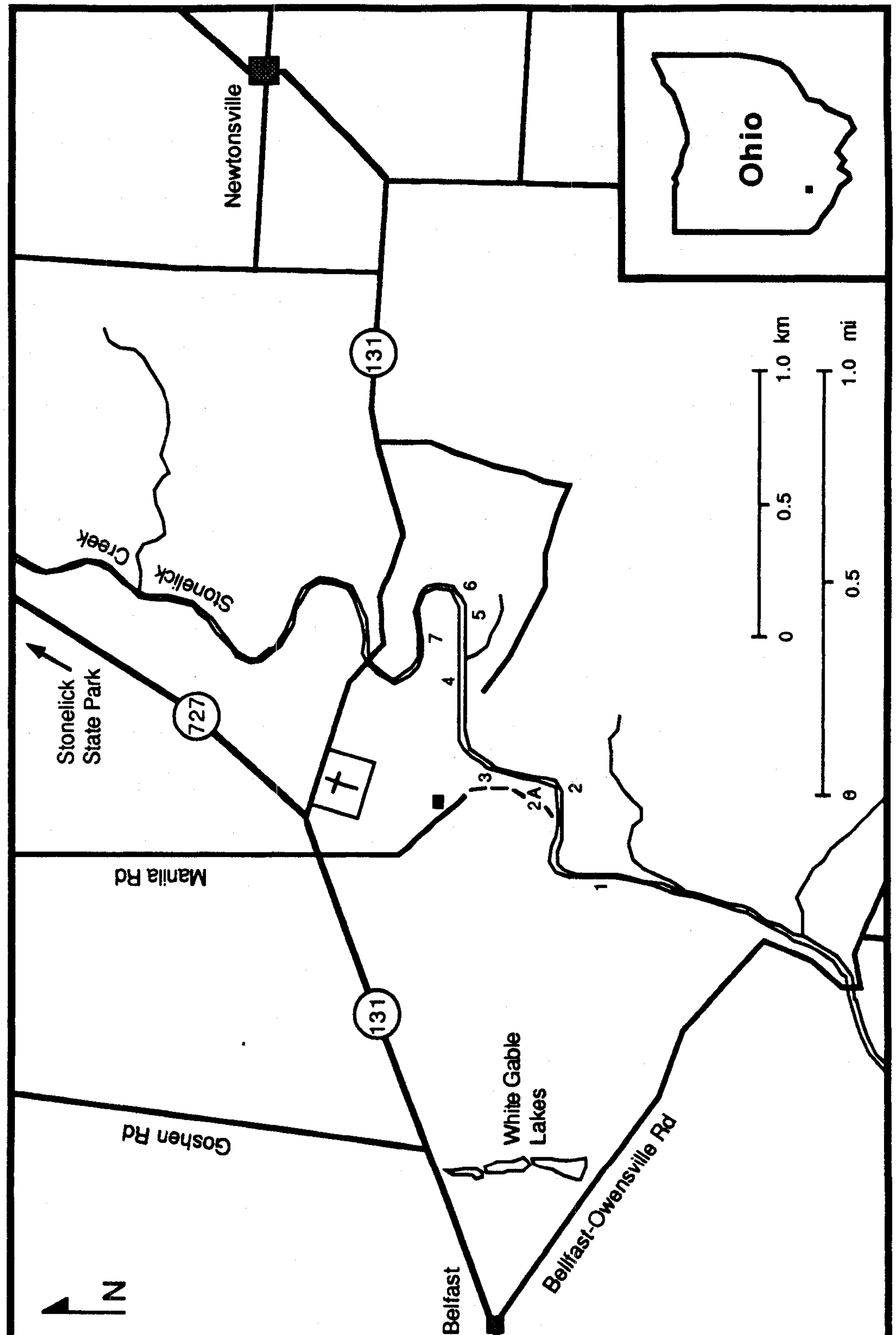

INDIANA
OHIO
Butler
Warren
Clinton
Highland
Adams
Brown
Hamilton
Clermont
■ 868
■ 2620
■ 2623
Stonelick Creek
O'Bannon Creek
CINCINNATI
MAYSVILLE
OHIO
KENTUCKY
Ohio River
N
0 10 20 mi
0 10 20 km
■ = ONDR-OGS core
⊙ = field area (this study)

Figure 14 - Locations of eight measured exposures along Stonelick Creek in Clermont County, Ohio. Each number along the creek corresponds with a single streamcut (see Appendix 2 for stratigraphic columns).


Newtonsville
131
Stonelick Creek
Stonelick State Park
727
Manila Rd
Goshen Rd
131
White Gable Lakes
Belfast
Belfast-Owensville Rd
N
Ohio
0 0.5 1.0 km
0 0.5 1.0 mi
1
2
2A
3
4
5
6
7

from each carbonate bed described at these exposures. The Bellevue-Corryville contact was present at the base of this exposure, and this facilitated correlation with the Stonelick Creek study site. The measured section was situated just upstream of the Ohio Geological Survey (OGS) File 16834 section; at the time of this investigation, that exposure was no longer accessible.

Carbonate rocks were described according to Dunham's (1962) textural classification with modifications made by Tobin (1982). For petrographic analysis, thin-sections from representative hand samples were used to confirm all carbonate textures and to correlate these to a megascopic (hand sample) level. Hand samples were then supplemented as the primary means of carbonate identification. In all beds, cements and matrix composition were noted. The occurrence of mud entrapment, geopetal indicators, calcite infilling, mud clasts, sole marks, lamination, cross stratification, graded bedding, amalgamated beds, and the presence of silty bed caps were recorded. The mineralogical compositions of grainstone, packstone, and calcisiltite samples were examined with x-ray diffraction. Selected hand samples were ground into powder and analyzed with the University of Cincinnati Siemens D-500 x-ray diffraction system to verify the presence of calcite, dolomite, quartz, and clays. Shales were described according to Potter et al., (1980) and were not examined in thin-section or by x-ray diffraction. The relative silt content, fossil content, and calcification of shales were noted.

For regional stratigraphic analysis, partial sections of the following three Ohio Department of Natural Resources (ODNR) Division of Geological Survey cores were measured: 868 from Warren County, Ohio (Clear Creek Township; Lebanon, Ohio 7.5-minute quadrangle), 2620 from Clinton County, Ohio (Marion Township; Blanchester, Ohio 7.5-minute quadrangle), and 2623 from Brown County, Ohio (Sterling Township; Mount Orab, Ohio 7.5-minute quadrangle). Corryville core material was examined on a cm scale. All beds thicker than 1 cm were described, and all lithologic and paleontologic information was noted and recorded. Unit contacts were defined on the basis of bedding style, bed thickness, and dominant lithologies.

Shale percentage logs were produced to substantiate vertical and regional stratigraphic variation within the Corryville Member. These logs represent the total thickness of shale within a 1 m interval as a percentage of that 1 m interval. Shale percentage logs were constructed for the O'Bannon Creek exposure, exposures 1 and 2 at Stonelick Creek, and all three cores with the aid of "Cumul" (unpublished program, written by Benjamin Dattilo). "Cumul" was developed to calculate the cumulative thickness for a given lithology within a specified "window" of stratigraphic section. For this study, "Cumul" was used to measure the total thickness of all shale and carbonate beds within a 10 cm "window". Beginning at the base of each measured core or field exposure, "Cumul" determined the lithologic content of each consecutive 10 cm of vertical section. The program output was then used to estimate the percent shale for each meter of section at a sampling interval of 10 cm. For example, the percent shale at 6.6 m above the base of the section was the total amount of shale present in the ten "windows" situated between 6.1 m to 7.1 m above the base of the section. Put simply, the resulting shale log constitutes a running average of shale percent per meter measured at 10 cm intervals within the section. Mean shale percentage for the Corryville Member in each core and field exposure was obtained by summing all shale percentages within a section and dividing by the total number of sampling points.

General Sedimentology

The Corryville Member is composed of interbedded terrigenous shales and fossiliferous limestones. This section defines the primary rock types and describes their sedimentary characteristics, associated sedimentary structures, and bedding character. In general, bedding contacts are planar to lenticular, with minor amounts of irregular- to wavy-bedded limestones. Shales are planar-bedded, platy- to flaggy-parted, and sparsely fossiliferous, but may occasionally be fissile and fossiliferous. The average thickness of limestone beds is 4 cm, and average shale thickness is 9 cm.

Eight types of carbonate rocks are recognizable within the Corryville Member. These are roughly equivalent to Tobin's (1982, Table 2, Fig. 12) "recurrent carbonate rock types". Carbonate textures include grainstone, packstone, wackestone, and micstone (or mudstone). Many limestone beds display lateral megascopic variation in mud and grain content, and this textural heterogeneity is represented by a dual, hyphenated classification (e.g. packstone-wackestone). The following petrographic descriptions were derived from over 450 hand samples collected at the two field sites are specific for the Corryville interval. Storm event beds and amalgamated beds compose approximately one-fourth of all Corryville strata, and a discussion of these beds has been included within this section.

Grainstones

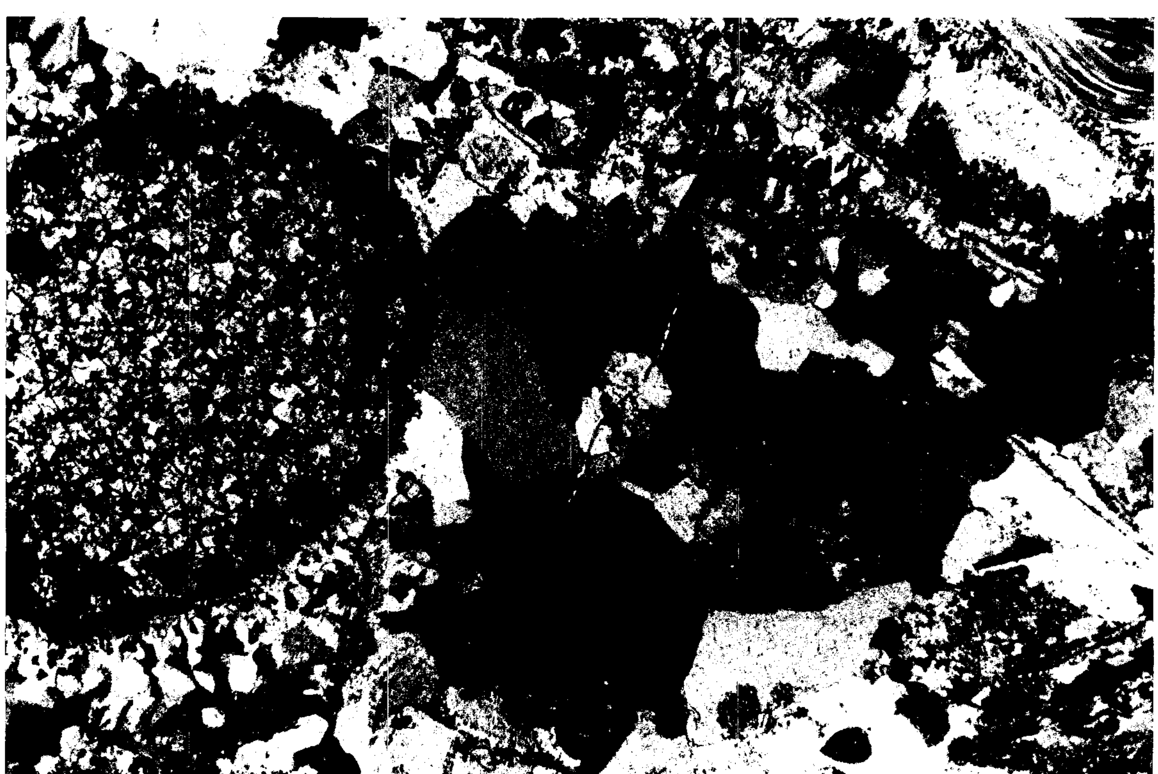
Four types of grainstones were identified by grain size and by approximate mud or silt content: coarse grainstones, fine grainstones, poorly-washed grainstones, and calcisiltites. The characteristics of calcisiltites varied from the other grainstone types, and they will be discussed in a separate section. In general, grainstones are continuous and thick. Many are capped by a thin (< 1.0 cm), yellowish-gray, sparsely fossiliferous layer of calcareous silt that may contain ichnofossils, articulated brachiopods and crinoids, or pelecypod molds. Upper bedding surfaces may display rare symmetric and asymmetric ripples and contain current-oriented cephalopods, brachiopods, ramose bryozoans, and crinoids. Rip-up clasts, intraclasts, and thin shale interbeds may be present within the lower portions of these beds and lamination is rare.

"Coarse" grainstones are thick, poorly to moderately well-sorted, continuous grain-supported carbonates with planar to irregular bedding contacts (Fig. 15). Coarse grainstones may contain up to 6 % calcareous silt or mud (Tobin, 1982), and most beds have a silty cap. Beds average 7 cm in thickness with a range of 2 to 14 cm. Coarse grainstones exhibit moderate to high fossil breakage, subhorizontal fossil orientation, and skeletal material of all sizes. Evidence of bioturbation is rare.

"Poorly-washed" grainstones, as defined by Tobin (1982), are grain-supported carbonates that contain 6-15% mud or silt matrix, but are otherwise similar to coarse grainstones. The distinction between poorly-washed grainstones and coarse grainstones is important because it permits the recognition that grainstones were subjected to variable amounts of winnowing, sorting, or environmental energy. Carbonate muds are concentrated around or beneath coarse fossil material. Poorly-washed grainstones are thick, continuous, and poorly to well-sorted, averaging 6 cm in thickness with a range of 2 to 13 cm (Fig. 16). Bedding contacts are planar, irregular, and wavy in equal amounts. Approximately half of all poorly-washed grainstones have a silt cap, and one in three have abundant convex-up shells on the upper bedding contact. Fossil material is subhorizontally oriented and displays moderate to

Figure 15 - Thin-section photograph of a poorly-sorted "coarse" grainstone. Note the general absence of matrix (scale: 1.15 cm = 0.4 mm).

Figure 16 - Thin-section photograph of a poorly-sorted "poorly-washed" grainstone. Note the small amounts of matrix present along the external edges of the larger bioclasts (scale: 1.15 cm = 0.4 mm).



high breakage. Internal mud sheltering, or sheltering porosity, and geopetal structures are fairly common. Poorly-washed grainstones rarely display sole markings or evidence of bioturbation.

"Fine" grainstones (Fig. 17) are nearly identical to coarse grainstones, but are composed of grains less than 2 mm in size. Larger grains are present in lesser amounts. These beds are generally continuous and well sorted with planar to irregular bedding contacts. Silt caps are uncommon. Bed thickness ranges from 1 to 9 cm and averages 4 cm. Normal grading is present, but lamination is rare. Fossil orientation is subhorizontal to random. Fossil material displays a high degree of breakage and faunal components can be difficult to identify in hand samples. Bioturbation is rare within this type of grainstone.

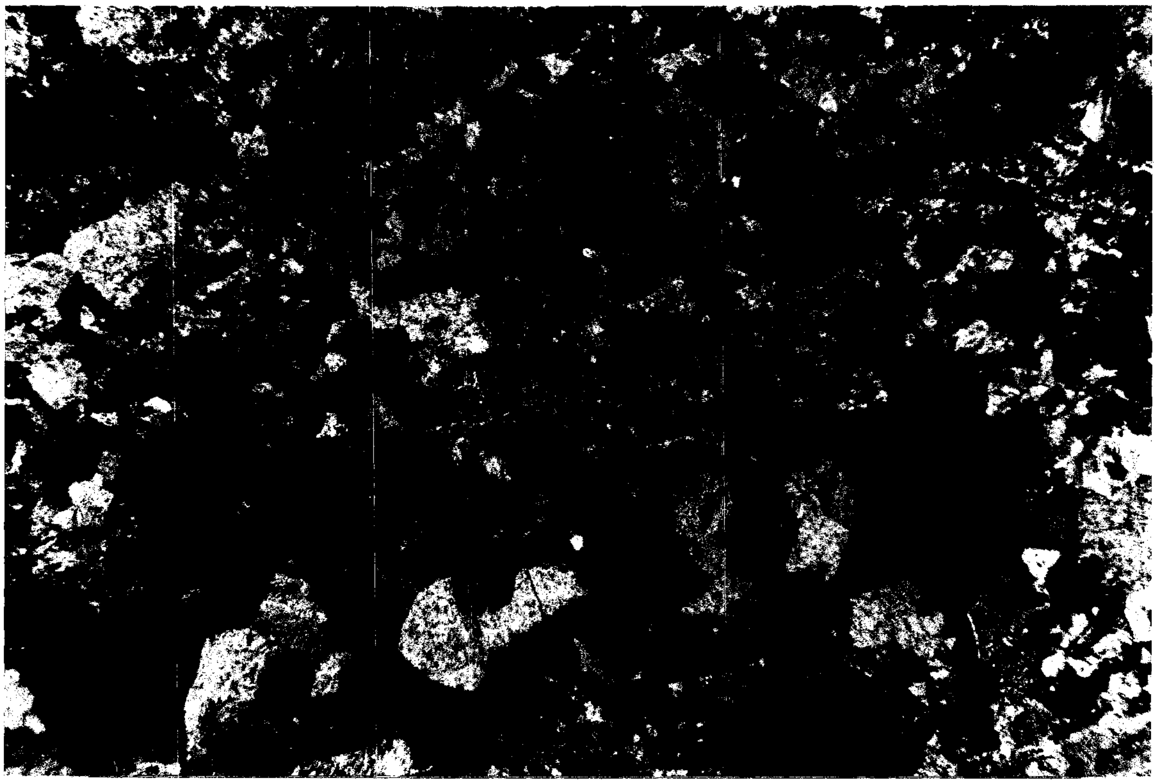
Packstones

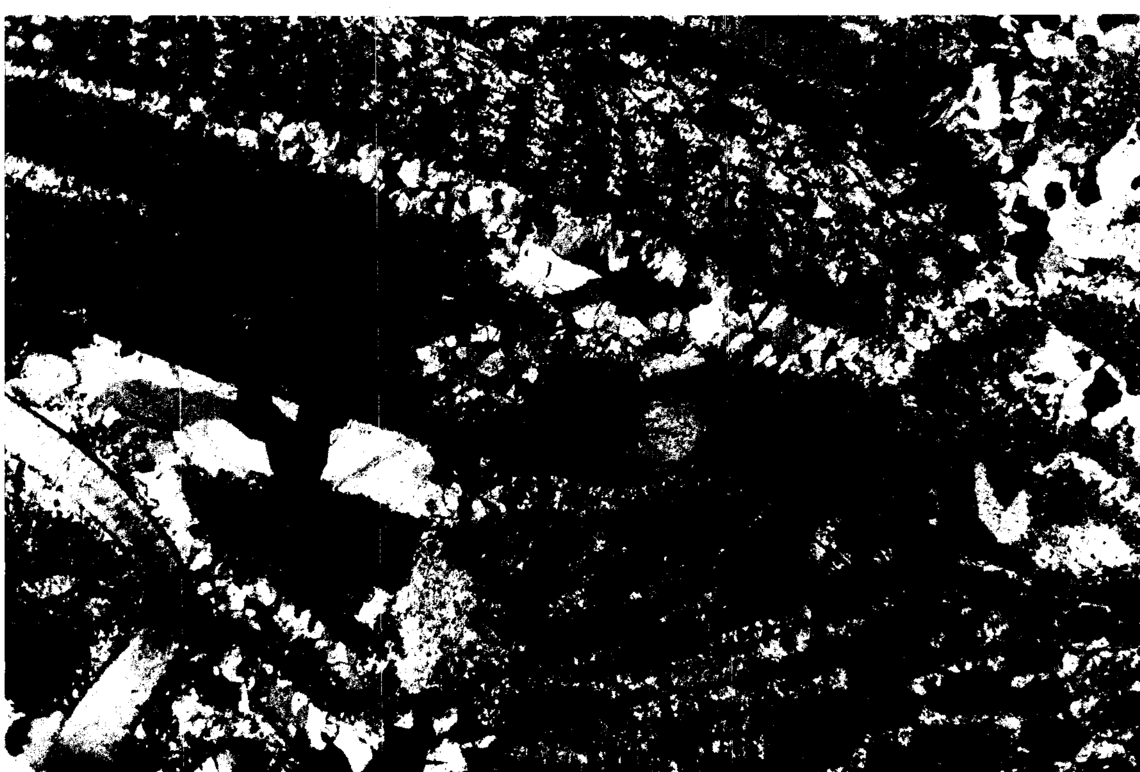
Packstones (Fig. 18) are the most abundant lithology within the Corryville section. Many other type carbonate beds were found to display a localized packstone texture and so were designated as packstone-grainstone or packstone-wackestone. Packstones are mostly continuous, poorly to well-sorted, grain-supported carbonates with 16 to 55% carbonate mud and silt (Tobin, 1982). These beds are generally thin (average 4 cm), but range from 1 to 18 cm in thickness. Bedding contacts are planar to irregular, and one-third of these beds have a thin silt cap. Lamination is rare. Internal and external geopetals are common as well as mud sheltering by brachiopod and mollusk shells. Concentrations of pyrite and peloids are not uncommon. Intraclasts, bioturbation, and sole marks are present, but rare.

One third of all packstones are fine, well-sorted packstones that contain a dark calcareous silt matrix and display bimodal skeletal sorting. Bedding

Figure 17 - Thin-section photograph of a "fine" grainstone. Grains exhibit a finer size and better sorting than seen in other types of grainstones (scale: 1.15 cm = 0.4 mm).

Figure 18 - Thin-section photograph of a packstone with abundant trilobite and bryozoan fragments (scale: 1.15 cm = 0.4 mm).





contacts are planar to irregular. Fossil grains are present as either small, unidentifiable fragments or as large, unbroken brachiopod and bryozoan material. Fossil orientation is subhorizontal, and internal geopetal structures are common. Burrows and escape traces are common.

Wackestones

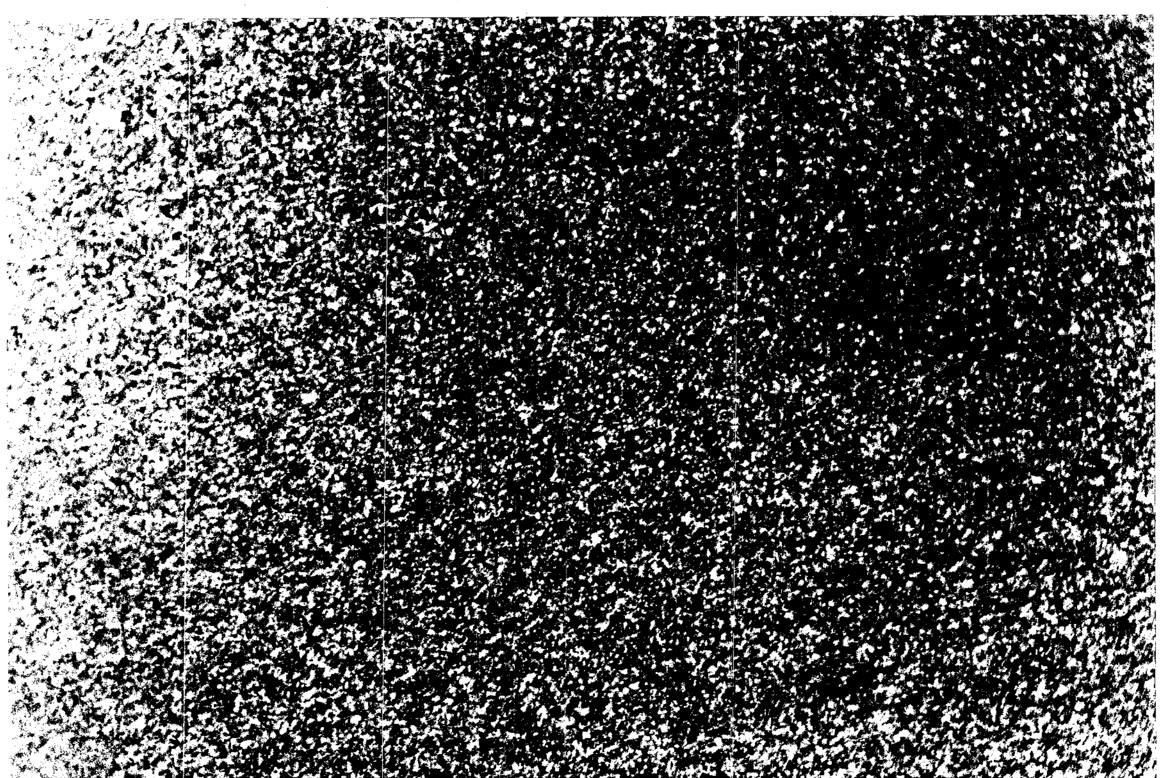
Wackestones are the second most abundant Corryville carbonate type and are similar in character to the packstones. Wackestones contain over 55% carbonate matrix and are poor to moderately well sorted (Fig. 19). Beds are generally thin (4 cm average thickness), but can be as thick as 10 cm. Wackestones are continuous to discontinuous, with planar, irregular, and wavy bedding surfaces. Many beds fine upwards to a calcareous silt top with convex-up shell material. Internal geopetal structures, planar lamination, and bioturbation are rare. Fossil orientation varies from subhorizontal to random, with a low to moderate degree of fossil breakage. Fine-grained wackestones, similar to fine packstones, are present in lesser numbers and nearly identical in all aspects.

Micstones

Micstones, the equivalent of Dunham's (1962) "mudstone", are composed of over 90% carbonate micritic muds (Fig. 20). These limestones account for less than 1% of all Corryville limestones. Beds are generally discontinuous with planar to wavy contacts. Lamination and sole marks are absent. Fossil material is rare. Most micstones are found amalgamated above or below a carbonate of a different texture. These beds may in fact be an "aureole" or "underbed" that

Figure 19 - Thin-section photograph of a wackestone. Note the presence of delicate gastropod and trilobite material (scale: 1.15 cm = 0.4 mm).

Figure 20 - Thin-section photograph of a micstone (scale: 1.15 cm = 0.4 mm).



has resulted from a diagenetic redistribution of carbonate material (Aigner, 1982, Fig. 9).

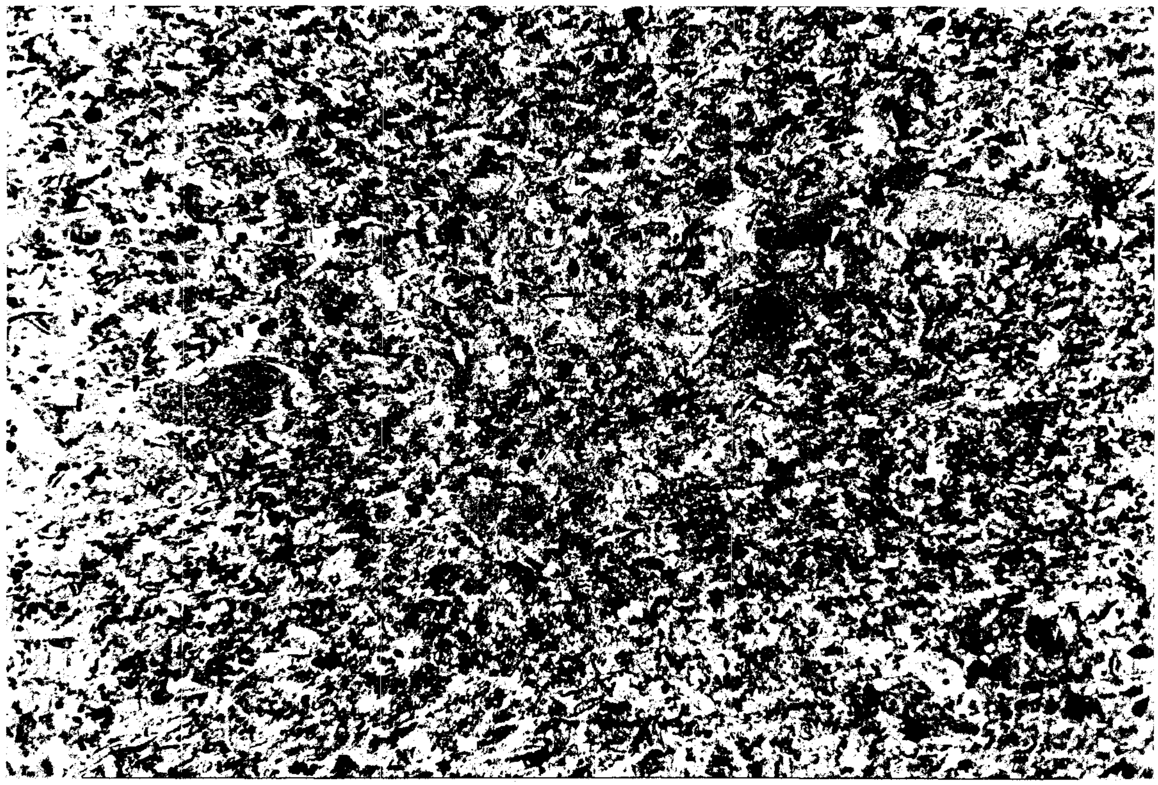
Calcisiltites

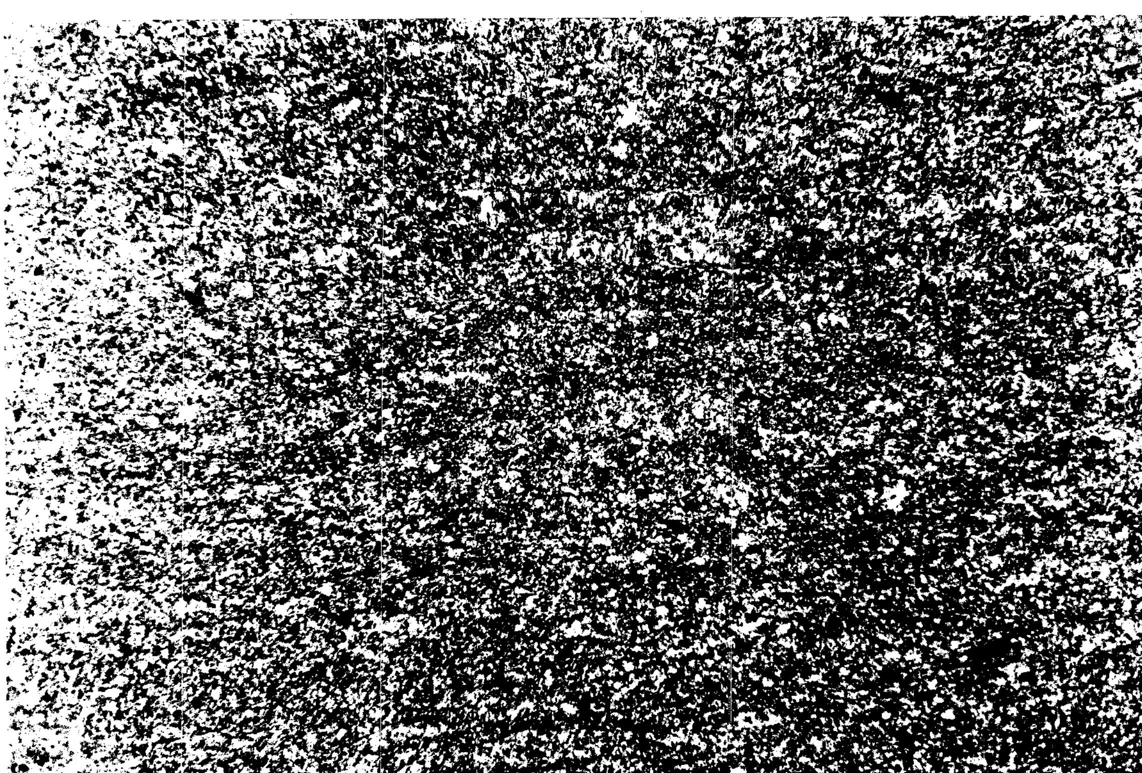
Calcisiltites (Fig. 21) are continuous to discontinuous, very well sorted grainstones with a mean grain size of < 0.5 mm and tiny subhorizontally-oriented fossil detritus (Meyer et al., 1981; Tobin, 1982). These beds may achieve a thickness of 15 cm, but they are generally thin with an average of 3 cm. One-third of all calcisiltites grade normally into a sparsely fossiliferous arenaceous calcisiltite. Contacts are planar and wavy and rarely irregular. Disseminated pyrite is fairly common within these beds. Approximately half of these beds contain planar lamination, small-scale hummocky cross-stratification (ssHCS), or both. Lamination results from an alternation of coarser and finer layers and differential cementation (Tobin, 1982). Basal bedding surfaces are commonly erosive and commonly display groove marks, tool marks, gutter casts, flute marks, and prod marks. Symmetrical and asymmetrical ripples, megaripples, and bioturbation are common at the upper bedding surface.

Large body fossils, including pelecypods, ramose bryozoans, and articulated crinoid stems can be found along the bedding surfaces of calcisiltites. A basal lag of fossil detritus, typically *Zygospira* valves and broken trilobite material, is observed in roughly half of these beds. Burrows, escape structures, and trace fossils are common, but these are restricted to the tops of beds and represent less than 20 to 30% reworking of the bed area.

Figure 21 - Thin-section photograph of a calcisiltite. Note good sorting and the abundance of very fine bioclasts (scale: 1.15 cm = 0.4 mm).

Figure 22 - Thin-section photograph of an arenaceous calcisiltite. Note weak planar lamination (scale: 1.15 cm = 0.4 mm).





Arenaceous calcisiltites

A distinction has been drawn between calcisiltites (as defined by Tobin, 1982) and arenaceous calcisiltites. Arenaceous calcisiltites are fine-grained carbonates that contain calcareous silt, moderate amounts of silt-sized quartz, and little or no identifiable skeletal material (Fig. 22). These carbonates are continuous to discontinuous in section and share most of the physical sedimentary features of calcisiltites and of siltstones described from the Kope and Fairview Formations (as described by Tobin, 1982; Jennette, 1986; Jennette and Pryor, in press). However, the abundance of calcareous silt in relation to quartz silt within this lithotype dictates that these beds should not be referred to siltstones. Arenaceous calcisiltites contain some dolomite cements and may grade laterally into a "typical" calcisiltite within a single field exposure. X-ray diffraction of arenaceous calcisiltites displayed two strong quartz peaks and significant peaks for the clay minerals illite and chlorite.

Arenaceous calcisiltites average 2 cm in thickness and generally range from 1 to 5 cm, although a few beds may approach 10 cm in thickness. Bedding contacts are planar to wavy (a "pinch and swell" appearance), and oriented tool marks and gutter casts are common. Approximately one-third of all beds display weak to strong lamination, either planar, cross-lamination, ssHCS, or a combination of the three. Lamination can be restricted to the top or bottom of an arenaceous calcisiltite bed. Disseminated pyrite is rare. One-third of all arenaceous calcisiltites have a basal fossil lag and a small number have a fossil lag on the upper bedding surface. Isolated skeletal material, when present, is either small and broken or large and articulated. Crinoid stems as long as 12 cm may be collected from arenaceous calcisiltites.

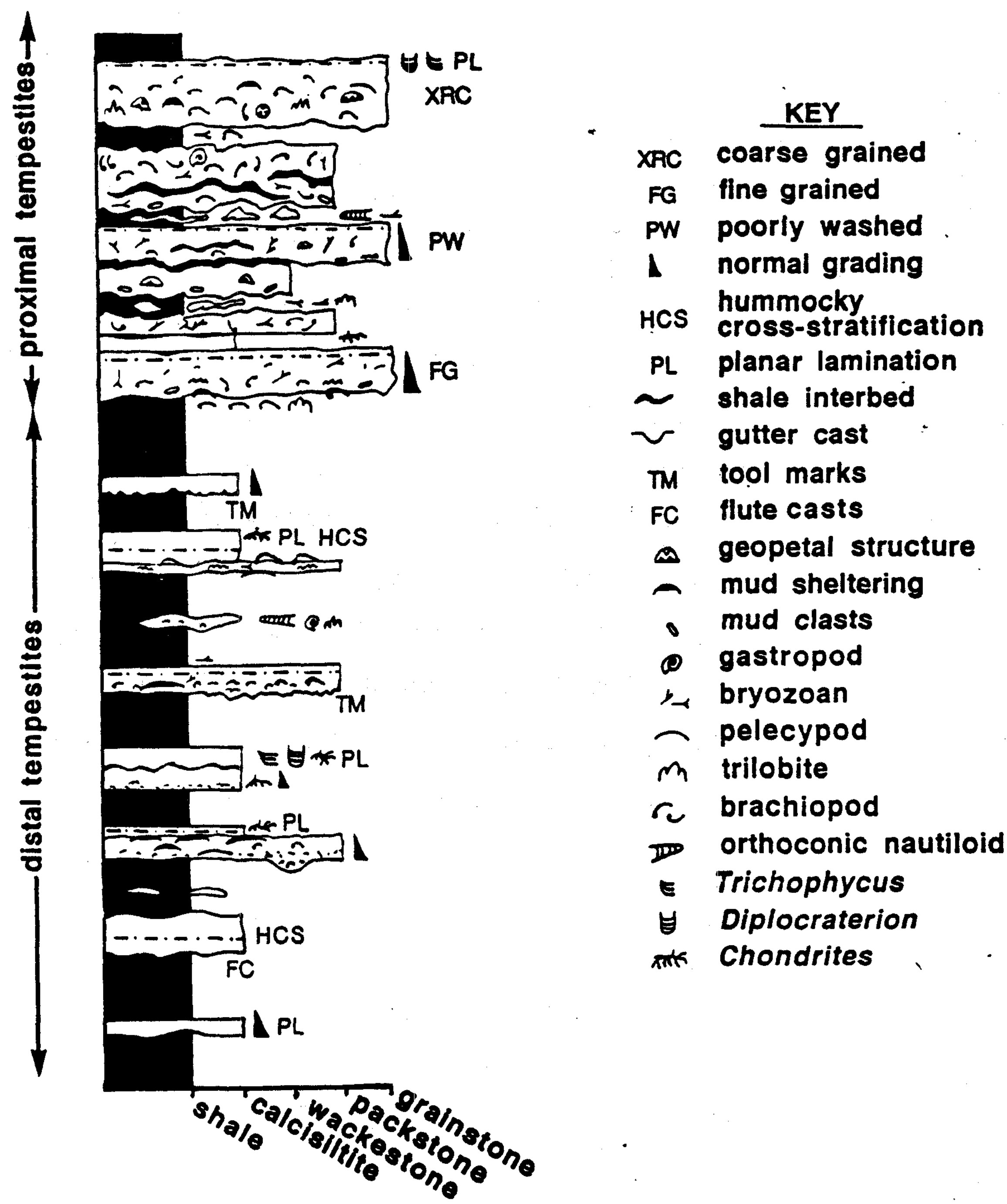
Shales

The field term "shale" is herein used to describe any predominantly clay-rich rocks finer than silt size, regardless of fabric or composition (Tobin, 1982). Corryville shales are blue to gray when fresh, silty, continuous, calcareous, and sparsely fossiliferous with platy to flaggy parting. The average Corryville shale is a dolomitic mudstone with a silt/clay ratio of 1.05 and a grain size of 28 micrometers (Tobin, 1982). Average shale thickness is 7 cm, but may be as great as 34 cm. Shales are indurated but soft and lack sedimentary structures, bioturbation, and lamination. In outcrop, most shale beds weather quickly to a yellow-gray color and are recessed in contrast to the more highly indurated limestones (Fig. 23). Occasional thin fissile-parted shales can be seen in section. These beds are calcareous and fossiliferous, discontinuous with irregular contacts, and typically less than 2 cm thick. When fossil material is present within the platy to flaggy shales, it occurs adjacent to bedding contacts or is restricted to distinct, horizontal stringers that merge laterally into a thin limestone bed. The occurrence of fossil stringers within shales and along limestone bedding contacts has been previously reported from other Cincinnatian units (Anstey and Fowler, 1969, p.677; Frey, 1987b).

Corryville shales have been shown to contain more silt than the shales of the overlying Cincinnatian units (Tobin, 1982). In addition, thin, discontinuous, silty or calcareous lenses can occasionally be seen within Corryville shales. These lenses average < 2 cm in thickness and < 40 cm in length and may contain either broken bryozoan, brachiopod, and trilobite fragments or a minute fossil hash. Certain thick silty shales contain soft, discontinuous, argillaceous layers that weather to a yellowish color. These are the so-called "butter shales"

Figure 23 - Idealized stratigraphic section showing the sedimentary features and bedding styles of amalgamated beds, tempestitic carbonates, and shales in the Corryville Member.

Idealized Corryville Bedding Sequence



or "trilobite shales", fine-grained beds noted for their well-preserved fossil assemblages (Caster et al., 1955; Brandt, 1980a; Brandt, 1986).

Storm Event Beds

Variations of the "ideal" storm bed (Kreisa, 1981b; Tobin, 1982) can be readily identified within the Corryville interval (Fig. 23). Tempestites grade conformably from a basal packstone into a calcisiltite and then unconformably into a calcareous, laminated arenaceous calcisiltite. These beds are generally discontinuous and average 3 cm in thickness, with a range of 2 to 8 cm. The lower contact is planar and erosional and the upper bedding surface may be sharp or gradational. The basal shell bed is typically a poorly-sorted packstone, but this can grade laterally to a wackestone or to a poorly-sorted grainstone. Storm bed tops are generally thin (< 2 cm) with planar lamination, localized bioturbation, and rarely ssHCS. Pelecypod molds can occur within the calcareous silt just above the basal packstone. Many tempestites are not overlain by an arenaceous calcisiltite, but instead are capped by a very thin (< 0.5 cm), analogous layer of calcareous silt. These are recognizable as tempestites because they contain diagnostic storm-generated features, including an erosional base, normal grading, gutter casts, tool marks, intraclasts, and infiltration fabrics. Variations in the appearance of tempestites are a function of grain size distribution and environmental energy (Kreisa, 1981b).

Amalgamated Beds

An "amalgamated bed" (composite bed) is here defined as a multiple-event bed consisting of two to five abruptly overlain carbonates within a single lithified unit (Fig. 23). These beds represent the accumulation of several erosive, depositional, and colonization events, and are often associated with storm-related deposits (Aigner, 1982; Kidwell et al., 1986; Norris, 1986). In most amalgamated beds, a basal fossiliferous packstone or grainstone is sharply overlain by several packstones or grainstones that display variable degrees of winnowing, sorting, and breakage of fossils. Mud clasts, or rip-up clasts, are common within the basal portions of these beds. Contacts between these amalgamated lithologies are planar to irregular and are recognizable in that they frequently contain thin (< 1.0 cm), discontinuous shale interlayers or simple flaser bedding (Reineck and Wunderlich, 1968). Interlayers of shale are presumed to be the remnants of previous shale beds that were not entirely eroded by subsequent storm events. The basal surface of amalgamated beds is typically erosive and may show evidence of loading. Amalgamated beds are continuous within an exposure, but the constituent layers are overlapping and generally discontinuous. Common variations of amalgamated beds include multiple calcisiltites with shale interbeds, multiple poorly-washed grainstones, and mudstones or arenaceous calcisiltites overlain by a packstone, the reverse of the typical storm bed.

Diagenetic History of the Corryville Member

A reconstruction of the diagenetic history of the Corryville Member is beyond the scope of this thesis; greater time and focus would be required for a proper treatment of the subject. A tentative interpretation of Cincinnatian carbonate and shale diagenesis was advanced by Tobin (1982), and observations made throughout this study were in accordance with that description. Tobin's "matrix" (1982, p. 48), a generally interstitial carbonate material less than 30 microns in size, was present within Corryville grainstones, packstones, and wackestones. This very fine material originated either as fecal pellets or as a result of mechanical deposition from suspension in a quiet-water environment (Tobin, 1982). Well-defined pellets were occasionally preserved beneath brachiopod shells, where they presumably were sheltered from the effects of winnowing and bioturbation (Holland, 1988). Sparry and drusy calcite were abundant, and collophane (cryptocrystalline phosphate) was seen primarily within bryozoan zoecia. Dolomite cements were detected in grainstone, packstone, calcisiltite, and arenaceous calcisiltite samples through x-ray diffraction techniques. Tobin (1982, p. 54) inferred a post-cementation and late diagenetic origin for this material because of its selective occurrence. Other minerals observed via hand sample include pyrite, quartz silt, hematite, and limonite.

Corryville Stratigraphy at Stonelick Creek

Through the correlation of partial stream exposures, a composite stratigraphic section of the Corryville Member was constructed (Fig. 24). Individual measured sections are described in Appendix 2. As measured in this study, the thickness of the Corryville Member at Stonelick Creek was approximately 19.43 m (63.3 ft). Previous estimates of unit thickness at Stonelick Creek include 23.27 m (Hinterlong, 1981) and 20.6 m (Schumacher, 1984). This disparity is attributed to the differential placement of the gradational upper unit contact. The mean shale percentage for the Corryville Member at Stonelick Creek was 59%, slightly less than the regional average of 63%. Shale percentage logs were computed for the partial exposures 1 and 2 (Appendix 3); these overlap to produce a nearly complete section. Average percent shale within 1.0 m of section was as high as 90% or as low as 31%. Shales contained infrequent, thin (< 1 cm thick), discontinuous (< 30 cm long) lenses of silt or carbonate, but these were not included in the calculation of mean shale percentage.

The fissile, irregular-bedded, fossiliferous shales and wavy- to irregularly-bedded limestones of the Bellevue Member were easily differentiated from the Corryville strata. Bellevue Member limestones at Stonelick Creek were generally thin and contain abundant shale interbeds, mud clasts, and haphazard- to subhorizontally-oriented brachiopod and bryozoan material. The Bellevue-Corryville contact was relatively sharp and apparent at Stonelick Creek and was placed at the lowest typical Corryville grainstone. The contact was observed in the area of exposure 1, where the thick basal grainstone formed a prominent overhang along the entire east-facing cliffside (Fig. 25). The basal grainstone bed of the Corryville Member did not display features

Figure 24 - Composite stratigraphic column of Corryville Member of Grant Lake Formation at the proposed type-section of Stonelick Creek, Clermont County, Ohio. Corryville is approximately 19.5 m thick at Stonelick Creek.

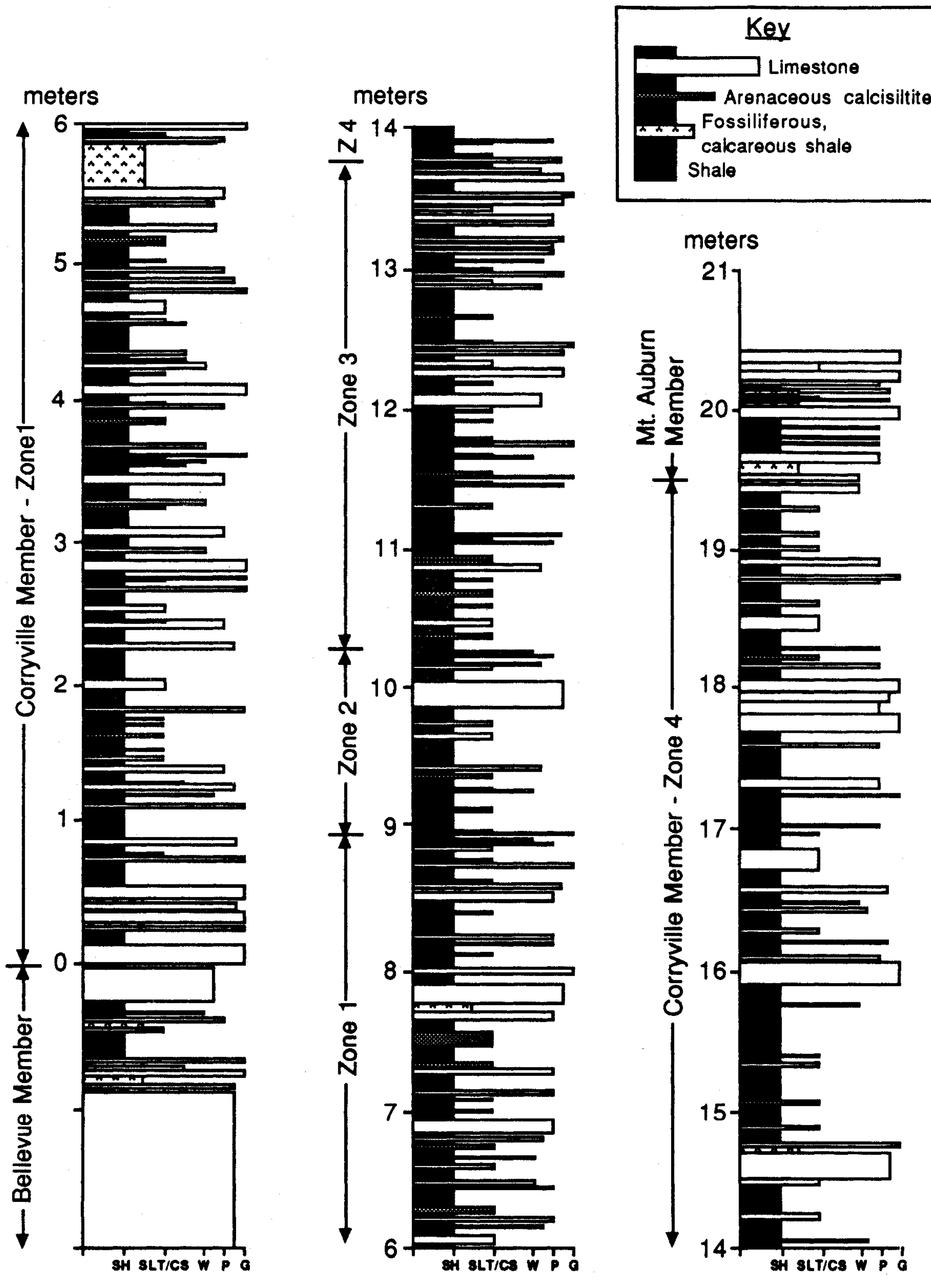
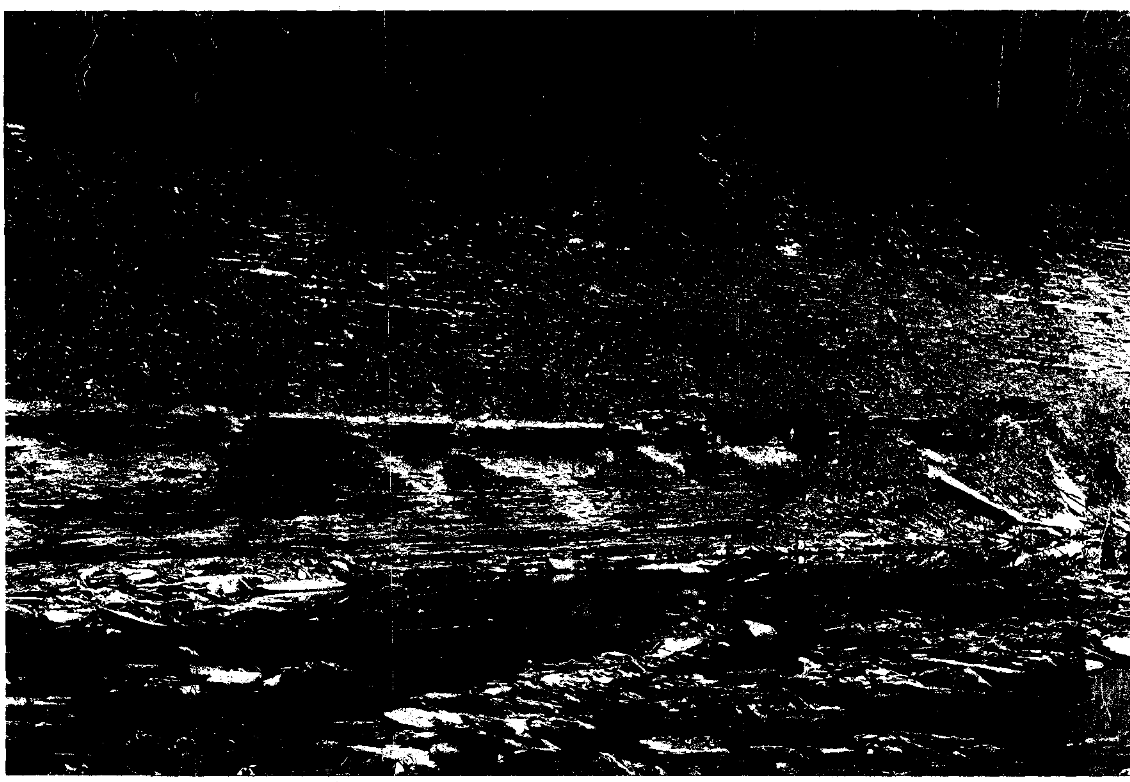

Key
Limestone
Arenaceous calcisiltite
Fossiliferous, calcareous shale
Shale
meters
6
5
4
3
2
1
0
Corryville Member - Zone1
Bellevue Member
SH SLT/CS W P G
Lithology
meters
14
13
12
11
10
9
8
7
6
Z4
Zone 3
Zone 2
Zone 1
SH SLT/CS W P G
Lithology
meters
21
20
19
18
17
16
15
14
Mt. Auburn Member
Corryville Member - Zone 4
SH SLT/CS W P G
Lithology

Figure 25 - Bellevue-Corryville contact along Stonelick Creek (exposure 1 of this study). Contact is demarcated by a thick, continuous grainstone ledge. Vertical staff at center of exposure is 1 m in length.



commonly associated with a marine transgression (e.g. phosphatic pebbles, karstification), but in exposures to the south, Holland (1992) reported a series of hardgrounds at the unit contact. Exposure 1 was the same section as Schumacher's (1984) Stonelick Creek A and OGS File 16836. The Bellevue Member contact was traced to a point upstream just south of exposure 2, where the grainstone formed the cap of a small waterfall.

The transitional interval between the Corryville and Mt. Auburn Members at Stonelick Creek was 1.0 m or thicker. Schumacher et al. (1991) suggested that the contact be placed midway within the transitional interval between the two members, and this investigation established the upper contact at the first thick (9 cm), irregular-bedded, fissile-parted, fossiliferous Mt. Auburn shale within the transitional interval. A thick amalgamated bed containing valves of *Platystrophia ponderosa* var. *auburnensis* was situated just above the unit contact. Sections containing the Corryville-Mt. Auburn contact were not well-exposed at the creek-level but could be seen along the tops of the highest cliffs along the creek (exposures 2 and 6).

Description of Internal Zonation

The correlation of eight overlapping stream exposures at Stonelick Creek has revealed considerable stratigraphic heterogeneity within the Corryville Member of the Grant Lake Formation. Although no individual, isochronous event beds were identified within the vertical section, larger scale variations in the distribution and thickness of carbonate and shale beds were observed. Stratigraphic correlation of many exposures has confirmed that these lithologic changes are laterally persistent and not localized phenomena. On the basis of field observations, the Corryville section was subdivided into four discrete, stacked stratigraphic "zones". To avoid confusion, this report will only use the term "zone" in reference to these specific entities or those previously described as intervals (e.g. the Kope-Fairview transition zone of Jennette, 1986).

The following zone descriptions were derived solely from the Stonelick Creek site. Each zone was defined through a combination of mean shale percentage, bedding character, and dominant carbonate lithotypes (Table 2). Pertinent paleontologic details were used as secondary criteria. Zone thicknesses ranged from 1.3 m to 8.9 m, with no overlap between contiguous zones. Because many Corryville beds were discontinuous in section, zone contacts were arbitrarily placed at the beds that most closely delineated the lithologic shift between zones. As a result, variations in the thickness of individual zones did occur between exposures, but these were slight and the general character of each zone remained constant. The question of whether or not these zones can be related to specific changes in the depositional environment or dynamics of deposition will be addressed later in this report.

Zone 1

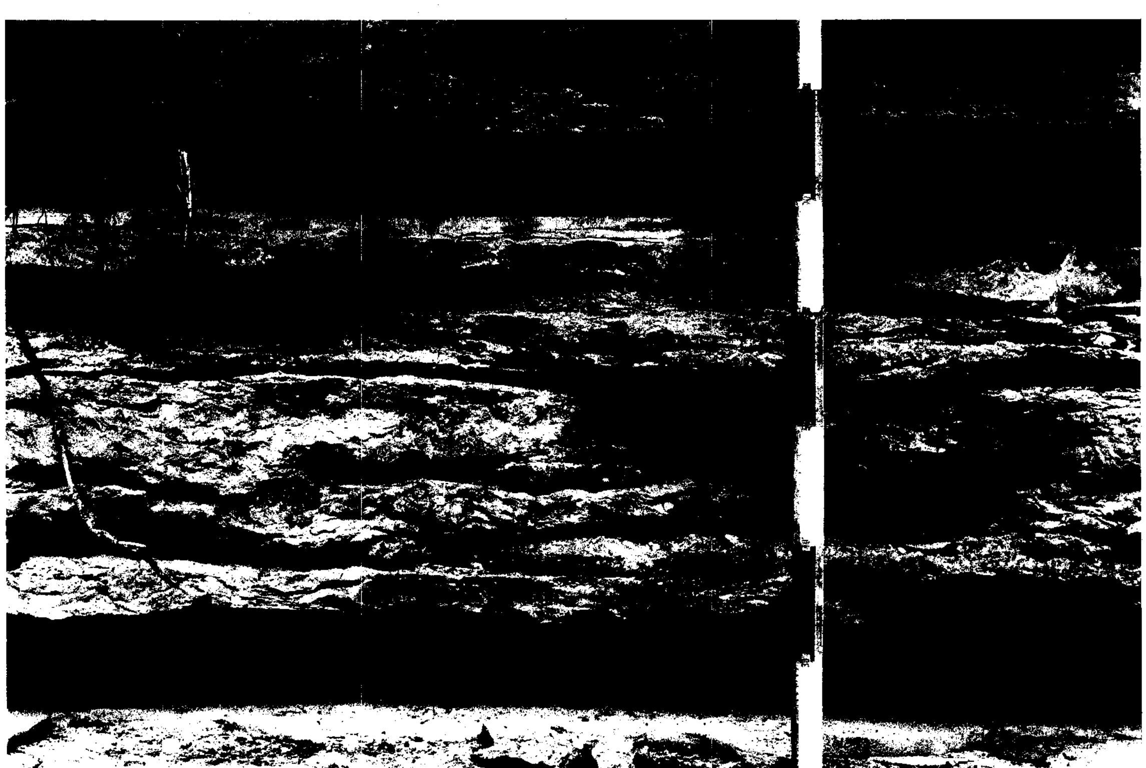
The lowest zone, referred to as "Zone 1", was approximately 8.9 m thick and extended upward from the Bellevue-Corryville contact in exposure 1 (Fig. 26). Portions of this zone were also seen in exposures 2, 2A, and 3 (Appendix 2). Zone 1 was dominated by a series of thick (6 cm average), packstones, grainstones, and calcisiltites. The majority of these beds were discontinuous and overlapping in section and did not correlate well between distant exposures. In order of descending abundance were the following lithotypes: packstones, wackestones, grainstones, calcisiltites, arenaceous calcisiltites, micstones. The basal 1.5 m consisted primarily of thick (7 cm average) coarse

Table 2 - Comparison of diagnostic stratigraphic, sedimentologic, and paleontologic characteristics used to delineate each of the four Corryville "zones". General characteristics of entire Corryville interval are also presented.

		Corryville Mbr.	Zone 1	Zone 2	Zone 3	Zone 4
STRATIGRAPHY	Average Thickness	19.43 m	8.89 m	1.29 m	3.58 m	5.67 m
	Mean Percent Shale	59%	57%	72%	55%	63%
	Range of Percent Shale	31 - 90%	45 - 61%	57 - 83%	31 - 66%	45 - 90%
SEDIMENTOLOGY	Avg. Carbonate Thickness	4 cm	6 cm	4 cm	5 cm	6 cm
	Avg. Shale Thickness	7 cm	6 cm	8 cm	6 cm	9 cm
	Dominant Type Carbonate	packstone wackestone aren. calcisiltite	packstone wackestone grainstone	calcisiltite aren. calcisiltite	aren. calcisiltite calcisiltite packstone	packstone calcisiltite aren. calcisiltite
	Bed Continuity	continuous to discontinuous	discontinuous	continuous to discontinuous	continuous to discontinuous	continuous
	Amalgamated Beds	25% of all beds	uncommon	rare	common	uncommon
	"Ideal" Storm Event Beds	rare to common	uncommon	rare	rare to common	rare
PALEONTOLOGY	Dominant Fossil Taxa	brachiopod bryozoan crinoid trilobite	brachiopod bryozoan trilobite pelecypod	*Zygospira* trilobite crinoid	bryozoan trilobite brachiopod pelecypod	brachiopod bryozoan crinoid trilobite
	Unique taxa	—	*Raf. nasuta* *Platystrophia*	articulated trilobites	artic. trilobites *N. martini* *E. popei*	articulated edrioasteroids and crinoids
	Relative Shale Fossil Content	sparse to abundant	sparse to abundant	sparse	sparse or abundant	sparse to moderate
	Trace Fossils	common	uncommon	rare	common to uncommon	uncommon
MISC.	Unique Stratigraphic Horizons	—	irregular-bedded horizons @ 5.5, 7.5, and 8.3 m above base grainstones in basal 1.5 m	"10-meter bed" butter shales	limestone content and amalgamation of beds incr. upsection butter shales	repeating bedding sequences (Corryville cycles) hardgrounds

Figure 26 - Strata of Zone 1 at Stonelick Creek (exposure 2 of this study). Note the close vertical spacing and relatively equal thickness of shale and limestone beds. Horizontal staff at left of center of exposure is 1 m in length.

Figure 27 - Irregular-bedded horizon in Zone 1 (from exposure 4 of this study). Note the abundance of amalgamated beds, the discontinuity of strata, and the irregular bedding surfaces in comparison to the overlying and underlying "typical", planar Corryville strata. Measurements on scale are in tens of cms.



and poorly-washed grainstones. Grainstones were generally half as abundant as packstones and wackestones, were fine, coarse, and poorly-washed in equal numbers, and decreased in abundance upsection. Conversely, the number of packstones and wackestones increases upsection. Micstones represented only 3% of all carbonates and were commonly amalgamated to one or more wackestones or packstones. Micstones appeared restricted to Zone 1.

This zone was less shale-rich than the others. Mean shale percentage ranges between 45% and 61% and averaged 57%. Shales were thinner, silty to argillaceous, sparsely to abundantly fossiliferous and averaged 6 cm in thickness. Thin, discontinuous calcareous lenses were fairly common within the shales of the lower 4.0 m of this zone. These lenses could be silty and often contained abundant fragmented to whole bryozoan and brachiopod material. Shale beds that were classified as sparsely fossiliferous can occasionally contain one or more thin, continuous horizontal lag(s) of fossil detritus. When traced in section, these lags developed into a discrete carbonate bed. The faunal composition of these fossil lags included variable amounts of ramose bryozoan, brachiopod, trilobite, crinoid, and gastropod fragments.

Three horizons of irregular- to wavy-bedded limestones and fissile-parted, fossiliferous shales occurred at specific intervals within the upper 4.0 m of Zone 1 (Fig. 27). Each irregular-bedded horizon (IBH) was laterally persistent and appeared to maintain its stratigraphic position relative to the Bellevue Member contact. For these reasons, and because the IBHs were distinctly different from typical Corryville strata, these horizons were excellent tools for stream exposure correlation. Fossil material within each IBH was generally broken, abraded, and randomly oriented. *Platystrophia* , *Rafinesquina* , and large ramose bryozoans were conspicuously abundant. Rip-up clasts and shale interbeds were common within the limestones.

The lowest, thickest IBH averaged 0.5 m in thickness and was situated approximately 5.5 m above the Corryville-Bellevue contact. This horizon contained thick, irregular-bedded packstones and grainstones and fossiliferous shales with numerous, discontinuous nodular-bedded limestones. Packstones and grainstones displayed flaser bedding, discontinuous shale interbeds that develop when muds fill ripple troughs and were subsequently covered by successive ripples or carbonate material (Potter et al., 1980). The discontinuous nodular-bedded limestones were interpreted as starved ripples that formed along a mud-dominated sea bottom. Fossil material was either small and highly fragmented or relatively whole. This IBH corresponded to Hinterlong's (1981, p. 36) "unit 2", a "light blue-gray coquina...[that] weathers to a moderately resistant rubbly surface". The upper two IBHs were situated at 7.5 m and 8.3 m above the Corryville-Bellevue contact. These were lithologically and faunally identical to the lower IBH, but were thinner (20 cm and 40 cm in thickness) and lacked the nodular-bedded strata.

Taxic diversity within Zone 1 was high, and skeletal material was abundant. Brachiopods, bryozoans, trilobites, crinoids, ostracods, and pelecypods dominated the fauna. Gastropods and cephalopods were present in lesser numbers. Bryozoan colonies were most abundant within this zone and exhibited predational boring and overturned orientation. Several beds, in particular those at exposure 2A, hosted more than one of these colonies. The trace fossils *Diplocraterion*, *Trichophycus*, and *Chondrites* -type-B were abundant within arenaceous calcisiltites, calcisiltites, silty caps of beds, and silty portions of amalgamated beds. Enrolled or extended trilobites were rare and were commonly associated with arenaceous calcisiltites or silt lenses.

Hinterlong (1981, Fig. 6) made reference to a trilobite-rich horizon within the shales just above the lowest IBH, but the occurrence of such a deposit could not be verified.

The brachiopods *Platystrophia* and *Rafinesquina nasuta* were restricted to Zone 1, at least within the Stonelick Creek area. *Platystrophia* valves were highly fragmented and never articulated. Where present, *R. nasuta* was highly convex, strongly geniculate, abundant, and articulated. Van Fossen (1951, p. 48, Fig. 1) stated that *R. nasuta* was present in a restricted horizon near the base of the Corryville that "makes an excellent stratigraphic marker". *R. nasuta* pavements occurred within Stonelick Creek exposures between 3.5 m to 4.0 m above the Bellevue Member contact, but whether these represented a single, continuous bed could not be determined.

Zone 2

The second zone ("Zone 2") extended from 8.89 m to 10.18 m above the Corryville-Bellevue contact and ranged in thickness from 1.01 m to 1.15 m. Zone 2 was complete in exposures 1, 2, 3, 4, and 5 (Fig. 28). The lower contact of Zone 2 was arbitrarily placed at the base of the first obvious and thick (> 9 cm) shale in the sequence of unusually thick shales;. This contact marked a shift from thick, closely bedded packstones and thin shales to thick, sparsely fossiliferous shales (8 cm average) and thin calcisiltites, limestones, and arenaceous calcisiltites (4 cm average thickness). Zone 2 was shale-rich (72%), with a mean shale percent ranging from 57% to 83%. Shales achieved a thickness in excess of 34 cm. Three-fourths of the non-shale strata were continuous to discontinuous calcisiltites and arenaceous calcisiltites, with sole marks, tool marks, basal fossil lags, normal grading, and rare planar lamination.

Figure 28 - Zone 2 in streamcut at Stonelick Creek (exposure 5 of this study). Lower shale-rich portion extends from just above water level to base of thick ledge and contains "trilobite shales". The ledge represents the upper carbonate-rich portion of Zone 2. Vertical staff at center of exposure is 1 m in length.

Figure 29 - Stream exposure at Stonelick Creek with central portion of Zone 3 (exposure 7 of this study). The base of this zone is shale-rich and is poorly exposed along the creek.

The remaining carbonates were thin packstones, wackestones and grainstones that appeared to represent a single depositional event.

The upper portion of Zone 2 contained 2 or 3 thick (12 - 19 cm), amalgamated carbonate beds that ranged from poorly-washed grainstones to packstones. The contact with Zone 3 was set at the top of the uppermost amalgamated bed. The lowest of these carbonates beds was a continuous ledge-former with a burrowed silt cap. Fossil material within this bed was generally broken, of all sizes, poorly to moderately sorted, and subhorizontally oriented. Because this persistent bed was situated approximately 10 m above the Bellevue Member contact, it was informally dubbed the "10-meter bed".

Fossils were less abundant within Zone 2, and taxic diversity was moderate. Preservation was either as whole and pristine individuals or as small to medium sized fragments. *Zygospira* , trilobite, and crinoid material were most abundant, and cephalopod molds and gastropods were not uncommon. Pelecypods and bryozoans occurred less frequently, but were occasionally concentrated in the thin packstones and wackestones. In contrast to the abundance of arenaceous calcisiltites and calcisiltites within this zone, ichnofossils were uncommon. Rare edrioasteroids have been collected from one of the thick, amalgamated packstone-grainstone beds (Bill White, personal communication, 1992); these articulated specimens lay atop convex-up *Rafinesquina* valves scattered along the upper surface of the bed .

Soft, discontinuous shales, commonly referred to as "butter shales" or "trilobite shales" (Forsyth, 1946; Brandt, 1980a; Brandt Velbel, 1985), were discovered within the sparsely fossiliferous shales of the upper one-third of Zone 2. These yellowish, fine-grained layers were the source of enrolled, elongate, and partially enrolled *Flexicalymene* and *Isotelus* specimens. Trilobite occurrence was limited to the specific "trilobite shale" layers, and individuals tended to be solitary and displayed little to no abrasion and no encrustation. Several enrolled *Flexicalymene* and a single *Isotelus* were recovered from Zone 2 at exposures 1 and 5. Many of the most productive exposures of Zone 2 near the S.R. 131 bridge are now buried under talus, the result of reduced creek flow after the construction of Stonelick Lake (Bill White, personal communication, 1992).

Although most shales were sparsely fossiliferous, an unusual stringer with whole, unabraded foliate bryozoans, gastropods, and cephalopods was present within the shale just below the "10-meter bed" at exposure 5. This lag deposit converted to a thin limestone horizon further along the section. A single fossil lens containing hundreds of articulated *Zygospira* was also collected from within the shales at exposure 1. This deposit appeared to represent an *in situ* life assemblage similar to those reported from the Richmondian Stage (Richards, 1972, Pl. 5). Roughly circular, the lens thinned towards the edges and was replete with *Zygospira* of all sizes. At the center of this lens was a thick cephalopod mold and several complete *Cyclonema* shells that would have supplied ample surface area for the development of a colony at the sediment-water interface.

Zone 3

The third zone (Fig. 29), from 10.04 m to 13.76 m above the Bellevue Member contact, was characterized by a lower mean shale percentage (55%), thinner shale beds (6 cm average), and an increased number of packstones and amalgamated beds. Mean shale percentage ranges from 31% to 66%. Amalgamated beds accounted for up to 45% of all beds present within this interval and were particularly abundant in the upper 1.0 m of this zone. Zone 3 was increasingly limestone-rich upsection "Rare ball and pillow structures" reported by Tobin (1982, p. 207) from Stonelick Creek were not observed, but these may have been mistaken for rare, wide loading casts present in exposure 3. This zone rarely outcropped and was only complete in exposure 2 (Appendix 2). Partial sections were present in exposures 3, 5, 6, and 7 (Appendix 2).

Unlike the lower two zones, Zone 3 was clearly heterogeneous in its shale percent and carbonate types and was further subdivided into the following three intervals:

1. The lowest 0.6 m of Zone 3 consisted of thick calcisiltites, arenaceous calcisiltites, and shales and was most similar lithologically to Zone 2. Amalgamated beds were rare. Mean shale percentage ranged from 55% to 61%. Abundant articulated trilobites have been recovered from this portion of Zone 3 (Bill White, personal communication, 1992), but no trilobite specimens were collected during this investigation. Bioturbation was common within the arenaceous calcisiltites and calcisiltites, and ichnospecies included *Chondrites*, *Diplocraterion*, and *Trichophycus*. A *Rusophycus* horizon was once exposed at the base of Zone 3 at Exposure 5, but this has since been covered by soil (Bill White, personal communication, 1992).

2. The next 2 m contained medium to thick shales, moderately thick arenaceous calcisiltites and calcisiltites, and abundant tempestites. Mean shale percentage ranged from 50% to 66%. This interval represented the greatest concentration of idealized storm event beds within the Corryville section at Stonelick Creek. Beds generally fined upwards and displayed planar lamination or ssHCS and an erosive basal surface with scour and tool marks. Isolated crinoid stems and large bryozoan fragments were present at the

surfaces of arenaceous calcisiltite beds. Pelecypod molds were abundant along the inner contacts of amalgamated beds and several were partially pyritized.

3. The upper 1 m of this zone was composed of thin shales and limestones and thick amalgamated beds. Mean shale percentage ranged from 31% to 59%. Amalgamated beds contained two-to-four thin packstones and grainstones and abundant shale interbeds and were up to 14 cm thick. Shales were fissile-parted, fossiliferous, and discontinuous and bedding contacts were wavy to irregular. Fossil orientation within carbonates was chaotic to subhorizontal, and fossil material displayed all degrees of breakage. Bioturbation was rare.

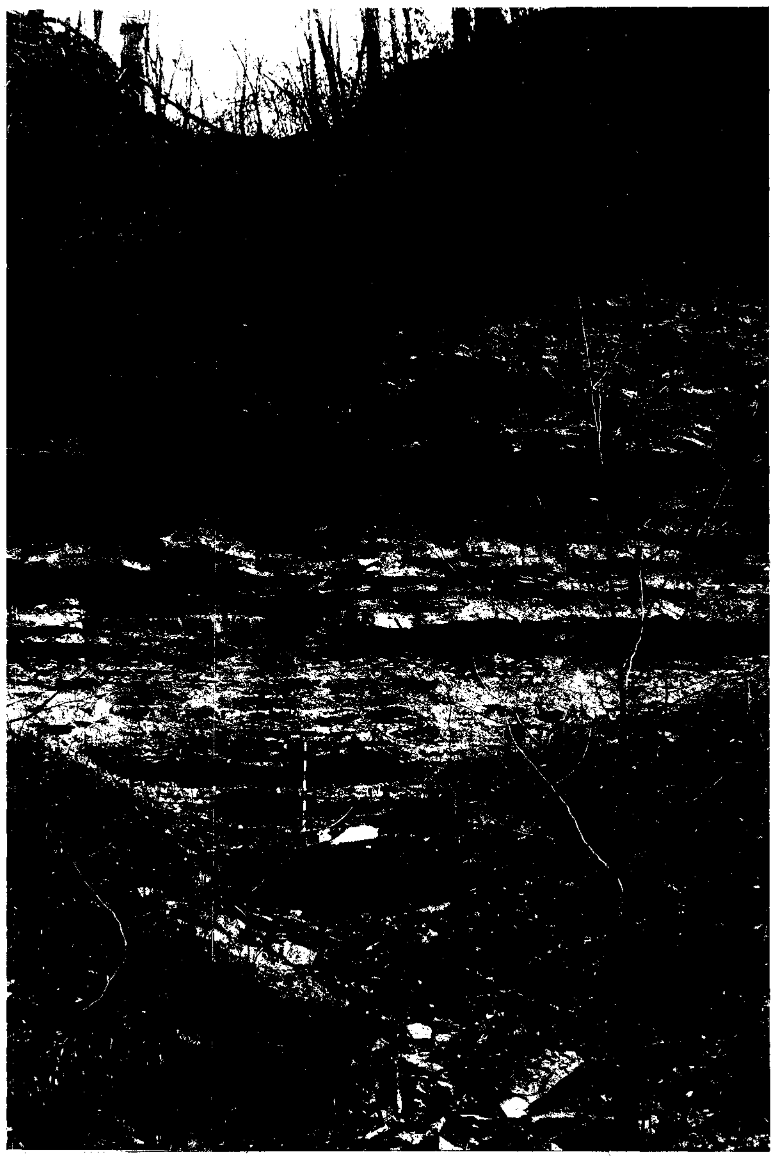
Excepting the lower 0.6 m portion, the strata of this zone were abundantly fossiliferous with a large number of cephalopods and pelecypods. Crinoid, bryozoan, and trilobite fragments were particularly abundant. One shale bed at exposure 2 was the source of long (> 30 cm), intact *Pycnocrinus* stems. Many of the unique Corryville species have been collected from Zone 3. The aglaspid, *Neostrabops martini* Caster and Macke (1952) was discovered "about three feet above low water of the creek in mid-summer" (p. 754) at what would be exposure 7 of this investigation. *N. martini* was recovered from a 2-to-3-inch thick, bioturbated, lenticular arenaceous calcisiltite bed that was overlain by a fine calcarenite and was underlain by blue calcareous mudstone (Caster and Macke, 1952). The holotype of the carpoid *Enoploura popei* Caster (1952) was also discovered from exposure 7, described as the first stream ford located 200 yds below the Ohio S.R. 131 bridge. The specimen was found atop "a loose calcarenite slab which had fallen from the middle section of the cutbank" (p. 36), which corresponds roughly to the center of Zone 3. The same exposure appeared to be the source of the type *Palaeoscia floweri* specimens (Caster, 1942).

Zone 4

The fourth and uppermost zone was approximately 6.7 m thick and extends from 13.76 m above the Bellevue Member contact to the Mt. Auburn Member contact at 19.43 m. Zone 4 was thicker and shalier than Zones 1 and 3 with a higher mean shale percentage (63%) that ranged from 45% to 90%. Shales averaged 9 cm in thickness, exhibited platy to flaggy parting, and were sparsely fossiliferous, although fossil content increased with proximity to the Mt. Auburn Member contact. One-third of all limestone beds within this zone were calcisiltites, and the thickest of these was 13 cm. Packstones and wackestones also accounted for one-third of all limestone beds and most were fine-grained with abundant convex-up *Rafinesquina* valves. Grainstones and arenaceous calcisiltites were present in lesser numbers. Many of the beds within Zone 4 were continuous and were correlatable between creek exposures for some distance (> 1 km). Because it was thick and appeared upstream of the largest exposures, Zone 4 was only complete in exposure 6 (Fig. 30) and, except for the very top, in exposure 2.

The most striking feature of Zone 4 was the presence of four, stacked, lithologically similar bedding sequences. These bedding sequences range in thickness from 1 to 2 m and bore a close physical resemblance to Zone 2. An individual sequence consisted of a lower shale-rich interval and an upper, thinner limestone-rich interval. The lower portion contained thick shales interbedded with thin (3 cm average), continuous calcisiltites, arenaceous calcisiltites, and fossiliferous packstones. Amalgamated beds were rare.

Figure 30 - Zone 4 at Stonelick Creek (exposure 6 of this study). The Zone 3-Zone 4 contact lies at the base of the exposure, approximately at the base of the vertical meter stick.



Calcisiltites and arenaceous calcisiltites were planar- to wavy-bedded and commonly laminated and displayed sole marks. Paleocurrent directions from sole marks were predominantly northwest-southeast in orientation. The upper limestone-rich portion, or "sequence cap", was essentially a prominent and thick (15 to 41 cm) amalgamated bed composed of two-to-four irregular- to planar-bedded grainstones and packstones. Discontinuous, fissile, and fossiliferous shale layers occurred within the limestones or along the contacts between the amalgamated beds. Sequence caps were more resistant to erosion and tended to form overhangs within field exposures. They were lithologically similar to Jennette's (1986, p. 62) "grainstone ledges" from the Kope-Fairview transition zone.

Fossil material was less abundant within the strata of this zone, in part due to the abundance of thick, sparsely fossiliferous shales. Bryozoans were small ramose and encrusting, and massive colonies were mostly absent. Ichnofossils and bioturbation were less common. *Chondrites* and escape burrows were the most common ichnospecies, and these increased in abundance near the Mt. Auburn Member contact. *Conostichus* sp. was found within the uppermost 3 m of the Corryville interval. This trace fossil appeared as a featureless conical hyporelief on packstones and calcisiltites, and extended 2 to 4 cm into the underlying shale bed. Krumpolz (1980) documented the presence of similar apex-downward conical structures within the lower 0.5 m of the Mt. Auburn Member, attributing these to the "filling of some sort of excavation of an organism" (p. 20). His figured specimens (Pl. 2, Fig. 4-6) were nearly identical to those seen in the Corryville Member and likely were the same type of trace. Tobin (1982) agreed that these cones were biogenic in origin and further suggested that they might be the resting traces or dwelling traces of sea anemones.

Paleontologically, this zone is notable for its rich echinoderm deposits. Edrioasteroid-bearing shell pavements have been discovered just below the Mt. Auburn Member contact in other areas of the southwestern Ohio and northern Kentucky area (Meyer et al., 1981; Rassmann, 1984; Meyer, 1990). These shell pavements all represent smothered *in situ* assemblages (obrution deposits), and one pavement was interpreted as an incipient hardground (Rassmann, 1981; Meyer, 1990). No such deposits were found at Stonelick Creek during this study, but the possibility of their existence at this site should not be dismissed. Concentrated *Iocrinus subcrassus* deposits were recovered from Stonelick Creek just north of the S.R. 131 bridge, most likely within or close to the transitional contact zone (Meyer et al., 1981; Schumacher, 1984). Scour channeling, sole marks, articulated crinoids, current orientation of crinoid crowns, bioclast abrasion and graded bedding were cited as evidence for deposition by unidirectional density currents (Meyer et al., 1981; Schumacher, 1984).

Regional Correlation of Stratigraphic Zones

Three cores and one partial stream exposure were examined to test whether the lithologic trends found within the Corryville Member at Stonelick Creek could be traced laterally throughout southwestern Ohio. The O'Bannon Creek site was chosen to test correlation between distant field exposures, and core data was employed to examine the zones over a longer distance, roughly 50 km. The regional structure of the Cincinnatian is simple (Hofmann, 1966a) and does not interfere with long distance correlation. The beds along the Cincinnati Arch have a shallow regional dip of < 0.5°, commonly only 1-2 m/km (Martin, 1975). Joints, folds, and thrusts decrease upsection from the Kope Formation to the Bellevue Member, where deformational structures are rare to nonexistent (Hofmann, 1966a). No structural anomalies have been previously cited in association with the Corryville interval.

O'Bannon Creek

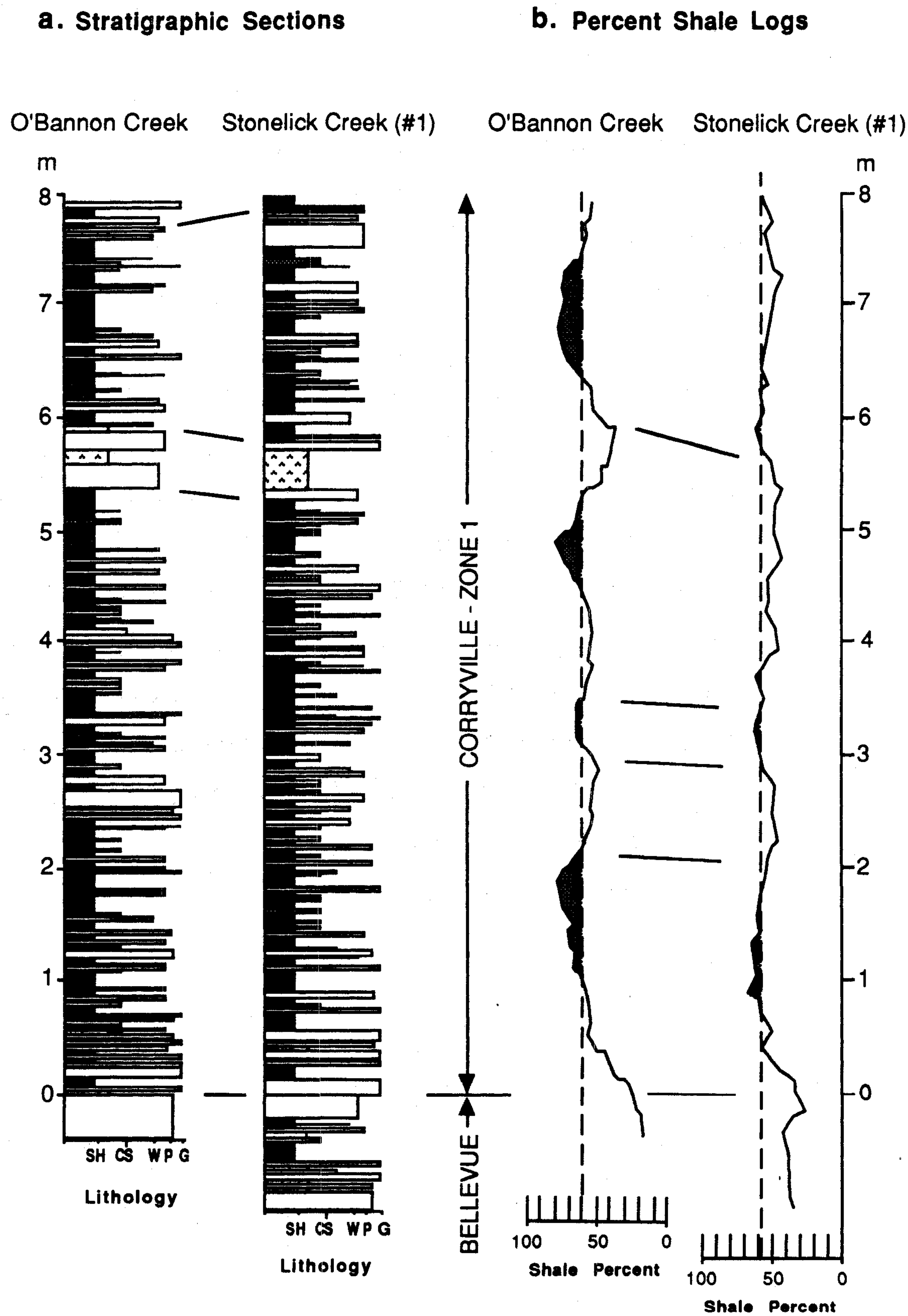
The O'Bannon Creek section represented the lower one-third of the Corryville Member of the Grant Lake Formation. Correlation with the Stonelick Creek section was facilitated by the presence of the Corryville-Bellevue contact. This contact was relatively sharp and was placed at the lowest typical Corryville grainstone (Appendix 2). Corryville strata were planar to lenticular with minor amounts of irregular- to wavy-bedded limestones. Shales were generally planar-bedded, platy- to flaggy-parted, and sparsely fossiliferous, but were occasionally fissile and fossiliferous. Average shale percentage for this section was 60%, as compared to 58% for the same interval at Stonelick Creek. Packstones, arenaceous calcisiltites, and calcisiltites were the most abundant lithotypes, with brachiopod shell pavements and silty bed caps common. Because the creek exposure was restricted to a thin, nearly vertical cliff gully, the lateral continuity and textural consistency of the individual beds could not be determined.

The O'Bannon section represented nearly all of Zone 1, lacking only the uppermost 1.0 m of section. Because individual beds within Zone 1 are typically discontinuous, correlation was based upon shale percent logs and the presence of the irregular-bedded horizons (Fig. 31a). In both the O'Bannon Creek section and the equivalent Stonelick section: (1) the lowest 0.5-meter-thick, IBH was present at 5.4 m above the Bellevue Member contact; (2) a second IBH was located 1.7 m above the first IBH; and (3) a series of thick grainstone beds marked the base of the unit above the Bellevue Member contact. Shale percent logs for the two sections displayed similar signatures (Fig. 31b). In the lower 4.0 m of the Corryville Member, shale-rich and limestone-rich intervals correlated closely. Above the 4.0 m mark, the logs were less obviously alike; the O'Bannon Creek section contained more sharply defined shale and limestone intervals. From 6.5 m to 8.3 m, however, both logs displayed a similar trend of decreasing, then increasing limestone content.

Cores

In lieu of field exposure data, three OGS cores were used to determine large-scale lateral variation within the Corryville Member in southwestern Ohio. These cores formed a 50 km transect that lay roughly along the predicted slope (Fig. 13) of the shallow upper Ordovician carbonate ramp. Core 868, situated at the northwest end of the transect, was representative of more distal conditions along the ramp. Core 2623, at the southeast transect end, lay just within the

Figure 31 - Comparison of the O'Bannon Creek section and the equivalent interval of the Stonelick Creek section (from exposure 1 of this study). a) Comparison of stratigraphic columns (for key to symbols, see Appendix 2). Note the generally equivalent positions of the two IBHs. b) Comparison of percent shale logs. Dashed lines are mean shale percentage, and stippled areas indicate intervals of log where shale percentage is greater than the mean. See Figure 24 for key of stratigraphic section.



a. Stratigraphic Sections
b. Percent Shale Logs
O'Bannon Creek
Stonelick Creek (#1)
O'Bannon Creek
Stonelick Creek (#1)
m
8
7
6
5
4
3
2
1
0
SH CS WP G
Lithology
SH CS WP G
Lithology
CORRYVILLE - ZONE 1
BELLEVUE
100 50 0
Shale Percent
100 50 0
Shale Percent
m
8
7
6
5
4
3
2
1
0

Grant Lake Formation-Grant Lake Limestone transition zone (Schumacher et al., 1991, Fig. 3), and therefore represented more proximal ramp conditions. Core 2620, drilled at a site approximately 7 km northeast of Stonelick Creek, was positioned at the center of the transect and roughly parallel to Stonelick Creek along the inferred strike of the ramp slope.

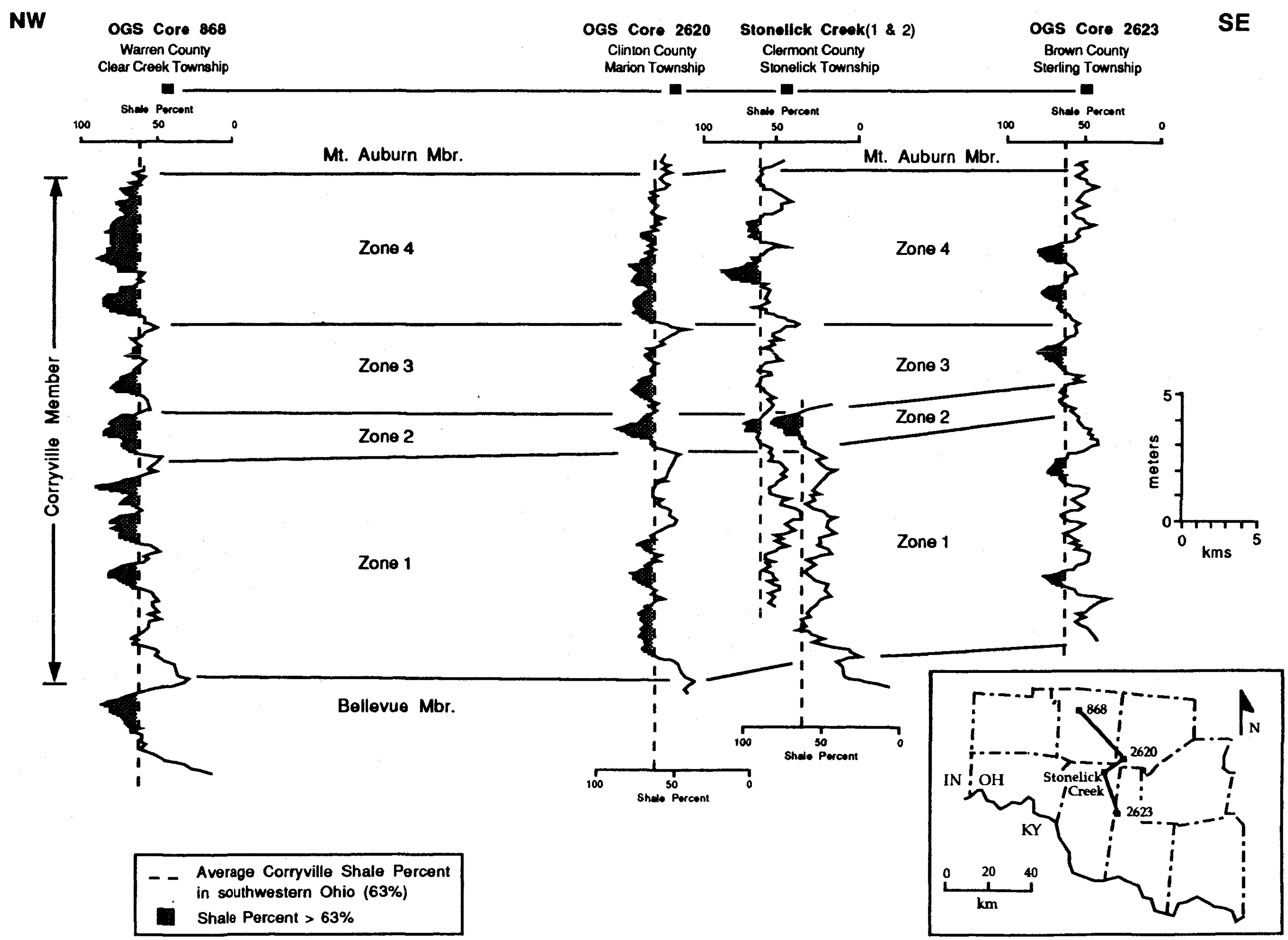
The four Zones were successfully identified in shale logs from each core. Changes in the thickness of the Corryville Member and of the individual Zones are summarized in Table 3. The thickness of the Corryville Member ranges from 20.27 m (Core 868) to 18.59 m (Core 2623), with increasing thickness from the southeast to the northwest. Schumacher et al. (1991) attributed a thickness of 22.8 m to Core 868, but this estimate included a thick, argillaceous shale interval at the base of the unit that is atypical of those shales found within the lower Corryville Member. In addition, this 1.5 m shale package is bounded by thick sequences of fissile, fossiliferous shale and Bellevue-type limestone. For these reasons, this shale was interpreted as an anomalous interval below the Corryville-Bellevue contact and within the upper Bellevue Member . This shale is too stratigraphically high within the Bellevue Member to be considered a tongue of the Miamitown Shale (Ben Dattilo, personal communication, 1992).

Mean shale percentage within the Corryville Member decreased from the northwest to the southeast as the ramp conditions became more proximal. This gradient is effectively displayed by the shading of all log sections with greater than 63% shale, the average shale percent for the region (Fig. 32). The highest mean shale percentage for the Corryville Member was observed in Core 868 at 67%. Core 2620 had a mean of 64%, and Stonelick Creek and Core 2623 were both 59%. Despite this 8% variation, shaley and limestone-rich intervals displayed remarkable stratigraphic consistency in relation to their position within the Corryville section. This trend is best elucidated through the shading

Table 3 - Comparison of the thickness and shale content of the four zones for each field site and rock core of this study.

Section	Corryville Mbr.		Zone 1		Zone 2		Zone 3		Zone 4	
	Thickness	Average Shale Percent	Thickness	Average Shale Percent (range)	Thickness	Average Shale Percent (range)	Thickness	Average Shale Percent (range)	Thickness	Average Shale Percent (range)
Stonelick Creek Composite Section	19.43 m	59%	8.89 m	57% (45-61)	1.29 m	72% (57-83)	3.58 m	55% (31-66)	5.67 m	63% (45-90)
O'Bannon Creek	7.83 m (incomplete)	60%	7.83 m (incomplete)	60%	--	--	--	--	--	--
Core #2623	18.59 m	59%	8.93 m	57% (36-77)	1.12 m	62% (53-69)	3.02 m	66% (55-82)	5.52 m	59% (42-80)
Core #2620	20.09 m	63%	9.13 m	60% (47-77)	1.15 m	72% (62-86)	3.82 m	63% (41-77)	5.99 m	65% (53-79)
Core #868	20.27 m	67%	9.19 m	62% (44-88)	2.00 m	70% (54-85)	3.22 m	65% (53-78)	5.86 m	74% (59-90)

Figure 32 - Shale log correlation of the Corryville Member in southwestern Ohio. Stippled areas of logs are those intervals in which the mean shale percentage is greater than 63%, the average Corryville shale percent for Ohio. Note the general decrease in shale-rich intervals to the southeast.

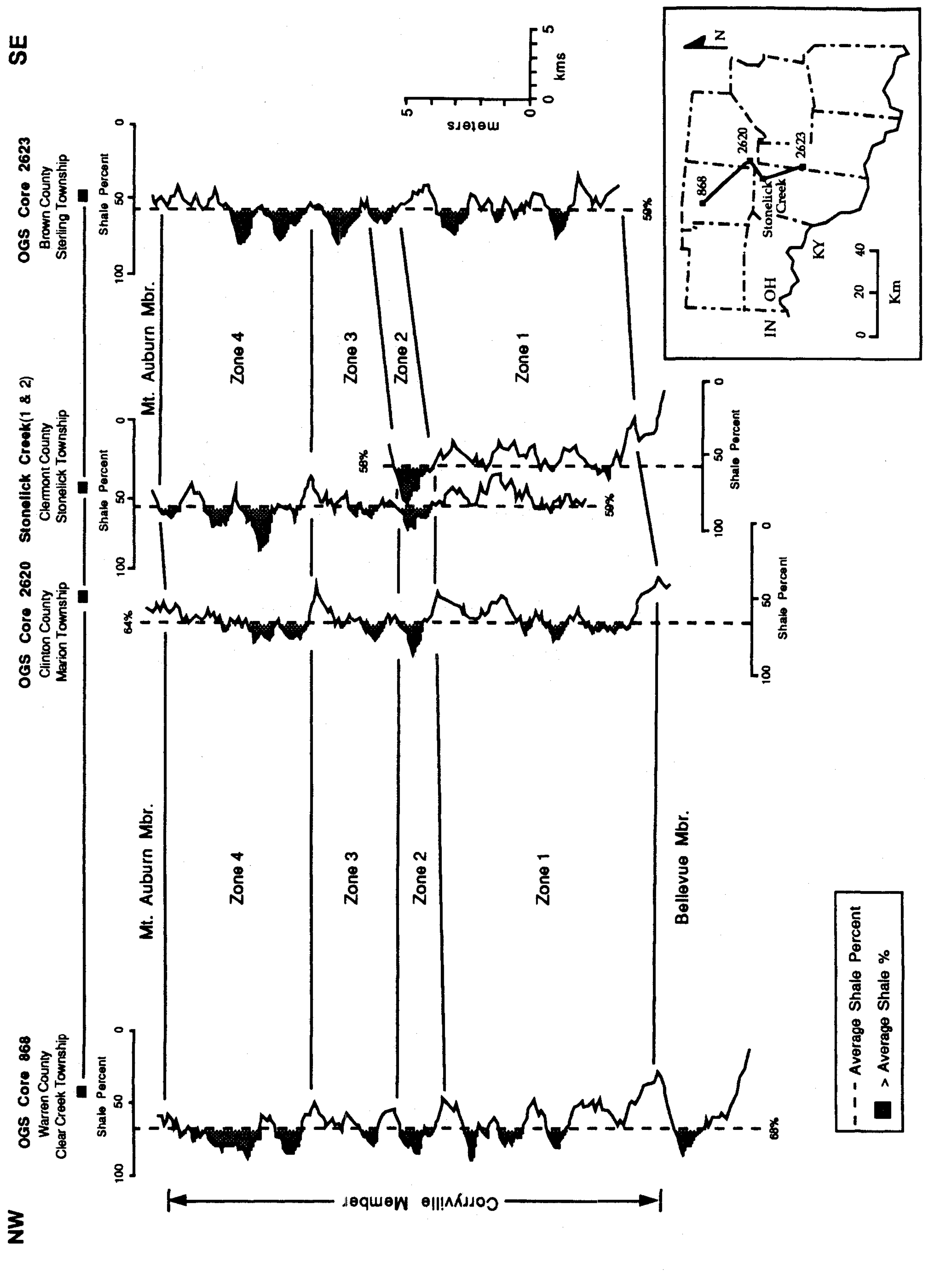

NW
SE
OGS Core 868
Warren County
Clear Creek Township
OGS Core 2620
Clinton County
Marion Township
Stonelick Creek(1 & 2)
Clermont County
Stonelick Township
OGS Core 2623
Brown County
Sterling Township
Shale Percent
100
50
0
Mt. Auburn Mbr.
Zone 4
Zone 3
Zone 2
Zone 1
Bellevue Mbr.
Corryville Member
meters
kms
IN
OH
KY
868
2620
2623
Stonelick Creek
N
0
20
40
km
Average Corryville Shale Percent in southwestern Ohio (63%)
Shale Percent > 63%

of shale-rich zones with respect to the individual mean shale percentage for each log (Fig. 33). Shading of the logs in this manner counteracts the southwestward decrease in shale content and emphasizes the relative ratio of limestone and shale within each core or section.

Core 2620 was the geographically closest and most stratigraphically similar to the Stonelick Creek section. Shale-rich and limestone-rich intervals were nearly identical for Zones 1, 2, and 3. Similar features include abundant grainstones near the lower unit contact, a thick, IBH at approximately 5.5 m above the lower contact, and an increase in amalgamated beds and grainstones at the top of Zone 3. In this core, the "10-meter bed" was represented by a set of closely-spaced packstones and grainstones, that may, in fact, be a single bed with abundant thin shale interlayers. The "10-meter bed" was easily identified within the surrounding thick shales, thin calcisiltites, and thin arenaceous calcisiltites of Zone 2 and lower Zone 3. Although the log signatures of Zone 4 were not identical for the two sections, the logs displayed a trend of upward increasing limestone content within Zone 4. A bed by bed analysis confirmed the existence of the four stacked repeating bedding sequences within both sections.

The alternation between shale-dominated and limestone-dominated intervals was most sharply defined in Core 868, and average shale thickness was greatest within this core (Fig. 33). As expected for a more distal ramp setting, the four zones were correspondingly thicker and shalier than in the other sections. Stratigraphic features observed in Core 868 were consistent with those seen elsewhere. Thick, planar-bedded grainstones still characterized the base of Zone 1. The lowest IBH increased to a thickness of 1 m and was situated 6 m above the Bellevue Member contact. Zone 2 grew to a thickness of 2 m, with a well-defined "10-meter bed" situated 11 m above the

Figure 33 - Shale log correlation of the Corryville Member in southwestern Ohio. Stippled areas of logs are intervals in which the mean shale percentage exceeds the individual average shale percent of the section (listed along the dashed line for each section). Shale-rich intervals retain their relative stratigraphic position along the transect.


NW
SE
OGS Core 868
Warren County
Clear Creek Township
OGS Core 2620
Clinton County
Marion Township
Stonelick Creek(1 & 2)
Clermont County
Stonelick Township
OGS Core 2623
Brown County
Sterling Township
Shale Percent
Mt. Auburn Mbr.
Zone 4
Zone 3
Zone 2
Zone 1
Bellevue Mbr.
Corryville Member
68%
64%
58%
59%
meters
kms
IN
OH
KY
N
868
2620
2623
Stonelick Creek
Km
- - - Average Shale Percent
> Average Shale %

base of the Corryville Member. Limestone content still increased upward in Zone 3, but amalgamated beds were absent at the top of the zone. The four repeating, stacked bedding sequences of Zone 4 were present and well-defined.

The log with the least similar signature was Core 2623, the most proximal ramp section. As expected, limestone beds were more abundant, generally thinner, and more closely spaced. Within Zone 1, the 5.4 m IBH and the two smaller IBHs were identifiable, and within Zone 4, the four stacked bedding sequences were also easily delineated. Zones 2 and 3, however, were thinner and contained less shale, and so were more difficult to recognize. Zone 2 was reduced to a concentration of thinly-spaced calcisiltites and arenaceous calcisiltites with no obvious "10-meter bed". In Zone 3, the characteristic upward increase in limestone content could be identified, but the lower portion appeared to have been condensed. As in the Stonelick Creek section, this core displayed an increase in bioturbation, most likely *Chondrites*, near the top of the Corryville section.

Discussion of Stratigraphy and Deposition

Examination of the stratigraphy of the Corryville Member of the Grant Lake Formation has led to the following conclusions: (1) the Corryville strata were dominated by episodic storm events; (2) small-scale intraformational cycles can be identified within the upper portion of the Corryville Member; and (3) lithologic trends and horizons within the Corryville section are laterally persistent and can be used for the purpose of correlation. The Corryville interval represents a distinct, heterogeneous lithofacies that can be differentiated from the Mt. Auburn and Bellevue Members by mean shale percentage, dominant carbonate texture, faunal composition, and dominant bedding style. Further implications of the sedimentology and stratigraphy, including possible depositional mechanisms, will be discussed in the final comprehensive interpretation section.

Storm Deposition

Corryville deposition was affected by periodic, large-scale, high-energy storm events, as indicated by the abundance of storm event beds and diagnostic storm-related sedimentary features. Evidence supporting high energy storm deposition includes tool marks, gutter casts, erosive bedding surfaces, rip-up clasts, normal grading, oriented fossil material, amalgamated beds, fossil lag deposits, and recognizable storm event beds. These storm features are common throughout the stratigraphic section and field study sites. Shelter porosity was common, and was presumed to have originated when shells came to rest convex-upward on the sediment surface and were buried rapidly (Kreisa and Bambach, 1982; Brett and Baird, 1986). Gutter casts, channel-like scour and fill structures, were most likely formed by aligned threads of secondary or helical offshore storm flow (Jennette and Pryor, in press). An examination of the physical structure of gutter casts suggests that a relatively short lapse of time occurred between the scour and fill events (Goldring and Aigner, 1982). The thick shales, planar bedding, abundant packstones and arenaceous calcisiltites, and well-preserved tempestites are similar to bedding reported from other storm-dominated, epeiric sea environments (e.g. Norris, 1986; Parsons et al., 1988).

The exceptional preservation of the graded storm-related deposits, skeletal materials, and associated trace fossils strongly supports Tobin's (1982) interpretation of the Corryville Member as a deeper water environment below normal wave base, but above storm wave base. Infiltration fabrics within packstones are evidence of episodic high energy events that have occurred in a normally low energy environment (Kreisa and Bambach, 1982). The presence of abundant carbonate matrix suggests minimal to no reworking of storm deposited packstones and wackestones. Fürsich (1982) recognized two types of storm effects: those that introduced sediment by bed-load transport, and those that did not introduce sediment, but instead reworked the storm sediments already present at the bottom. Within the Corryville interval, the first type is exemplified by the abundant calcisiltites, arenaceous calcisiltites, and the graded tempestites, at least in the final event. The second type corresponds to the less common grainstones and amalgamated beds that display the effects of several episodes of winnowing, reworking, and possibly transport. The dominance of preserved single event beds agrees with the assertion that the fairweather energy level was low.

The lack of bioturbation, high degree of parallelism, and absence of body fossils within most Cincinnatian shales has been used as evidence to suggest that deposition of muds was at times rapid (Tobin and Pryor, 1981; Jennette and

Pryor, in press). Corryville shales display some evidence of storm deposition, including packages of graded bedding, thin limestone and silt lenses, and discrete fossil-rich horizons within shale layers (e.g. "trilobite shales", Brandt Velbel, 1985). Thick shale intervals can contain several of these features, and this suggests that these "beds" actually represent several discrete, low energy depositional events. Thin fossil stringers within the shales occurred when there was less material to be worked into a large shell bed or when the storm energy is too low to form shell beds (cf. Norris, 1986), especially in distal settings (Jennette and Pryor, in press). Sole marks at the base of tempestites imply that the shale was well enough indurated for scouring to occur and to be preserved. Similarly, rare rip-up mud clasts within the limestone reflect the erosion and reworking of the at least partially lithified shale beds by high energy storm events (cf. Norris, 1986; Jennette and Pryor, in press).

Seaward flowing gradient currents were responsible for the transport of materials offshore from proximal to distal environments (cf. Jennette and Pryor, in press), physical scour structures resulting from these currents can indicate the offshore direction. Groove casts, megaripples, and gutter casts from the Kope through Bellevue sequence indicate that storm flow in was generally directed downramp and to the north (Hofmann, 1966b; Meyer et al., 1981; Schumacher, 1984; Jennette, 1986; Jennette and Pryor, in press). In the Corryville interval, these sedimentary structures were relatively scarce, and several prominent current-related sedimentary structures, such as microripples, low-angle cross lamination, and climbing wave-ripple lamination, were absent. Small-scale hummocky cross-stratification was less common than planar lamination, and it is possible that the effects of unidirectional currents were more dominant than wave currents (cf. Jennette and Pryor, in press). Tool mark and gutter cast orientations varied from 240° to 315°, a NW/W orientation similar to that reported by Tobin (1982). Tobin (1982, p. 223), believed that the slope of the carbonate ramp was less steep during the Corryville time than for the Kope through Bellevue time.

While the details of the Corryville Lagerstätten will be discussed in the taphonomy chapter, it is important to note here that these death assemblages have been attributed to either rapid episodes of sediment influx (Brandt, 1980b; Meyer et al, 1981; Schumacher, 1984; Meyer, 1990) or storm-related unidirectional density currents (Meyer et al, 1981; Schumacher, 1984). That the Lagerstätten have been preserved from the effects of exhumation, secondary reworking, scavenging, and bioturbation can be considered further evidence that the Corryville Member was normally a lower energy, deeper water environment. Deep burial may account for the preservation from biological effects, but an environment of normally higher energy would most likely have excavated the accumulated muds above the smothered deposit. Brett and Seilacher (1991) stated that the preservation potential and the probability of occurrence of smothering (obrution) deposits increases downslope and in deeper water, particularly within the distal facies beyond storm wave base.

Corryville Cyclicity

Small-scale Corryville cycles were reexamined in terms of the proximality concept (Aigner 1982,1985) and with the proximality criteria that Jennette (1986) and Jennette and Pryor (in press) used to define small-scale cycles within the underlying Kope and Fairview Formations. Tobin (1982) recognized 1.09 m-thick megacycles within the Corryville interval and inferred that the entire unit consisted of these stacked, asymmetric transgressive cycles. In contrast, this investigation has found that the vertical thickness of small-scale

Corryville cycles varied from 1 m to slightly greater than 3 m, and that cycles were clearly observed only within the upper 9.5 m of section. Zone 2, Zone 3, and the four stacked sequences of Zone 4 are here interpreted as small-scale, regressive bedding sequences. In this instance, the terms "cycle" and "bedding sequence" (after Jennette and Pryor, in press) are synonymous and will hereafter be used interchangeably to describe the same depositional phenomena. A depositional mechanism for these cycles will be presented in the final discussion section.

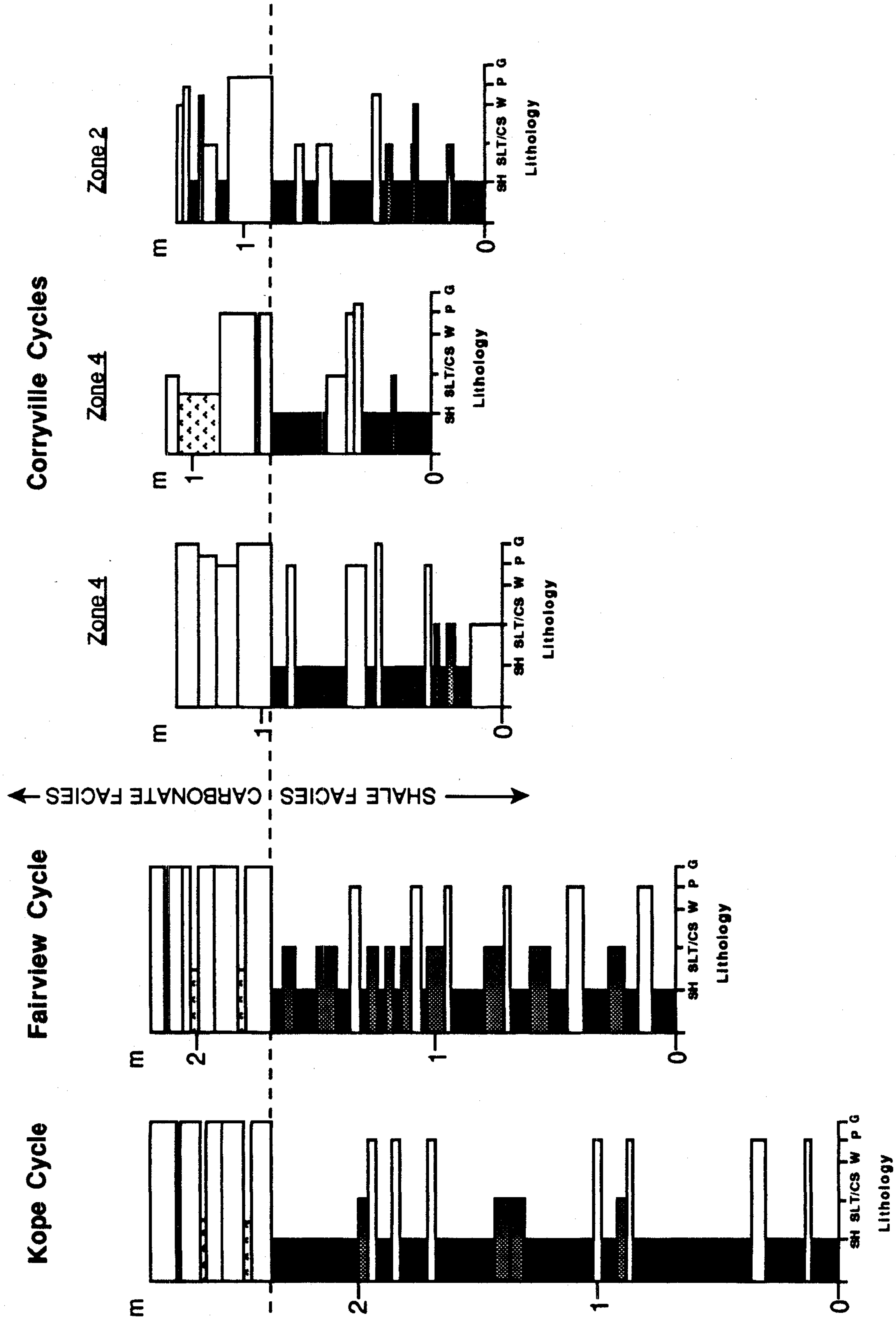
Each cycle is composed of two distinct subfacies, a carbonate-dominated (proximal) facies and a shale-dominated (distal) facies (Fig. 23). The stratigraphic order of these facies remains the subject of debate; whether they represent transgressive or regressive sedimentation could not be readily determined by this study because of the absence of a transitional facies. However, recent workers (Diekmeyer, 1992; Holland, 1992) have gravitated towards the regressive model of Jennette and Pryor (in press), and for the sake of consistency, this investigation follows suit. The appeal of the Jennette and Pryor interpretation is three-fold: (1) it is concordant with the larger shoaling-upwards Cincinnatian cycles; (2) the asymmetry and character of the cycles fits well with their proposed glacio-eustatic depositional mechanism; and (3) the bedding sequences compare favorably with those from similar storm-dominated epeiric sea environments (e.g. Aigner, 1985).

Given that the carbonate facies overlies the shale facies, then the lithology and sedimentary features of each Corryville bedding sequence reflect an increase in environmental energy and frequency of storm reworking over time. General upward trends within a bedding sequence include: (1) the thickening of individual beds; (2) an increase in amalgamated beds; (3) an increase in grainstones; (4) an increase in fossiliferous shales; (5) a decrease in finergrained beds (arenaceous calcisiltites, calcisiltites); (6) a decrease in shale thickness; (7) a decrease in bioturbation; and (8) a shift from planar and wavy to planar and irregular bedding contacts. These patterns follow proximality trends observed in modern environments (e.g. Aigner, 1985). The dichotomous nature of Corryville bedding sequences is less distinct than that of the underlying cycles of the upper Kope and Fairview Formations (see Jennette and Pryor, in press), and this may reflect less pronounced extremes in environmental energy and water depth. Corryville cycles typically contain a more variable carbonate facies and a vertically thinner shale facies than other described Cincinnatian cycles (Fig. 34). Unlike upper Kope cycles, Corryville cycles are not uniform and do not vary in predictable fashion (e.g. decreasing thickness upsection).

The base of each bedding sequence is an interval dominated by terrigenous shales, and this reflects deposition in a distal setting. The thick shale beds may contain several graded sequences and so represent several preserved low energy storm events. The thin (3 cm average) and continuous carbonate beds contain comparatively little fossil material, display normal grading, tool marks, basal fossil lags, planar lamination, and *Chondrites.*, and appear to be distal tempestites that each represent a single depositional event. Bryozoan colonies can be recovered from the shales, and fossil materials within the arenaceous calcisiltites and shales have been interpreted as allochthonous (cf. Westrop, 1986; Jennette and Pryor, in press).

The carbonate facies represents a shift to a more proximal, higher energy environment, probably at or just below normal wave base (Kreisa, 1981b; Aigner, 1985; Jennette, 1986; Jennette and Pryor, in press). The preservation of this facies implies that Corryville Member sediments were deposited even during periods marked by relatively lower sea levels. This facies is typically composed of closely-spaced proximal tempestites and fossiliferous shales (the

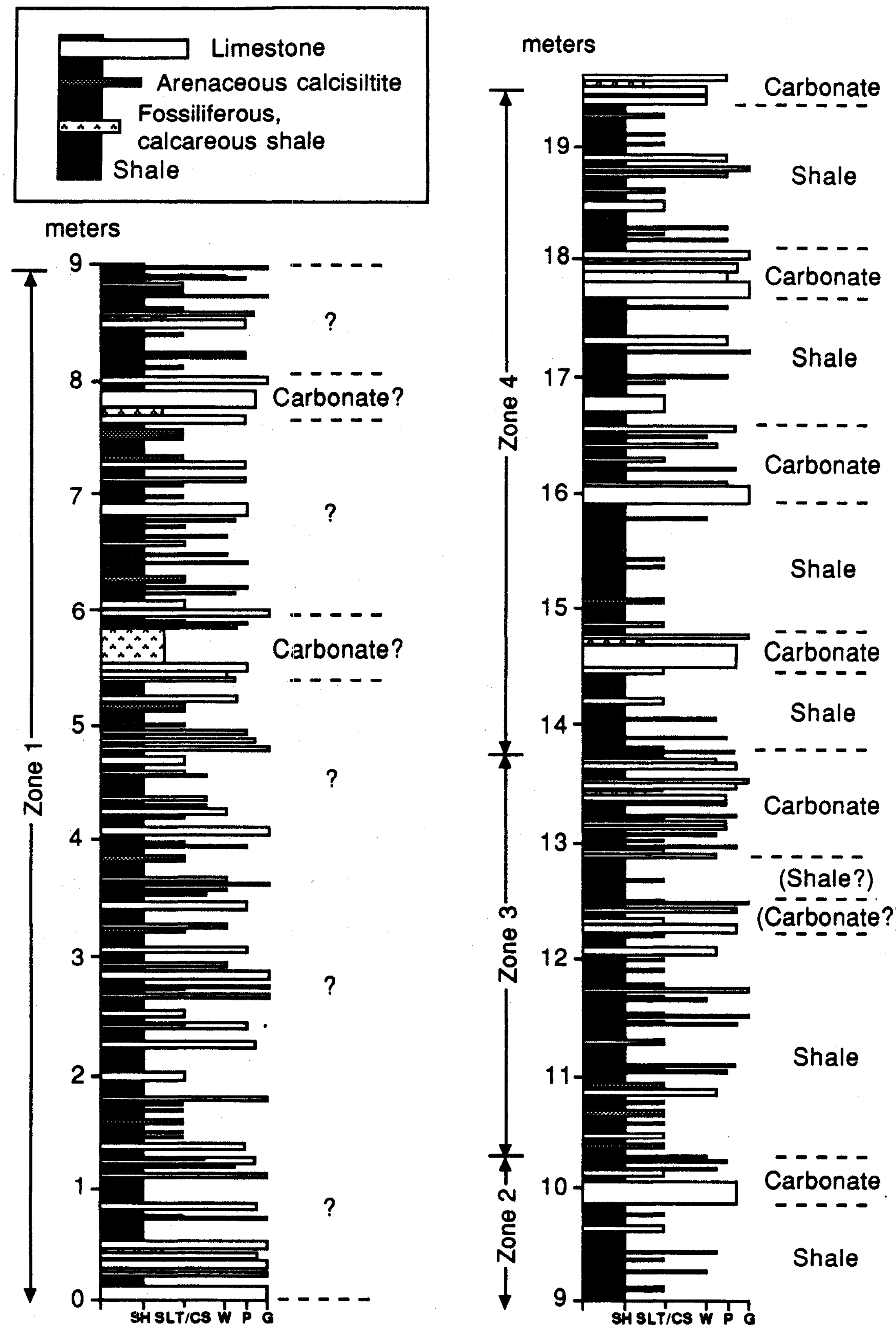
Figure 34 - Comparison of small-scale cycles from the Kope Formation (modified from Jennette, 1986), the Fairview Formation (modified from Jennette, 1986), and the Corryville Member of the Grant Lake Formation. See Figure 24 for key of stratigraphic section.


Kope Cycle
Fairview Cycle
Corryville Cycles
Zone 4
Zone 4
Zone 2
CARBONATE FACIES
SHALE FACIES
m
0
1
2
SH SLT/CS W P G
Lithology

"bioclastic silts" of Holland, 1992) that display amalgamation, rip-up clasts, chaotic shell orientation, discontinuous shale interbeds, planar or irregular bedding surfaces, and varying amounts of sorting, breakage, and matrix. Calcisiltites, arenaceous calcisiltites, and sparsely fossiliferous shales can be seen within the carbonate facies, and these may simply reflect a storm events of comparatively lower intensity. Corryville carbonate facies are more resistant to weathering and are similar to the "grainstone ledges" of the upper Kope and Fairview Formations (Jennette, 1986; Jennette and Pryor, in press). The contact with the underlying distal facies is commonly sharp.

It is important to note that these cycles are present only within the upper 10.5 m of the Corryville interval at Stonelick Creek (Fig. 35). The absence of identifiable cycles within the lower 9.0 m of section (Zone 1) should not promote the assumption that cyclic depositional processes were inactive at that time, but may in fact be a function of reduced preservational conditions. Interestingly, the sedimentologic and taphonomic characteristics of the three IBHs of Zone 1 are physically similar to those observed in the carbonate facies. These horizons lack an underlying shale facies at Stonelick Creek and cannot be unequivocally interpreted as carbonate facies. However, an examination of the "distal" transect core reveals what appear to be two bedding sequences, each approximately 2 m thick, in the same stratigraphic interval of Zone 1 (see 9.5-13.5 m of Core 868, Appendix 2). The lower 5.0 m of Zone 1 in Core 868 still contains no bedding sequences. In this core, the lower IBH is sandwiched between two shale-rich intervals, and this would suggest that at least the lowest IBH is indeed the carbonate facies of a cycle. The surrounding shale facies were therefore preserved only within the distal ramp settings, a trend predicted by ramp proximality relationships (Aigner 1982, 1985). Further study of "distal"

Figure 35 - Placement of cycle facies within the composite Corryville section from Stonelick Creek, Clermont County, Ohio. Cycles cannot be clearly differentiated within Zone 1.


Limestone
Arenaceous calcisiltite
Fossiliferous, calcareous shale
Shale
meters
Carbonate?
Carbonate?
Zone 1
SH SLT/CS W P G
meters
Carbonate
Shale
Carbonate
Shale
Carbonate
Shale
Carbonate
Shale
Carbonate
(Shale?)
(Carbonate?)
Shale
Carbonate
Shale
Zone 4
Zone 3
Zone 2
SH SLT/CS W P G

cores and surface exposures needs to be completed for verification of these cycles.

Lateral Persistence of Stratigraphic Trends

A lack of large exposures has been the primary obstacle to regional correlation of the Corryville Member. This study has shown to a limited extent that systematic intraformational variations in shale percentage and dominant carbonate lithology are a potentially valuable stratigraphic tool in both the surface and subsurface. The lateral persistence of the four "zones" and the accuracy of their stratigraphic placement are strong evidence that these patterns are continuous, regional phenomena.

Many of the proximality relationships predicted along a shallow carbonate ramp were reflected within the cross-section of this study (Fig. 32; Table 3). For example, the shale-rich Zone 2 increased in thickness and mean shale percentage to the northwest, the inferred distal and downramp direction. In Zone 1, there was no appreciable change in thickness along the transect, but the mean shale percentage did decrease to the south (upramp) as expected. Core 2623 had thinner shale beds and more limestones than any of the other sections, trends consistent with more proximal deposition (Aigner, 1985; Norris, 1986). These proximality trends may be of limited utility for correlation into the Grant Lake Limestone, however, because the shale facies thin and lose their character, the arenaceous calcisiltites disappear, and the limestones all adopt the appearance of proximal tempestites. The relatively deeper conditions of the Grant Lake Formation appear to have been better for the preservation of distal tempestites and small-scale cycles.

As with the stratigraphic "zones", the Corryville cycles are recognizable within the study area and arguably represent widespread changes in depositional energy and conditions. Unlike many of the cycles within the Kope-Fairview transition zone, Corryville cycles display a non-repetitive stratigraphic order and are of widely varying thickness and character. The Corryville cycles are best resolved to the northwest, as seen in Core 868 (Appendix 2) and in Tobin's (1982, Appendix 3) Rumpke Landfill section to the northwest of Cincinnati, Ohio. Ideally, cycles could be used to estimate the relative stratigraphic position of isolated Corryville Member exposures throughout southwestern Ohio, in particular those exposures that lack apparent unit contacts. Caution should be exercised when dealing with cycles of less than a meter in thickness because several of the smaller bedding sequences within Zone 4 did not display a strong signature on the mean shale percentage logs. Perhaps if logs were developed using a running average based on a half meter of section rather than a meter, the resolution would be high enough for the recognition of every cycle.

Event stratigraphy, which uses continuous tempestites and isochronous horizons that display a unique sedimentologic, paleontologic, or taphonomic signature, might result in a greater stratigraphic resolution (Aigner, 1982). No isochronous event beds were discovered through the course of this investigation, but they could be present within the upper portion of the Corryville Member, where cycles were pronounced and bedding was more continuous. Individual tempestites are probably difficult to trace for long lateral distances as the proximal portion of the layer is bounded by an erosional zone and the distal portion is thinned by a lack of sediment supply (Seilacher and Aigner, 1991; Aigner, 1982). The "10 meter bed", for example, was prominent at Stonelick Creek, but appeared to split into several smaller, stratigraphically equivalent beds in the more distal ramp setting to the northwest. Conversely, the IBHs were correlatable throughout the study area, but these probably did not represent single event deposits. Unlike the gutter cast marker bed of the upper Kope Formation (Jennette, 1986, p. 108; Jennette and Pryor, in press), each IBH was composed of several separate, discontinuous beds that displayed evidence of multiple episodes of reworking and amalgamation. Jennette and Pryor (in press) stated that bedding cycle tops in the upper Kope and Fairview Formations represent isochronous time lines, and this may also hold true for the Corryville cycles.

The presence of systematic stratigraphic variation within the Corryville Member necessitates a revised approach to the regional correlation of this interval. Previous studies (Tobin, 1982; Schumacher et al., 1991; Holland, 1992) have assumed that the Corryville facies was fairly homogeneous in lithology and so have made assumptions concerning the total thickness, shale content, and lithology of the Corryville Member from partial field exposures not representative of the entire Corryville interval. For instance, Tobin (1982) studied only partial upper Corryville Member exposures within the Cincinnati area (Blue Rock Road, Middletown), and his conclusions concerning limestone abundance and megacycle distribution do not reflect realistic trends. Unless the relative stratigraphic position of an exposure can be determined, the stratigraphic description of the Corryville Member must not rely solely upon partial field exposures. The use of core data with the complete Corryville Member is more reliable and preferable.

Conclusions

1) The Corryville Member is a single shale-rich (63% regional average) facies that contains abundant storm-deposited packstones, calcisiltites, and arenaceous calcisiltites. Shales are terrigenous and sparsely fossiliferous, and beds are continuous to discontinuous and planar. Eight carbonate lithotypes were identified from the Corryville interval, all of which display diagnostic storm-related sedimentary features.

2) The thickness and mean shale percentage of the Corryville Member vary geographically as predicted by proximality relationships. Both increase to the north and northwest, the distal portions of the inferred paleoramp slope.

3) The Corryville interval is stratigraphically heterogeneous, and variations in mean shale percentage, bedding character, and dominant carbonate lithotype can be used to divide the unit into four informal subunits, or zones. The zones are laterally persistent and can be used to correlate local and distant field exposures and rock cores.

4) This investigation has recognized small-scale bedding sequences within the upper half of the Corryville unit and interpreted them in the context of proximality trends as regressive cycles. Each cycle is composed of a lower shale facies and upper carbonate facies that differ in shale content, carbonate lithotype, bedding character, and thickness.

FAUNAL DISTRIBUTION AND PALEOECOLOGY

Introduction

Recent work in the area of southwestern Ohio (Hay, 1981; Tobin, 1982; Schumacher et al., 1991) has done much to clarify the regional lithofacies relationships and depositional trends associated with the strata of the Cincinnatian Series. Only within the past few years has the same thorough approach been adopted for the quantitative examination of Cincinnatian faunal distribution trends (e.g. Anstey and Rabbio, 1989; Diekmeyer, 1990, 1992). The rich fauna of the Corryville Member of the Grant Lake Formation has been well collected by academic and amateur fossil enthusiasts, but little has been done to describe the distributional patterns within this unit. The Corryville Member has most recently been interpreted as the transgressive phase of a large-scale shoaling upward cycle (Tobin, 1982), and a study of the paleoecology of this interval can address questions concerning the temporal response of the benthic fauna to this significant environmental shift. The identification of range-restricted species and biologic event horizons can aid regional correlation and further the chronostratigraphic resolution of this interval.

On the basis of lithology and faunal morphology, Tobin (1982) described the Corryville facies as a deeper-water, low energy environment episodically disrupted by high energy storm events. In this distal environment, preservation of skeletal materials was most likely dependent upon a rapid burial and removal from the destructive effects of dissolution (Fürsich, 1978; Davies et al., 1989). The non-preservable component (soft-bodied organisms) and much of the preservable component (organisms with hard-parts) of the living benthic community disappeared soon after death (Cummins et al., 1986), and ecologically significant processes such as faunal succession were not likely to have been preserved after storm processes (Schindel, 1980; Westrop, 1986; Diekmeyer, 1990). However, if the Corryville Member was a "low" energy environment characterized by a lack of regular post-storm lateral mixing, bioturbation, and resuspension of sediments, fossil preservation should have been enhanced; the undisturbed distal tempestites should reflect the preservable component of the original prestorm community. If the storm processes were constant throughout the period of Corryville deposition, then changes in the fossil biota of this unit over time would more likely reflect an ecological mechanism than a diagenetic or sedimentologic overprint.

Diekmeyer (1990, 1992) established a connection between small-scale regressive bedding sequences and systematic variations in community structure within the upper Kope Formation of the Cincinnatian Series. The presence of small-scale cyclicity in the Corryville Member (Tobin, 1982) suggests that the depositional dynamics were variable and complex and may have affected macrofaunal distribution patterns. Distal tempestites, such as are common within the Corryville interval, offer paleontologists an excellent opportunity to examine autochthonous or parautochthonous fossil assemblages (Lehman and Pope, 1989). More proximal tempestites, however, contain sedimentary features that imply increased amounts of reworking and transport (Aigner, 1985; Jennette, 1986; Jennette and Pryor, in press), and these could alter the diversity of fossil assemblages over time. Variations in faunal distribution within the vertical section will be examined to determine if they reflect predicted stratigraphic trends and associated physical biases or instead must be explained by ecological processes such as short-term ecologic succession. A biological response will differ with episodic and gradual sedimentation rates and this can be used to gauge time and the time frame of depositional processes.

A study of macrofaunal distribution will establish if the Corryville fauna represents a single biofacies (or paleocommunity) and the range of variability encompassed by that ecological unit. This investigation will describe the composition of the Corryville fossil assemblages through fine scale sampling and computer-based multivariate analytic techniques. Multivariate analysis can help to emphasize environmental parameters (e.g. salinity, oxygen content, temperature) that will alter faunal distribution but will leave no recognizable sedimentologic signal (Springer and Bambach, 1985). Previous studies of the Corryville Member have been hampered by a lack of complete and laterally extensive exposures, and this thesis will circumvent that obstacle by using a tightly-correlated composite section from along Stonelick Creek in Clermont County, Ohio. A faunal census of the Corryville Member will be taken based upon samples collected at closely-spaced, vertical stratigraphic intervals. This investigation will seek to address the question of whether distributional trends reflect taphonomic processes or some ecological response to environmental changes.

Previous Work

Paleocommunities and community succession

An examination of faunal distribution necessitates a review of the processes by which skeletal assemblages were formed, including an understanding of the original ecological relationships of the component taxa. Since the advent of community paleoecology, there has been considerable debate over the formal definition of the term "community" as it applies to the fossil record (Cisne and Rabe, 1978; Springer and Miller, 1990). Because skeletal assemblages typically contain only the preservable component of the original biocoenosis, paleocommunities cannot be defined with the same criteria used to define modern communities (Walker and Bambach, 1973; Boucot, 1981; Dodd and Stanton, 1981). Past studies of fossil assemblages have advanced community definitions that emphasized one or a combination of the following factors: faunal interdependence, the presence of recurring, numerically common species, and specificity of habitat or geographic location (Boucot, 1981). Bretsky (1970) broadly described a community as "an association of recurring species that are numerically dominant and show some relationship to a physical environment or environmental parameter". This definition allows for the reconstruction of skeletal-based paleocommunities in relation to lithofacies patterns that can be confirmed through quantitative methods. Bretsky's (1970) definition is accepted for this thesis when referring to fossil communities.

Community succession, the more or less orderly changes in a community in a particular area through time, has been invoked as an important process in the formation of diverse fossil assemblages (Walker and Laporte, 1970; Walker and Alberstadt, 1975; Hinterlong, 1981; Walker and Diehl, 1986). According to Walker and Alberstadt (1975), community succession resulted from both physical (allogenic) and biological (autogenic) controls and operated repeatedly within certain stratigraphic sequences (Walker and Alberstadt, 1975). "Short-term" community succession was common in unstable environments where the community structure was frequently destroyed by episodic, allogenic sedimentation and then rapidly re-established in an autogenic progression from the low-diversity pioneer stage to the mature (or climax) community stage (Walker and Alberstadt, 1975; Fürsich, 1978; Harrison and Mahan, 1981, Fig. 9). This process may have occurred at a rate of tens of years or less (Miller et al., 1988), and the resulting community was a diverse collection of tiered, epifaunal organisms (Richards, 1972; Harrison and Mahan, 1981; Ausich and Bottjer, 1982).

Walker and Diehl (1986) argued that succession was not a simple process and that syndepositional marine sedimentation, increasing substrate complexity, and post-depositional sediment dewatering had a pronounced effect on community development. Kidwell and Jablonski (1983 and Kidwell, 1986), suggested that the composition and dynamics of a benthic community could also be affected by the biological or physical accumulation of dead, discarded hardparts along the sea bottom ("taphonomic feedback"). Shell material substantially increased the complexity and stability of the substrate and allowed new species to migrate into the environment to the exclusion of earlier infaunal colonizers (Kidwell, 1986).

In the Late Ordovician Cincinnatian epeiric sea, succession occurred repeatedly and often proceeded beyond initial colonization stages to produce diverse fossil assemblages (Harris and Martin, 1979; Krumpolz, 1980; Harrison and Mahan, 1981; Hinterlong, 1981; Brandt, 1989). Many authors (Harrison and Mahan, 1981; Walker and Diehl, 1986) believe that Cincinnatian environmental and substratal conditions were patchy and that colonies generally graded into uninhabited sedimentary surfaces. Cincinnatian pioneer communities consisted of flat opportunistic brachiopods (commonly strophomenids) adapted to muddy environments (Harrison and Mahan, 1981; Hinterlong, 1981). Once the post-mortal accumulations of these pioneering species had accumulated and eventually stabilized the substrate, encrusting and ramose bryozoans migrated into the community, trapping sediment and eventually adding to the accumulation of skeletal debris (Harrison and Mahan, 1981). According to Ausich and Bottjer (1982), the mature Late Ordovician soft-bottom epifaunal community consisted of three tiers: (1) a 5 cm tier for organisms feeding in the water close to the sediment-water interface (brachiopods, bryozoans, echinoderms, mollusks); (2) a 10 cm tier (bryozoans, crinoids, graptolites); and (3) at least a 50 cm tier (crinoids).

Bias in the faunal record

Biological, physical, and diagenetic biases can distort the faunal distribution, and a proper paleoecological interpretation must include a critical appraisal of all recognized and potential bias. Biological bias can result from the differing generational timing of component species and from short-term variability of species populations (Peterson, 1977). In large-scale systems, such as in shelf settings or carbonate ramps, trophic structure, diversity, size distribution, and relative abundances of species can vary in a spatially complex manner (Norris, 1986). Physically induced biases include differential erosion, selective hardpart destruction, transportation and sorting effects, mixing of indigenous and exotic elements, time averaging, and diagenetic effects (Johnson, 1960; Peterson, 1977; Aigner, 1982; Westrop, 1986; Davies et al., 1989). Several investigations have shown that the relative abundance of brachiopods can be altered by differential valve breakage (Sheehan, 1978; Holland, 1988; Velbel and Brandt, 1989). Early and late diagenetic processes can lower levels of diversity by selectively removing specific taxa (Kreisa and Bambach, 1982; Davies et al., 1989). The aragonitic shells of pelecypods and gastropods are often preferentially dissolved in early diagenesis, followed by calcitic shells, high-magnesium calcite echinoderm ossicles, and lastly apatitic (phosphatic) skeletal remains (Seilacher, 1982).

Storm events act to modify the fossil record and may cause a preservational bias within storm reworked sediments (Kreisa and Bambach, 1982; Westrop, 1986). Proximality gradients along a platform or shelf will affect the type and condition of hardparts found within a storm deposit (Aigner, 1985). In many storm beds, macrofossils appear to have been winnowed but relatively untransported (Kreisa and Bambach, 1982; Westrop, 1986). These reworked beds reflect the community structure over a long period of time and can be considered as a "time lapsed" view of succession (Schindel, 1980; Parsons et al., 1988). Time-averaging and amalgamation can potentially increase the diversity of a bed, especially with increased bioturbation, colonization, and amalgamation (Walker and Bambach, 1973; Norris, 1986; Miller et al., 1988). In Devonian epeiric sea sediments of the Hamilton Group in New York, Miller et al. (1988) found a positive relationship between the variety of storm effects and the benthic fossil diversity, and they believed that storm deposition controlled the degree of potential realized for community growth.

One method that has been used effectively to detect the presence of bias in the faunal record is quantitative multivariate analysis (Gauch, 1982). The primary purpose of multivariate analysis is to treat complex faunal data as a whole that can be summarized and then examined objectively for similarity relationships, community structure, and faunal distribution patterns within a vertical stratigraphic section or along an environmental gradient (e.g. Osborne, 1969; Cisne and Rabe, 1978; McGhee and Sutton, 1981; Springer and Bambach; 1985; Miller, 1988; Meyer et al., 1989; Miller et al., 1992). Quantitative methods are preferable in terms of speed and detail, and the results can be displayed graphically to assist interpretation. Diekmeyer (1990,

1992) used cluster analysis and polar ordination to demonstrate that the facies progression of the Cincinnatian Kope to Bellevue sequence was accompanied by quantifiable changes in the faunal assemblage.

Corryville Paleontology

The Corryville Member is well-known for its abundant, diverse, and exceptionally preserved open-marine fauna. The Corryville Member has been lauded as the richest and most interesting of all the fossil horizons in the Cincinnati area (Kerr, 1951; Caster, 1952; Caster and Macke, 1952; Caster et al., 1955; Hinterlong, 1981; Schumacher, 1984), and aspects of its paleoecology have been examined in several taphonomic studies (Brandt, 1980a; Hinterlong, 1981; Meyer et al., 1981; Schumacher, 1984; Meyer, 1990) and autecological and/or systematic studies (e.g. Caster, 1952; Caster and Macke, 1952; Osgood, 1970; Morris and Rollins, 1971; Bell, 1972; Richards, 1972; Alexander, 1975). The taxonomy of the Corryville Member, however, has not been directly addressed since the original faunal descriptions and is in need of serious revision. The purpose of this section is to provide a current summary of the known Corryville fauna (see Appendix 4 for the faunal list).

The macro-invertebrate fauna includes articulate and inarticulate brachiopods, trepostome bryozoans, pelecypods, gastropods, trilobites, orthoconic nautiloids, crinoids, and other echinoderms. Pelecypods were dominantly endobyssate and epibyssate, with shallow infaunal, endobyssate, and epifaunal reclining filter feeders and infaunal palp-probiscide deposit feeders (Frey, 1987a). The most abundant skeletal materials in the Corryville Member of the Grant Lake Formation are trilobite fragments (*Flexicalymene* and *Isotelus*), crinoid columnals, ramose bryozoan fragments, pelecypod molds, and articulated to fragmented brachiopod valves (*Rafinesquina, Zygospira*, and *Plectorthis*). Several species of *Rafinesquina*, including *Rafinesquina alternata*, may be present within the Corryville strata (see Van Fossen, 1951), but because this thesis will not address species-level taxonomic variation, the genus will simply be referred to as "*Rafinesquina*". *Rafinesquina nasuta*, an easily differentiated species, will be referred to by species when pertinent. Microfossils present within the Corryville Member include ostracods, conodonts, and scolecodonts. These comprise a minor component of the faunal assemblage and tend to be less well-preserved. The Corryville Member falls stratigraphically within the *Amorphognathus ordovicicus* conodont Zone and the *Amplexograptus gracilis* graptolite Zone, but the stratigraphic boundaries for these Zones are not well-defined (Bergström and Mitchell, 1986).

Less common within the fauna are conularids, *Cornulites*, graptolites, and fenestrate bryozoans. The species *Rafinesquina nasuta* is found primarily within the Corryville Member and has been cited as a useful index fossil for the interval (Carpenter and Ory, 1961). Unique to the Corryville Member are rare echinoderms, including edrioasteroids (Pojeta, 1971; Bell, 1972), asteroids (Dalvé, 1948; Schumacher, 1984), the carpoid *Enoploura popei* (Caster, 1952), and the only known Cincinnatian and post-Cambrian aglaspid merostome *Neostrabops martini* (Caster and Macke, 1952). *E. popei* and *N. martini* are known only from Corryville beds. Reference to Corryville sponges, stromatoporoids, hyolithids, cyclocystoids, and a cystoid (all from Dalvé, 1948) could not be verified. Representative specimens of such Corryville taxa could not be found within the University of Cincinnati fossil collections. In light of the lengthy and thorough collection history for this Cincinnatian unit, the probability that these species were indeed discovered from the Corryville Member should not be dismissed.

Ichnofossils and escape structures are present and abundant throughout the Corryville interval and have been described and well documented (Osgood, 1970; Osgood, 1981). In general, Cincinnatian strata have been ascribed to the *Cruziana* ichnofacies, an inner sublittoral, well-lighted environment with abundant oxygen and nutrients (Osgood, 1981). The most common Corryville ichnospecies include *Chondrites* - "type B", *Trichophycus venosum* ("turkey tracks"), and *Diplocraterion biclavatum* (the "dumbbell" U-shaped burrow); these are frequently found in association (Osgood, 1970, p. 336; Meyer et al., 1985). *Chondrites* - "type B" is a loose group of tunnels with no preferred arrangement that intersect the "vertical plane at various attitudes" (Osgood, 1970, p. 336). *T. venosum* was once considered to be the resting trace of orthoconic cephalopods (Flower, 1955), but examination of associated striae and spreiten has raised serious doubt concerning such an origin (Osgood, 1981, p. 48). The U-shaped burrows of *Diplocraterion* were probably lived in by vermiform organisms that filtered water and nutrients through the burrow (Meyer et al., 1981).

Less common ichnofossils are *Lockeia siliquaria*, *Asteriacites stelliforme* (an asteroid impression), *Phycodes flabellum*, *Paleophycus* - "type B", *Rusophycus carleyi*, and *Rusophycus pudicum*. *R. carleyi* and *R. pudicum* have been interpreted as the resting and feeding traces of *Isotelus* and *Flexicalymene*, respectively (Osgood, 1970). One *R. carleyi* recovered from Stonelick Creek exceeded 15 cm in length (Brandt et al., 1992). *Conostichus*, a conical-shaped convex hyporelief interpreted as a sea anemone burrow (Pemberton et al., 1988), is present within the upper Corryville section. Unique to the Corryville Member are *Fascifodina floweri*, a vertical bundle of tunnel systems set in a semi-elliptical pattern, and *Palaeoscia floweri*, a series of regular to irregular concentric circles marked by a central pore (Caster, 1942;

Osgood, 1970). *P. floweri* was originally interpreted as a siphonophore trace (Caster, 1942), but subsequent study suggested that these could be "either feeding traces or the sweep marks of an agglutinated tube" (Osgood, 1970, p. 397).

Many of the well-preserved invertebrate fossils occur in association with specific event beds. These assemblages have been characterized as "fossil Lagerstätten", unique fossil deposits with a high degree of articulation that yield an unusual amount of paleontologic and taphonomic information (Meyer, et al, 1981; Seilacher et al., 1985; Meyer, 1990; Brett and Seilacher, 1991). Dense deposits of articulated crinoids (*Iocrinus subcrassus*) have been recovered from the upper Corryville Member from Blue Rock Road in Hamilton County, Ohio and from Stonelick Creek in Clermont County, Ohio (Meyer et al., 1981; Schumacher, 1984). Abundant and articulated edrioasteroids (*Isorophus, Streptaster*, and *Carneyella*) were discovered intact on the strophomenid brachiopod shells of two shell pavements in the upper portion of the Corryville Member in Florence, Kentucky (Meyer, et al, 1981; Meyer, 1990) and at Blue Rock Road in Hamilton County, Ohio (Meyer, 1990). Edrioasteroid abundance was estimated at 17-30 individuals per m^2 (Meyer, 1990). On the basis of isopachous fibrous to bladed calcite cements similar to those found in modern environments of early sedimentation, Rassmann (1981) inferred that these pavements were incipient hardgrounds.

Stonelick Creek, in particular, has been the discovery site of many of the rarest and most unusual of the Corryville taxa and ichnofossils. The holotype, and only known specimen, of *N. martini* Caster and Macke was collected at Stonelick Creek (Caster and Macke, 1952). The holotype of *Palaeoscia floweri* was also collected along the creek (Caster, 1942). All three known specimens wherein a *Flexicalymene* was found *in situ* within a *R. pudicum* burrow were discovered from the Corryville strata at Stonelick Creek (Osgood, 1970). One large *Iocrinus subcrassus* bed (over 9,000 cm^2 in area) was collected from an exposure of uppermost Corryville Member situated 1 km north of the Ohio State Route 131 bridge (Meyer et al., 1981; Schumacher, 1984). In addition to crinoid material, the assemblage of this deposit included bryozoan, brachiopod, pelecypod, cephalopod, scolecodont, graptolite and asteroid material.

Methods

Field study and Laboratory Analysis

For the examination of faunal distribution within the Corryville Member, samples were collected from the proposed Corryville Member type-section (Schumacher et al., 1991) at Stonelick Creek in Stonelick Township, Clermont County, Ohio, in the summer and fall of 1990. Thirty-six bulk samples were collected from limestone beds at Stonelick Creek exposures 1 and 2 (Fig. 14); these two stream cuts form a composite section that represents the entire Corryville interval. Shale beds were not sampled because they typically contained little to no skeletal material. Limestone samples were taken at 0.5 m intervals from a continuous vertical section beginning just above the Corryville-Bellevue Member contact to slightly below the contact with the Mt. Auburn Member. The stratigraphic location of each sample was noted and can be seen in the column descriptions in Appendix 2. The average bedding surface of each sample, regardless of bed thickness, was approximately 150 cm^2. Because of the limited width of most stream exposures (< 2 m), duplicate samples could not be collected along a single bedding plane, precluding a study of the lateral variability in faunal distribution.

In the laboratory, the lithology of each sample was determined and the macrofaunal content of each sample was examined through a dissecting microscope and tallied. When a bedding surface was hidden beneath a thin layer of silt, an air abrasive with dolomite grit was used to reveal the fossil material. All whole brachiopods, gastropods, pelecypods, and cephalopods were identified to the generic level and counted as individuals. Because many of the shells exhibited some variable amount of breakage, only individual specimens with an apex or umbo were counted. Individual counts were first completed at the exposed upper and lower bedding surfaces. Each sample was then split horizontally, and macrofossils were counted from along the split surface, a plane estimating the center of the bed. When a pelecypod, cephalopod, or gastropod was preserved as an enigmatic mold, it was listed as "unknown" for its particular taxonomic class. Although little can be said about the paleoecology or phylogeny of unidentifiable specimens such as pelecypods and gastropods, their relative frequencies were recorded. Microfossils were also noted, but taxonomic identification was limited to the most general level. Counts were considered representative and complete when the relative abundances of individuals per taxa were not significantly changed by the addition of new individuals.

Highly disarticulated and fragmented fossil material was examined separately from whole fossil material. Because colonial organisms, molting organisms, and organisms that undergo rapid post-mortem disarticulation all contribute to the accumulation of skeletal fragments, the number of individuals represented by such an accumulation is difficult, if not impossible, to determine. Therefore, disassociated skeletal material cannot be directly compared with individual specimen counts within the same sample. However, the relative abundances of all fragmented materials can be quantified for a sample and then can be compared with similar data from the other samples. To accomplish this, a point count system was utilized. A 50-point grid, with points arranged in five rows of ten with 1 cm point spacing, was photocopied onto a thin acetate sheet and then placed upon the upper and lower bedding surface of the bulk sample. Every identifiable crinoid, trilobite, and bryozoan fragment coinciding with a grid point was counted and recorded. If one bedding surface was obscured by a silt layer, counts from the measurable bedding surface were then doubled, given a uniform fossil distribution throughout the sample. Point counts were not doubled in normal graded samples where identifiable fossil material was limited to the basal portion of the bed.

Taxonomic identification of bryozoan material must be made through thin-section analysis. The emphasis of this study was to determine how the taxa as a whole responded to environmental change. Therefore, all bryozoan specimens were described as one of the five following morphologies: small ramose (diameter < 2 mm), large ramose (diameter > 2 mm), foliate, encrusting, and massive (colonies displaying near complete preservation). Ramose bryozoans were either thin and delicate or robust and thick and were subdivided to better reflect this dichotomy. For reference purposes, all sample numbers are followed with the collection height in meters from the base of the exposure. For example, 147-2 (10.73 m) means bed 147 of exposure 2, situated 10.73 m from the base of the exposure.

Multivariate Analyses

Three separate quantitative multivariate methods, cluster analysis, polar ordination, and factor analysis, were utilized to determine the similarity of the faunal assemblages within the bulk samples. The following multivariate computer programs were employed: (1) "Clap" (written by J. Sharry and J.J. Sepkoski in 1976 and modified for microcomputer by A. Miller in 1987) for cluster analysis; (2) "Polar II" (written in 1976 by J. Sharry and J.J. Sepkoski, Jr., revised in 1980 by Sepkoski, and revised in 1988 for microcomputer by A. Miller) for polar ordination; and (3) "CABFAC" (written by J.E. Klovan in 1970, updated by J.J. Sepkoski, Jr. in 1983, and modified for microcomputer use by A.I. Miller in 1988) for factor analysis.

Each multivariate analysis was carried out in the Q-mode, where the similarity among the bulk samples was measured by comparing the presence and relative abundance of the fossil taxa and taxonomic groups (the "variables") of each sample. The Unweighted Pair Group Method with Arithmetic Averaging, or UPGMA, was used for the cluster analysis (Sneath and Sokal, 1973, p. 230-234). The quantified Czekanowski's (Dice) Similarity Coefficient (Sepkoski, 1974) and Cosine θ Coefficients of Proportional Similarity (Davis, 1986) were separately run with both the cluster analysis and polar ordination. CABFAC automatically selected Cosine θ and was programmed to perform a Varimax rotation (for review see Davis, 1986, p. 556). Further details concerning the technical nature of these multivariate methods have been previously described (Sepkoski, 1981; Cisne and Rabe, 1985; Springer and Bambach, 1985; Davis, 1986; Diekmeyer, 1990; Reyment, 1991) and will not be repeated here.

The data were prepared in a uniform manner for each faunal analysis. Prior to each analysis, the individual counts of each sample were percent transformed to reduce the effects of large variations in sample size (Springer and Bambach, 1985). To do this, the number of specimens within each taxa or taxonomic group was divided by the total number of specimens within the sample and then multiplied by 100 to yield a percentage. Point counts, already out of 100, did not require transformation. In addition, a log transformation was carried out to mute any bias resulting from the abundance differences between variables that varied by as much as 2 orders of magnitude.

Thirteen species or major taxonomic groups were used as the variables for each of the 36 samples: *Rafinesquina*, *Zygospira*, *Platystrophia*, *Plectorthis*, *Onniella*, *R. nasuta*, *Cyclonema*, *Cyclora*, orthoconic nautiloids, pelecypods, bryozoans, trilobites, and crinoids. The large number of unidentifiable pelecypod molds most likely represented several separate genera, and to avoid misleading species abundances, all pelecypod counts were combined into a single category. Several taxa, including *Loxoplocus*, *Amphilichas*, *Anomalodonta*, and *Acidaspis*, were excluded from the final multivariate analysis because they were too rare to have had an appreciable role in the comparison of sample similarity. The relative scarcity of microfossil material also precludes this group from large-scale Cincinnatian paleoecologic analysis.

The results of these multivariate analyses were compared with the depositional trends established through the stratigraphic description of the entire Corryville interval.

Results

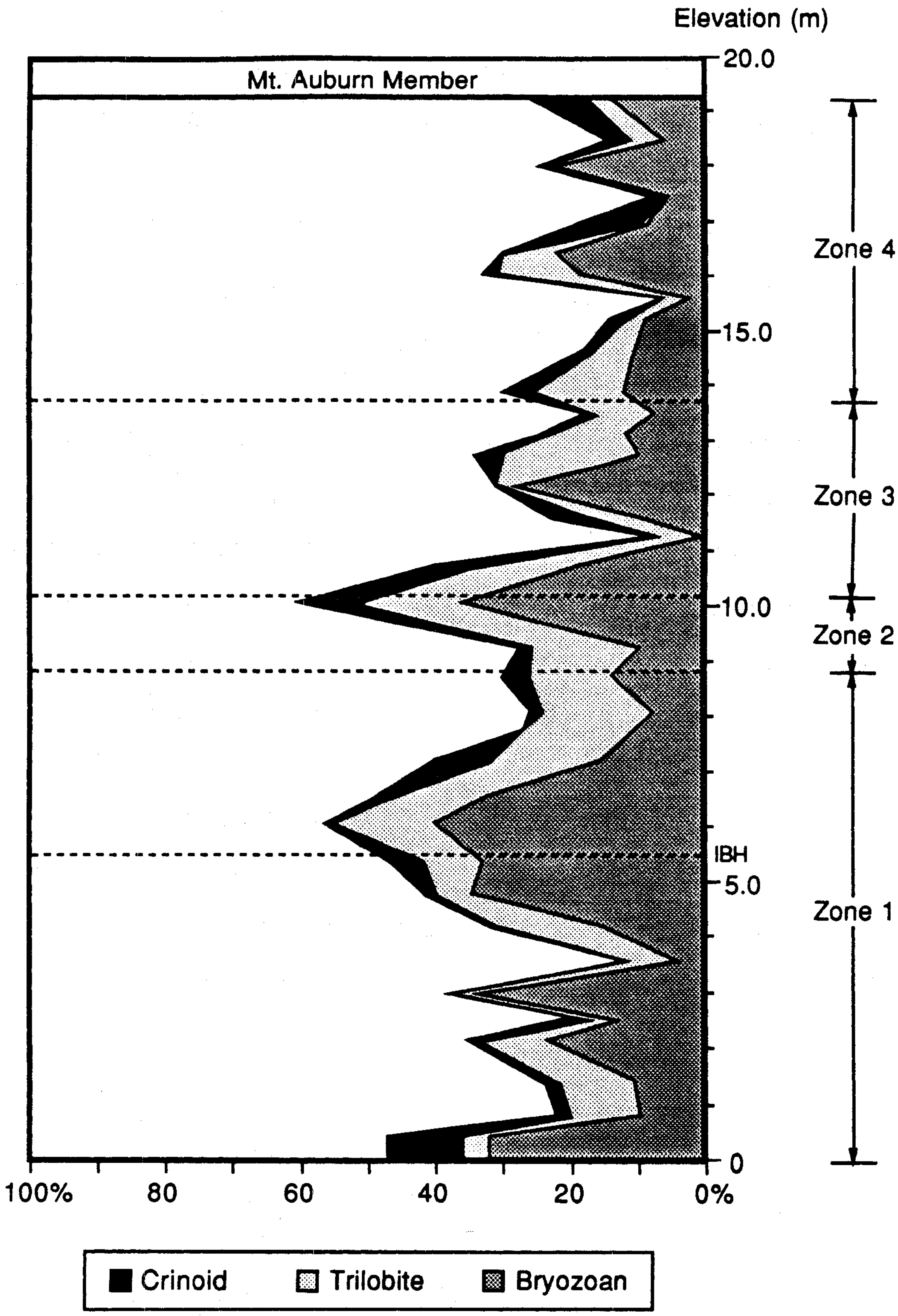
Results of the Faunal Census

The purpose of this section is to detail the more obvious macrofaunal distribution trends as seen within the bulk limestone samples. The principal outcome of the faunal census was the recognition that faunal composition remained relatively consistent throughout Corryville time. All samples were polytaxic, and most material from this study was not found articulated or in the inferred life position. Samples varied from one another primarily in the relative numbers of individuals per taxon, rather than in the relative numbers of taxa. Point count and individual count data is listed in Appendix 5. Ichnofossils will be discussed in the taphonomy section.

Bryozoan material and *Zygospira* were the only taxa or taxonomic groups observed within each sample. Taxic diversity and species richness per sample were not estimated because of the abundance of unidentifiable bryozoans and other fragments. Hinterlong (1981) found that the highest generic diversity (genera/m^2) corresponded to limestones situated within the stratigraphic center of the Corryville Member, roughly Zones 2 and 3 of this study, but this was not verified. Certain species, namely *Cyclora*, *R. nasuta*, *Plectorthis*, and *Platystrophia*, were not uniformly distributed within the section. *Cyclora* was found only in samples within the upper 5 m of the Corryville Member. *Platystrophia*, *Plectorthis*, and *R. nasuta* were restricted to the lower 9.0 m of the unit, and as a result, brachiopod diversity was lower within the upper half of the Corryville Member.

Figure 36 displays the percent relative abundance of bryozoan, trilobite, and crinoid fragments within the stratigraphic section. Bryozoan and trilobite

Figure 36 - Percent abundances of bryozoan, trilobite, and crinoid fragments throughout the Corryville stratigraphic section. Abundances were determined through point counts from bulk limestone samples. The base of the Corryville Member is set at the 0 m elevation.


Elevation (m)
20.0
Mt. Auburn Member
15.0
10.0
IBH
5.0
0
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Crinoid
Trilobite
Bryozoan

fragments were most abundant, although both were reduced in number and size in the stratigraphically highest samples. Trilobite fragments were generally isolated sclerites of *Flexicalymene* and *Isotelus*, and rarely *Amphilichas* and *Ceraurus*. Crinoid ossicles were mostly single, abraded to pristine columnals. One *Lichenocrinus* (crinoid holdfast) was discovered in the uppermost Corryville section on an upper bed surface atop a large, convex-up brachial interior valve; seven isolated gumdrop-shaped bryozoans of less than 3 mm in diameter were located adjacent to the *Lichenocrinus*. With one exception all of the intervals in Zones 2, 3, and 4 that contained comparatively low amounts of fragmented materials corresponded to the shale facies of small-scale cycles. A low point-count probably occurred at 13.5 m because the sample was an amalgamated fine packstone and wackestone, and both of these lithotypes contained mostly tiny, unidentifiable skeletal material. The other sample with a very low abundance of fossil fragments at approximately 3.6 m was a wackestone dominated by high numbers of articulated *R. nasuta*.

Six species of articulate brachiopods were identified from the Corryville Member (in descending order of abundance): *Zygospira modesta*, *Rafinesquina alternata*, *Rafinesquina nasuta*, *Plectorthis* sp., *Platystrophia* sp., and *Onniella* sp.. *Rafinesquina* and *Zygospira* were by far the most abundant taxa, although their relative amounts varied widely within the section (Fig. 37). Samples with the highest diversity of brachiopods were collected within the lower 2.0 m of section, and samples that displayed relatively high taxic diversity were collected from the 3.0 m to 9.0 m interval. *Plectorthis* reached maximum abundance at approximately 7.0 m, and *R. nasuta* was most abundant at approximately 3.5 m.

Rafinesquina were generally geniculate and alate, and specimens were comparatively small. Hinge length was measured for all complete and nearly complete *Rafinesquina* valves (Fig. 38). Confidence intervals were not

Figure 37 - Relative abundances of articulate brachiopods and pelecypods as distributed in the Corryville stratigraphic section. Pelecypods are combined into a single category that includes *Ambonychia*, *Modiolopsis*, *Caritodens*, *Anomalodonta*, and taxonomically unidentifiable molds. The base of the Corryville Member is set at the 0 m elevation.

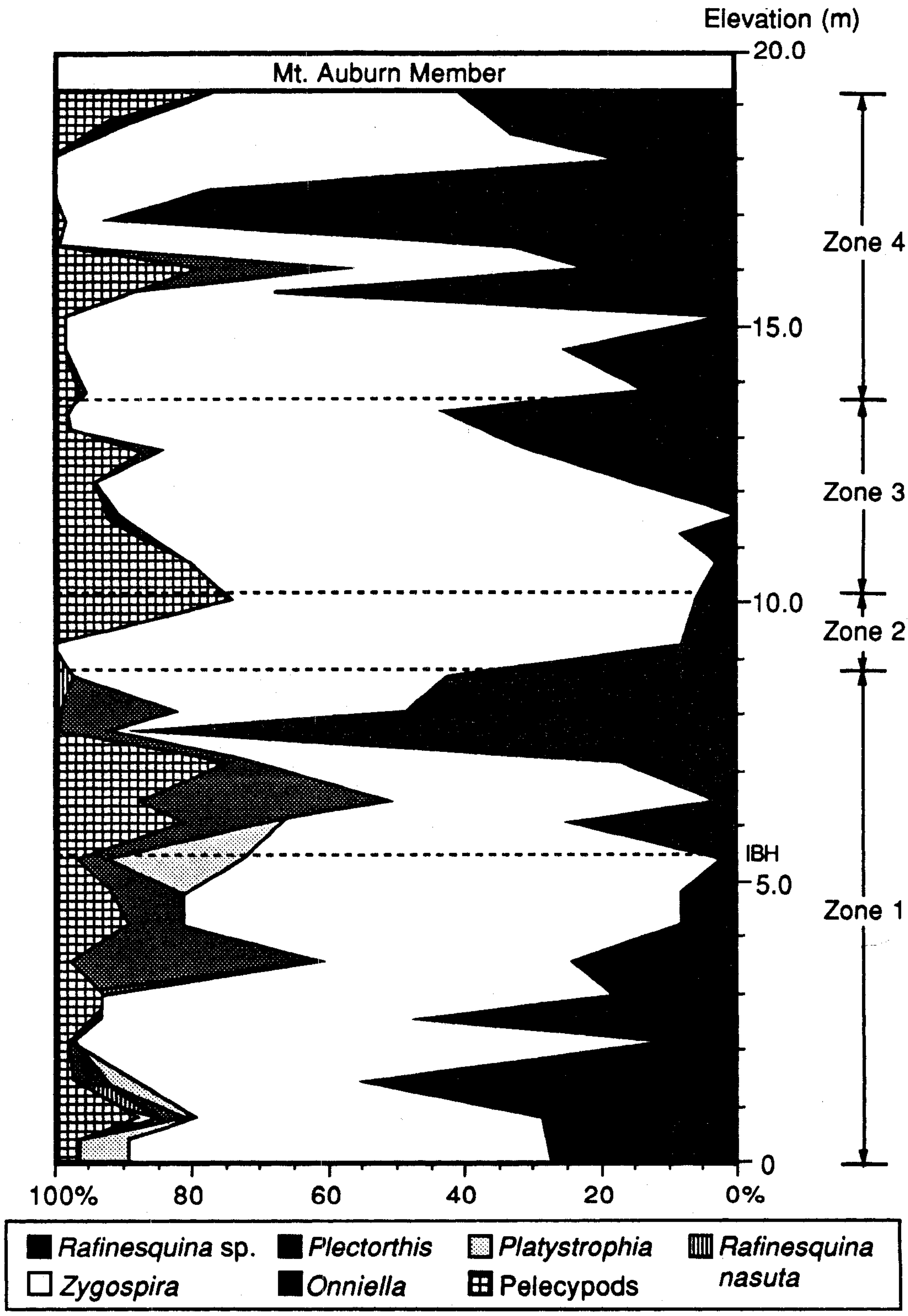
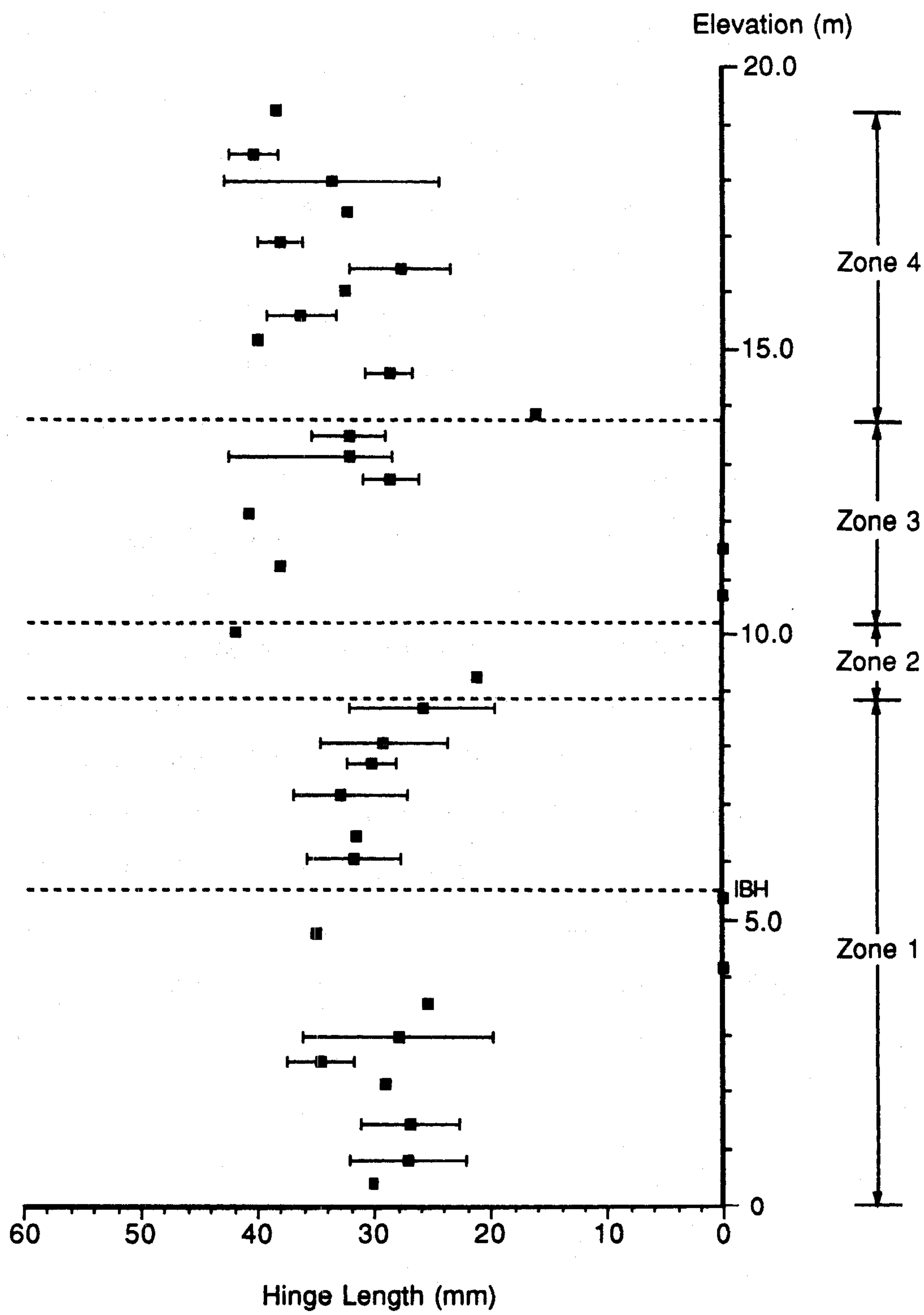

Elevation (m)
Mt. Auburn Member
20.0
15.0
10.0
5.0
0
IBH
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Rafinesquina sp.
Plectorthis
Platystrophia
Rafinesquina nasuta
Zygospira
Onniella
Pelecypods

Figure 38 - Mean *Rafinesquina* hinge length throughout the Corryville stratigraphic section. No obvious trends were present. 95% error bars were calculated for samples with $\geq$ 5 measured individuals. The base of the Corryville Member is set at the 0 m elevation.


Elevation (m)
20.0
15.0
10.0
5.0
0
IBH
Zone 4
Zone 3
Zone 2
Zone 1
60
50
40
30
20
10
0
Hinge Length (mm)

determined for samples with less than 5 hinge measurements. Average hinge length was approximately 32 mm. Hinterlong (1981) noted an upsection increase in *Rafinesquina* valve size in the Corryville section, and although no significant trend or trends were identified from this study, several of the samples within Zone 4 did contain larger than average valves (36-40 mm). Larger, heavier *Rafinesquina* are more typical of agitated, shoaling environments (Alexander, 1975), and an upsection increase in size may have been in response to increasingly turbulent environmental conditions.

In order of decreasing abundance, bryozoan morphotypes were as follows: small ramose, large ramose, foliate, encrusting. Large ramose bryozoans were most abundant at the base of the unit, small ramose and foliate bryozoans were ubiquitous, and encrusters were generally present in proportion to the amount of relatively whole molluscan and brachiopod valves. The most easily identifiable ramose bryozoan was *Parvohallopora ramosa* , a form with a thick diameter and high, sharp monticules that were infrequently fused into a spiraling ridge. In the field, *Parvohallopora* was infrequently preserved as an entire colony, or "thicket". Only one sample, 171-2 (12.11 m), contained large, possible *in situ* bryozoan colonies that appeared to have been transported with or buried below a thick layer of calcareous silt. The most diverse assemblages of bryozoan morphotypes were seen in the middle and upper portions of Zone 1 from 4.15-7.70 m. Other thick intervals, including 8.04-11.55 m (uppermost Zone 1 to the center of Zone 3), 13.09-15.57 m (upper Zone 3 to lower Zone 4), and 16.89-19.24 m (middle to upper Zone 4), were dominated by fragmented, unidentifiable, and small ramose bryozoan fragments. Intervals of high relative fragment abundance are not necessarily correlative with the carbonate facies of small-scale cycles.

Pelecypods were present in two-thirds of the bulk samples, but 86% of all bulk samples contained 3 or less recognizable specimens. Pelecypods were found within all lithotypes, but were observed most commonly as convex-upward molds on the upper surface of a bed or in the upper silty portion of ideal tempestites. Of the various pelecypod taxa, *Ambonychia* and *Caritodens* were easy to identify because of their characteristic ribbing and calcitic shell, respectively. Modiomorphoids were abundant but less well-preserved and were difficult to identify to even the level of genera. Many pelecypod molds displayed a thin, black, carbonaceous lining, possibly the remains of the periostracum. Pelecypod abundances reached a peak within samples from two stratigraphic intervals: the first from 5.4 m through 7.2 m (mid-Zone 1) and dominated by *Ambonychia*, and the second from 10.0 m through 12.7 m (upper Zone 2 to middle Zone 3) that contained a mixed pelecypod assemblage with more modiomorphoids and unidentifiable molds (Fig. 37). Samples with few to no pelecypods occurred within the stratigraphic section between 7.3 m and 10.0 m (upper Zone 1 and lower Zone 2) and between 16.4m to 18.5 m (upper Zone 4). These distributions suggest that although pelecypod distribution did not correspond closely with the defined stratigraphic Zones, specific intervals within the section were consistently pelecypod-rich or pelecypod-poor.

Gastropods and cephalopods were observed in approximately 50% and 20% of the samples, respectively. When present, these taxa never composed more than 10% of the specimens within the sample. *Cyclonema* was more common in samples from Zone 1, and *Cyclora* was restricted to samples from Zone 4. Inarticulate brachiopods were rare. Edrioasteroids, conularids, asteroids, carpoids, *Anomalocrinus*, and *Hebertella*, all supposed Corryville species, were not observed within either the bulk samples or stream exposures along Stonelick Creek. *Anomalocrinus*, *Hebertella*, and *Platystrophia*. were more conspicuous within the Corryville Member of the Grant Lake Limestone at the Thomas More Parkway site (Appendix 1). In contrast to the results of this census, Tobin (1982) cited *Onniella* as a common Corryville brachiopod genera. In all likelihood, Tobin probably confused *Onniella* with *Plectorthis* , an abundant orthid that superficially resembles *Onniella*, although this species may have been more common in exposures in western Ohio and southeastern Indiana.

The most abundant microfossils were ostracods, present within over half of all the samples. In some instances, these shells exceeded 100 individuals per bedding surface alone. Ostracods were rare at the very top of the Corryville section. Both scolecodonts and conodonts were preserved as isolated and slightly broken elements. Scolecodonts, the pharyngeal jaws of polychaete worms, were jet black in hue, roughly conical in shape, and generally less than 2 mm in length. Conodonts were amber to dark brown in color and broken. Microfossils could only be observed on bedding surfaces because of advanced cementation within the limestones.

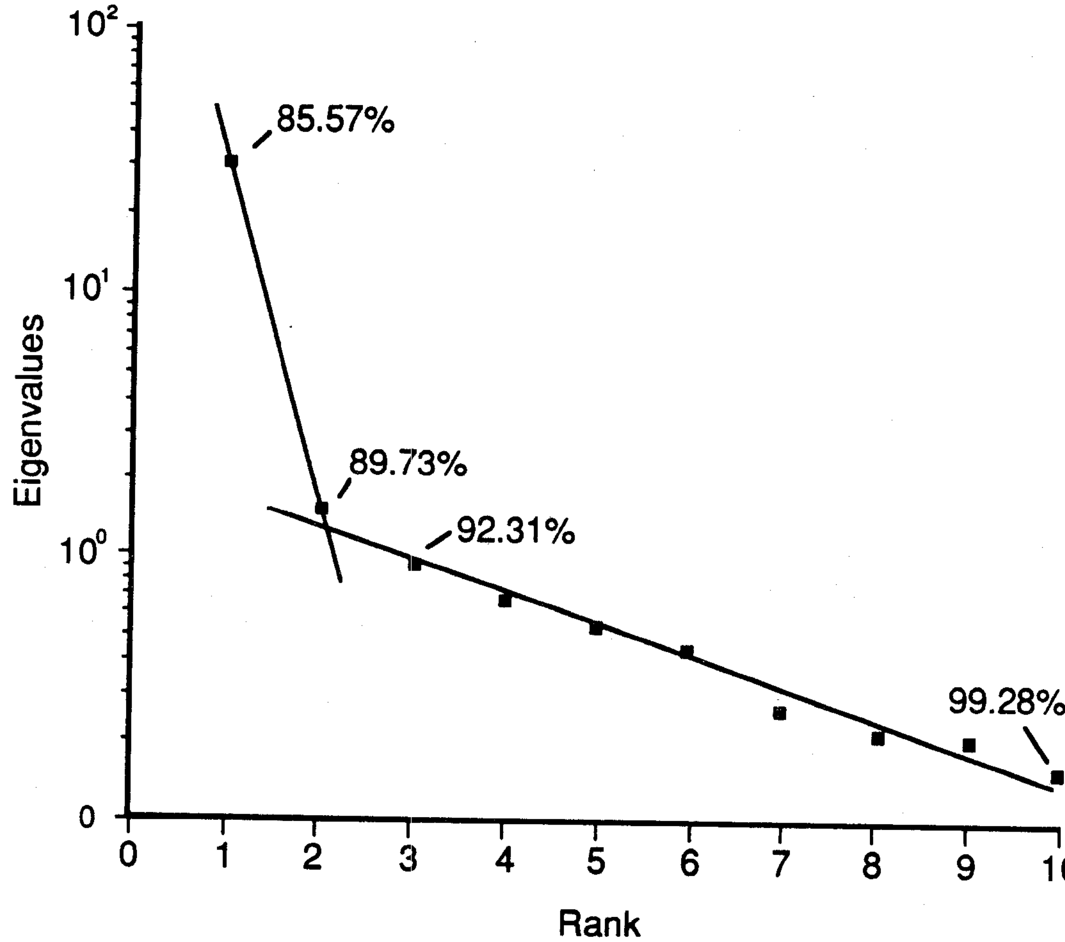
Results of the Multivariate Analyses

Appendix 5 lists the raw point count data used for the multivariate analyses. Of the analyses performed, the rotated factor analysis produced the most clearly-defined, meaningful sample groups; for this reason, only the factor analysis results will be presented here. The cluster analysis and polar ordination were able to define the most and least similar of the samples, but they were not able to clarify any other distributional trends within the majority of the samples. Most intersample differences were a function of relative abundance, not of taxonomic composition, and factor analysis appeared to be the best technique for elucidating the structure of this type of data. It may be that the methods by which cluster analysis and polar ordination determine sample similarity (averaging and selecting distant endpoints, respectively) work better with samples that display distinct taxonomic variations rather than relative abundance variations. For the same reason, the Cosine θ coefficient, which is sensitive to the relative proportions of the variable (Davis, 1986, p. 563), appeared to resolve these similarity relationships more readily than the Dice coefficient.

The factor analysis explained 99.28% of the sample variance with ten generated principal vectors that had eigenvalues ranging from 30.81 to 0.16. The majority of the variance, 85.57%, was described by the first principal vector, and 92.31% of the variance was explained by the first three principal vectors. The principal factor loadings all displayed high communality, a measure of goodness of fit. A "scree graph" (see Sepkoski and Miller, 1985, Fig. 4) was constructed to compare the relationship between the magnitude of the eigenvalues and the 10 principal vectors (Fig. 39). The break in slope of the two fitted lines at the second principal vector indicates that comparatively less variance was explained by the higher-numbered factors (cf. Sepkoski, 1981). In this study, three rotated vectors were sufficient to explain the data.

Following Varimax rotation, CABFAC recomputed the variable factor scores for each of the three rotated factors (Table 4); these scores were used to determine how the individual variables related to the rotated factors (Sepkoski, 1981). Not surprisingly, the first two rotated factors appeared to define the relationship between *Zygospira*, *Rafinesquina,* and pelecypods, the three most abundant sample components. The first rotated factor had a high factor score (0.688) with *Zygospira* and moderately high score with pelecypods (0.470), and the second had a very high factor score (0.833) with *Rafinesquina* sp. A third

Figure 39 - A scree graph displaying the relationship between the 10 principal vectors and their relative eigenvalues. Vectors are ranked by order of occurrence and eigenvalues are plotted logarithmetically. The two fitted lines indicate that comparatively less variance was explained by the higher-ranked vectors. The first vector described 85.57% of the variance amongst the samples, and the first three described 92.31%.



10^2
10^1
10^0
0
Eigenvalues
85.57%
89.73%
92.31%
99.28%
0
1
2
3
4
5
6
7
8
9
10
Rank

Table 4 - Correspondence of variables with the three Varimax rotated axes (factors). Highest positive and negative values in bold indicate those variables most closely associated with the factors.

Factor Score Matrix for Varimax Rotated Factors 1, 2, and 3

Variable	Factor 1	Factor 2	Factor 3
Bryozoan	0.318	-0.163	0.235
Trilobite	0.200	-0.019	0.411
Crinoid	0.258	-0.078	-0.077
Rafinesquina sp.	-0.234	**-0.833**	0.244
Zygospira	**0.688**	-0.317	-0.004
Platystrophia	0.020	0.035	0.094
Plectorthis	-0.139	0.266	**0.752**
Rafinesquina nasuta	-0.206	-0.091	0.249
Onniella	0.069	0.005	-0.046
Pelecypod	**0.470**	0.214	0.163
Cyclonema	0.011	0.008	0.114
Cyclora	-0.049	-0.212	-0.109
Orthoconic nautiloid	-0.028	0.020	0.140

brachiopod, *Plectorthis*, had a 0.752 factor score with rotated factor 3. The "loadings" of the rotated factors were a measure of how the individual samples were related to the individual factors, and these were examined in relation to the stratigraphic section. Figure 40 shows a nearly inverse relationship between the loadings of axis 1 (*Zygospira* and pelecypods) and axis 2 (*Rafinesquina*). The loadings for axis 3 are highest within Zone 1 and the middle of Zone 2, portions of the section where *Plectorthis* was observed. A subsequent Varimax rotation of the first four principal vectors increased the cumulative variance to 94.2%, but did not appreciably change the positions of the samples or the high factor scores associated with the first three rotated factors. The fourth rotated factor reflected a strong relationship (-0.620) with *Cyclora*.

Two-dimensional ordination plots (Figs. 41, 42, and 43) were constructed to display the relationships of the samples to the three rotated factors (the graph axes). Each axis has been marked by the associated faunal distribution trend as interpreted from the dominant variable factor scores. To illustrate the general stratigraphic position of the samples in each group, symbols representing the four zones were substituted for sample numbers. Five groups of samples were delineated on the basis of sample position with respect to the three rotated factors. These five sample groups were defined by the following faunal associations: (A) *Zygospira*-pelecypod dominated samples with little to no *Rafinesquina*; (B) samples with high *Plectorthis*, high *Zygospira*, moderately high pelecypods, and comparatively low *R. alternata*; (C) samples with high numbers of *R. nasuta* , and moderate *Zygospira*, bryozoan fragments, and trilobite fragments; (D) samples of high and moderately high abundances of *Rafinesquina*, *Zygospira*, bryozoans, and trilobites; and (E) by *Rafinesquina* - dominated samples with low abundances of fossil fragments, pelecypods, and

Figure 40 - Loadings of three rotated factors (axes) from a Q-mode factor analysis plotted against the Corryville stratigraphic section. The base of the Corryville Member is set at the 0 m elevation. Below each axis is the variable(s) most closely associated with that axis (see Table 4). The arrow indicates the direction in which the abundance of each variable is highest. Note that where *Plectorthis* is most abundant, *Rafinesquina* is less so. *Zygospira* and pelecypods are least abundant near the tops of Zones 1 and 4, where *Rafinesquina* abundance is high.

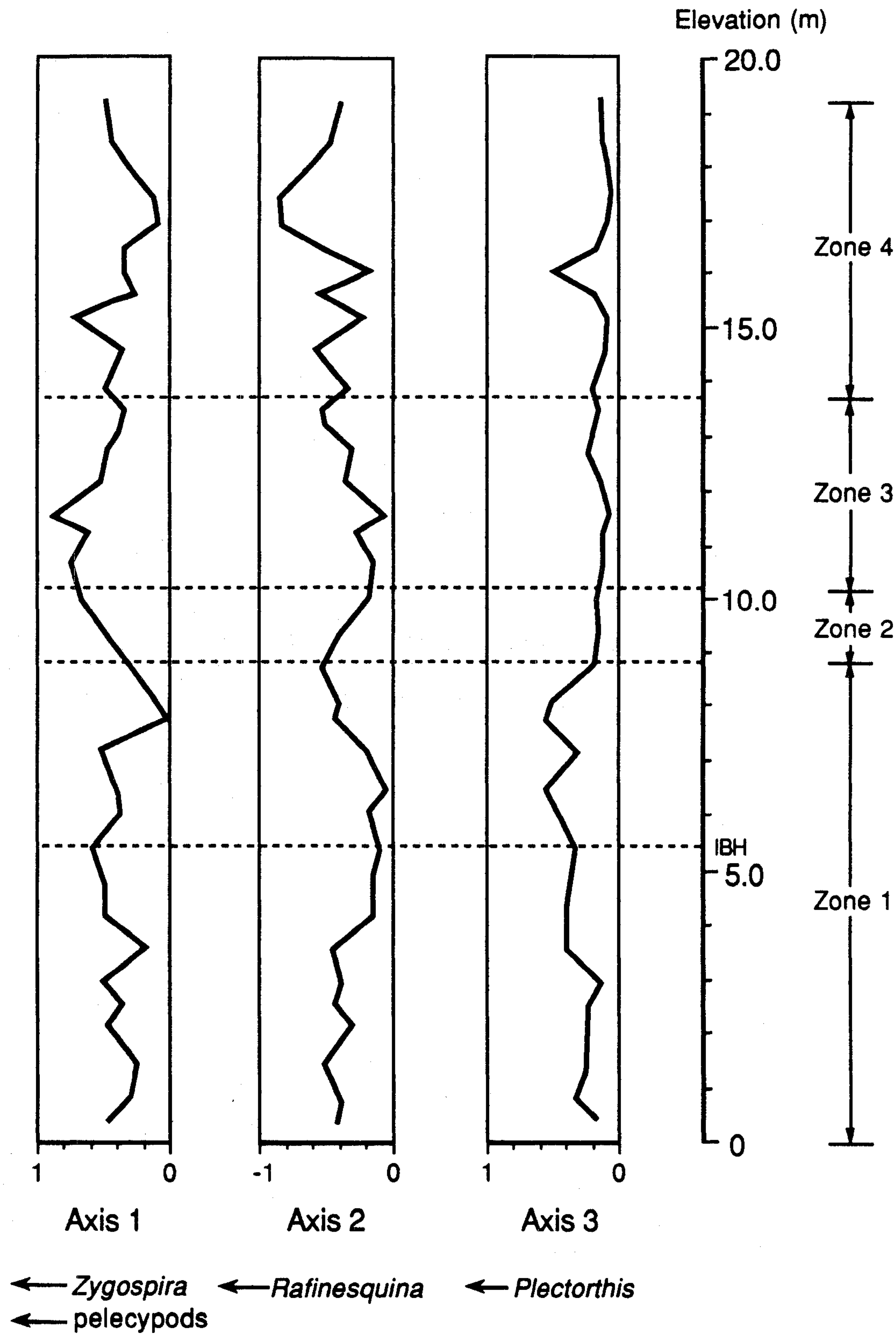

Elevation (m)
20.0
15.0
10.0
IBH
5.0
0
Zone 4
Zone 3
Zone 2
Zone 1
1
0
-1
0
1
0
Axis 1
Axis 2
Axis 3
← Zygospira
← pelecypods
← Rafinesquina
← Plectorthis

Figure 41 - Q-mode factor analysis plot of the Axis 1-Axis 2 plane. Abundance trends associated with individual axes are included. Each geometric symbol represents the position of a single sample within the larger sample groups.

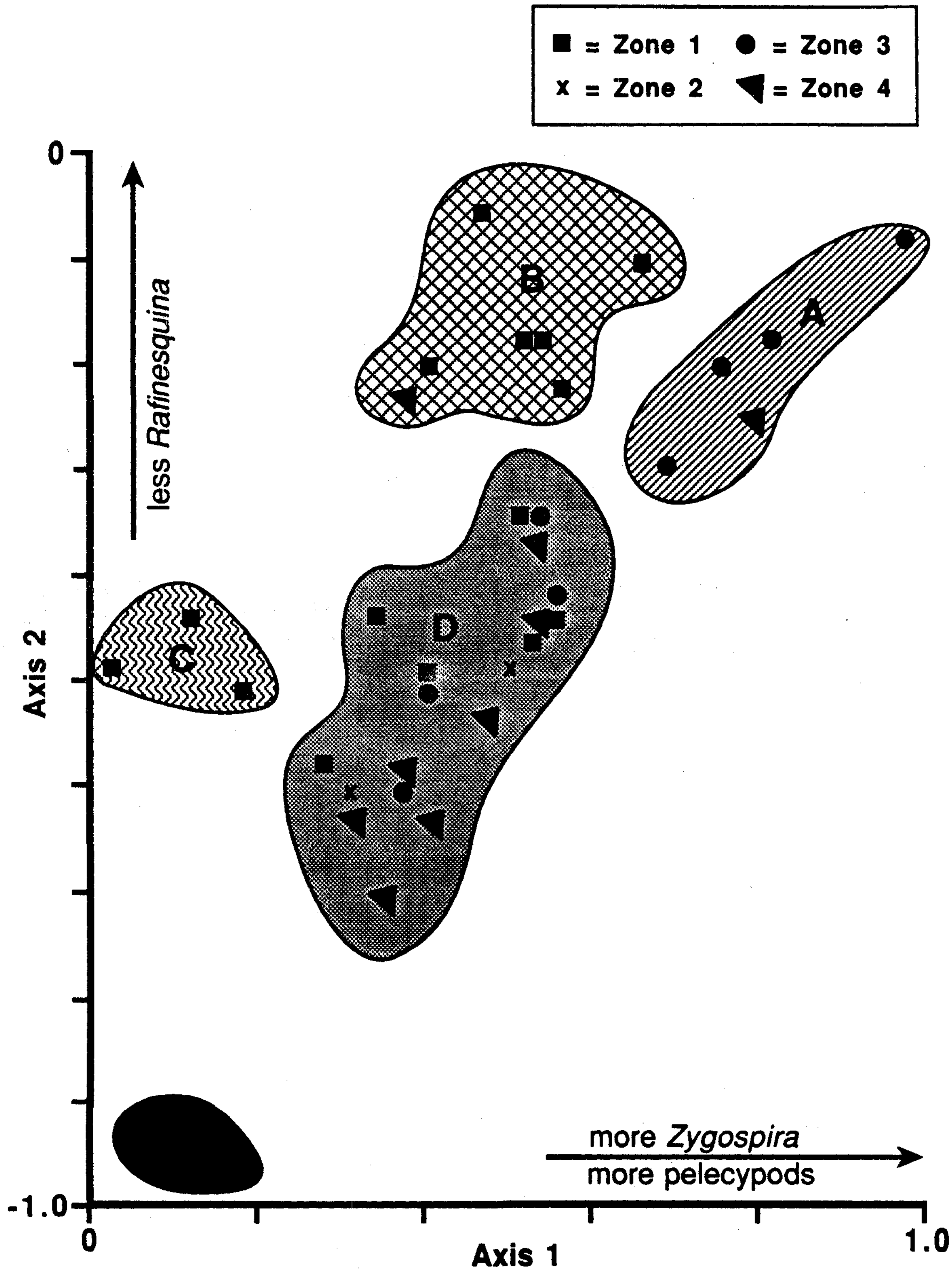

■ = Zone 1
● = Zone 3
x = Zone 2
◀ = Zone 4
0
-1.0
0
1.0
less *Rafinesquina*
Axis 2
B
A
C
D
more *Zygospira*
more pelecypods
Axis 1

Figure 42 - Q-mode factor analysis plot of the Axis 1-Axis 3 plane. Abundance trends associated with individual axes are included. Each geometric symbol represents the position of a single sample within the larger sample groups.

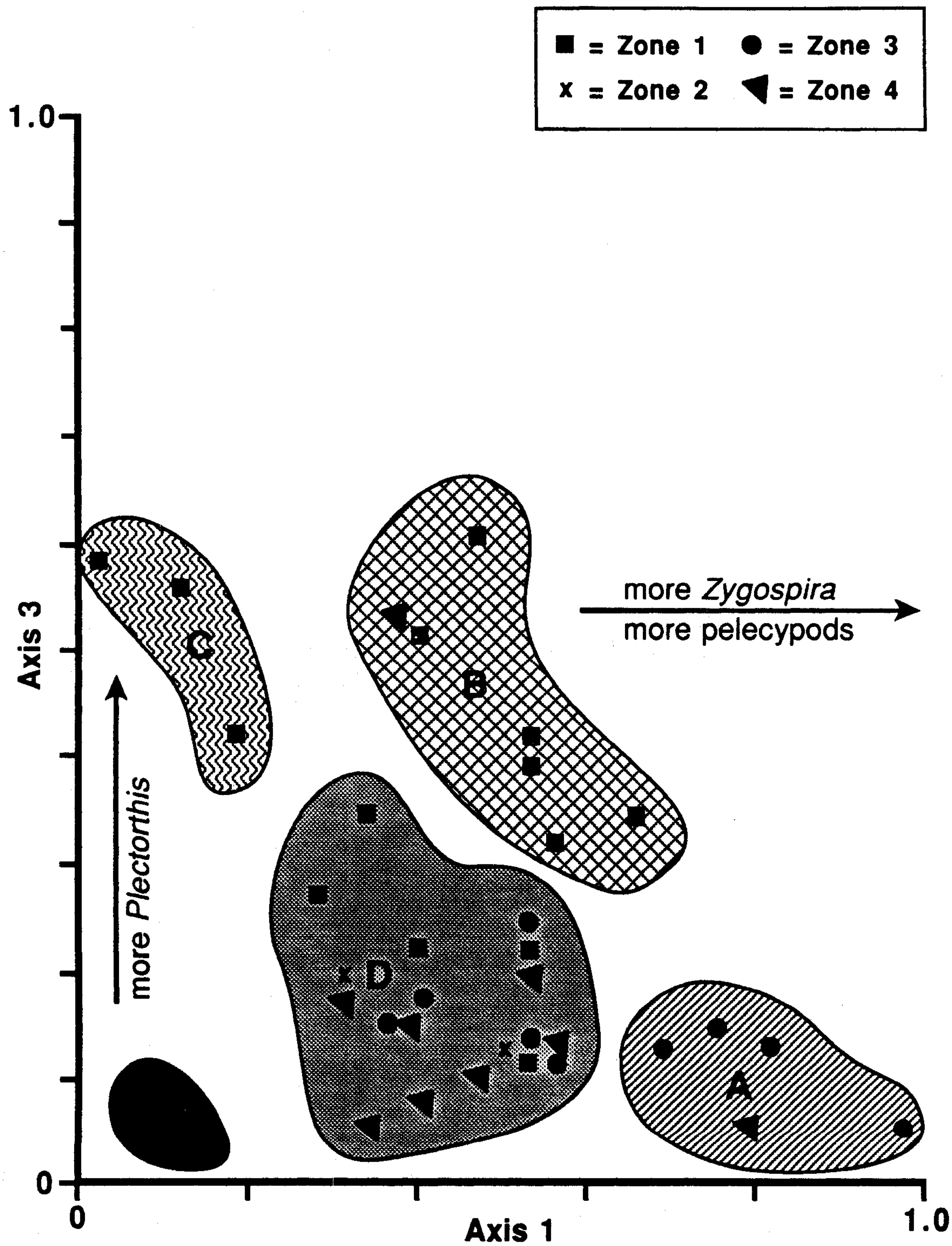
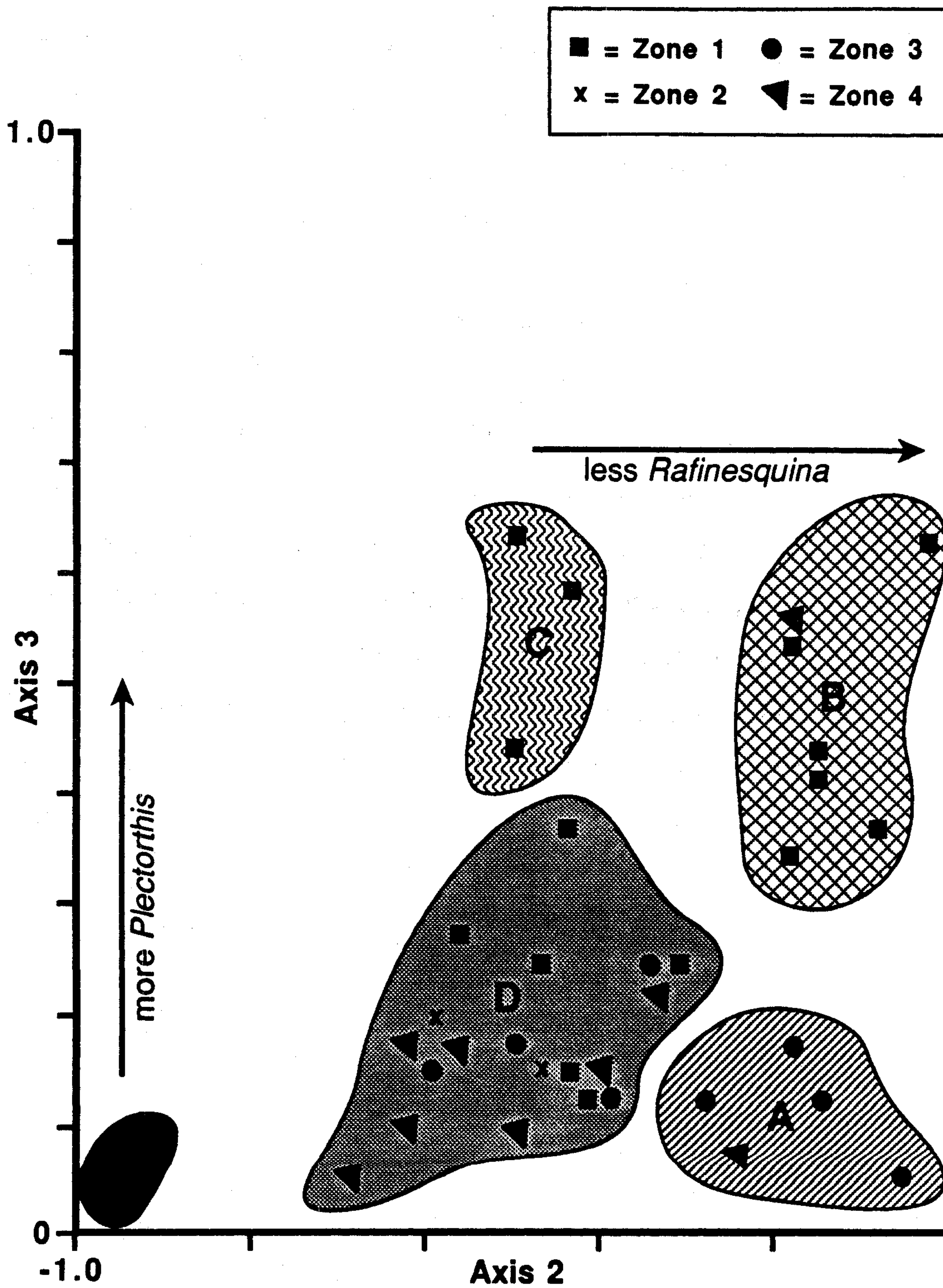

■ = Zone 1
● = Zone 3
x = Zone 2
◀ = Zone 4
1.0
0
Axis 3
more Plectorthis
A
B
C
D
more Zygospira
more pelecypods
0
Axis 1
1.0

Figure 43 - Q-mode factor analysis plot of the Axis 2-Axis 3 plane. Abundance trends associated with individual axes are included. Each geometric symbol represents the position of a single sample within the larger sample groups.


■ = Zone 1
● = Zone 3
x = Zone 2
◀ = Zone 4
1.0
0
-1.0
0
Axis 3
Axis 2
more *Plectorthis*
less *Rafinesquina*
A
B
C
D

other brachiopods. Figure 44 lists the normalized taxonomic compositions of the samples that compose each of the five groups.

Samples from the largest group, D, were situated throughout the section (Fig. 45). These samples contained fossil assemblages with a moderately diverse biota of brachiopods, bryozoans, trilobites, brachiopods, gastropods, and occasionally crinoids (Fig. 46). No single variable or ratio of variables defined this group, and samples were of every type of carbonate texture. Samples varied slightly in faunal composition, but apparently not enough to be plotted apart from the rest. Therefore, group D was interpreted as representative of the most "common" Corryville biota, and it is from this standard that the more unusual Corryville assemblages were distinguished. The remaining four sample groups fit two trends: (1) groups defined by the presence and high abundance of unique articulate brachiopods; and (2) and groups marked by a distinct variation in the relative abundances of one of the three dominant variables, *Rafinesquina*, pelecypods, and *Zygospira*. Unlike group D, groups A, B, C, and E generally occurred within separate, specific stratigraphic intervals (Fig. 45).

Samples in groups B and C were different from those of group D primarily because, in addition to the typical Corryville species, they contained high abundances of unique articulate brachiopods and/or pelecypods. Both B and C contained abundant *Plectorthis* and plotted high along axis 3 (Figs. 42 and 43). C samples were composed of high numbers of *R. nasuta* (Fig. 47), and B samples had abundant pelecypods (Fig. 48). With one exception, B and C were stratigraphically situated within the middle and upper portions of Zone 1; a single sample from group B was collected from a carbonate cycle facies in Zone 4 (Fig. 45). No strong association of faunal distribution with sample lithology was seen in B and C. These groups were closely related in the cluster and

Figure 44 - Histogram showing the relative abundances of variables within the larger sample groups defined through the Q-mode factor analysis. Each row of symbols represents the faunal composition of a single sample.

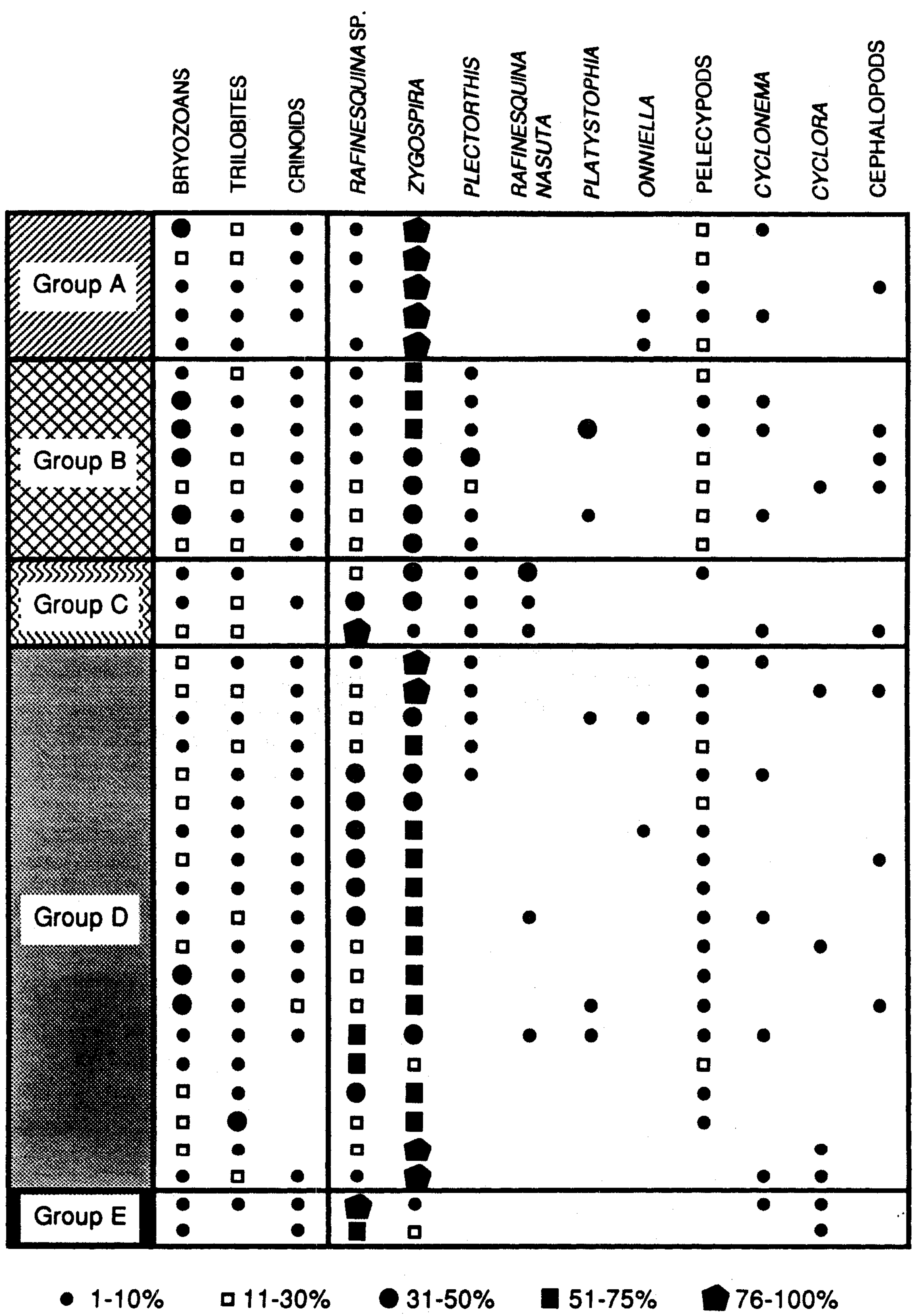

BRYOZOANS
TRILOBITES
CRINOIDS
RAFINESQUINA SP.
ZYGOSPIRA
PLECTORTHIS
RAFINESQUINA NASUTA
PLATYSTOPHIA
ONNIELLA
PELECYPODS
CYCLONEMA
CYCLORA
CEPHALOPODS
Group A
Group B
Group C
Group D
Group E
1-10%
11-30%
31-50%
51-75%
76-100%

Figure 45 - Stratigraphic location of samples from the five Q-mode factor analysis groups within the Corryville Member. Patterned rectangles each represent a single bulk sample. Vertical thickness of samples is exaggerated in rectangles. See Figure 24 for key of stratigraphic section.

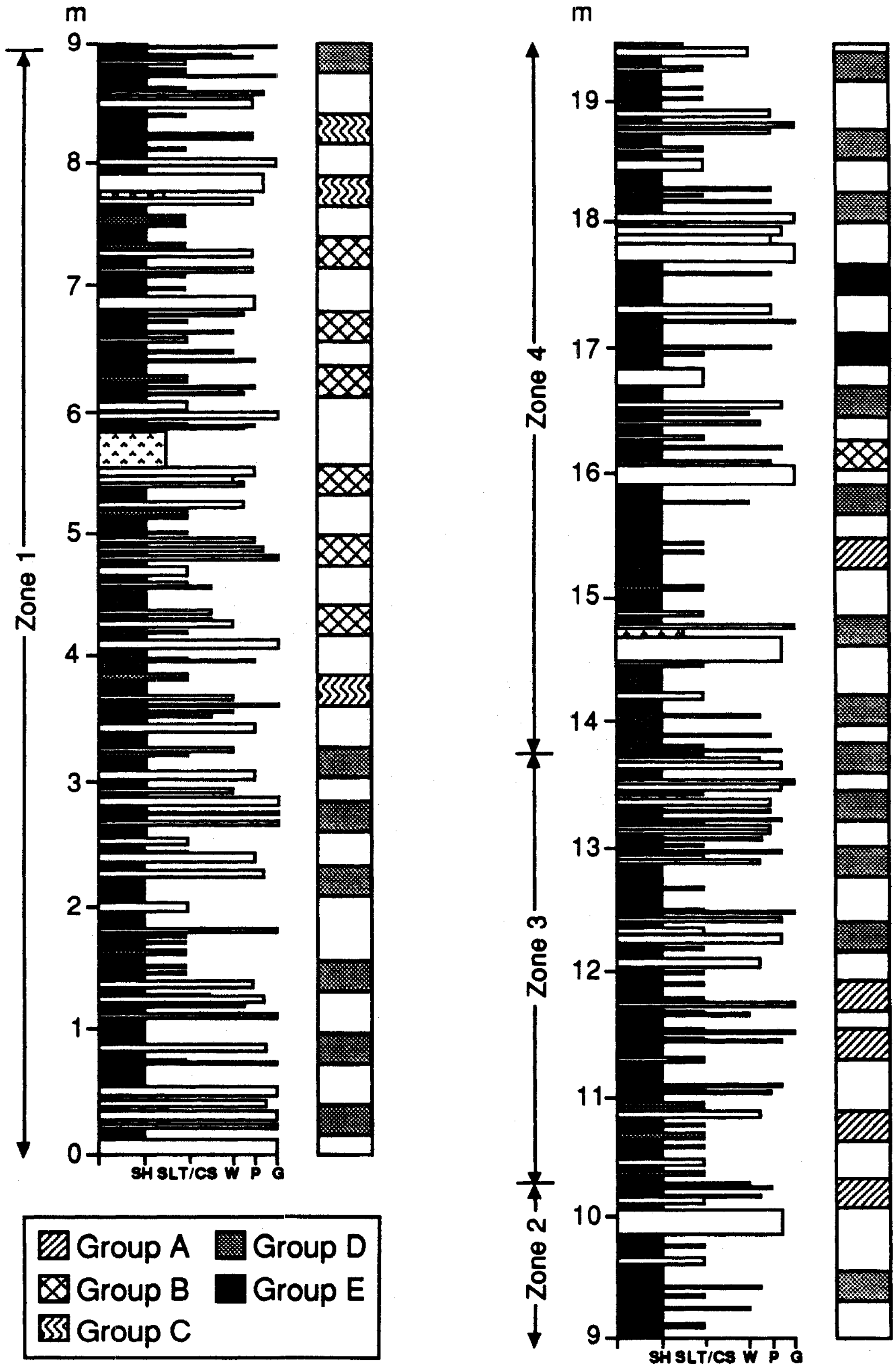
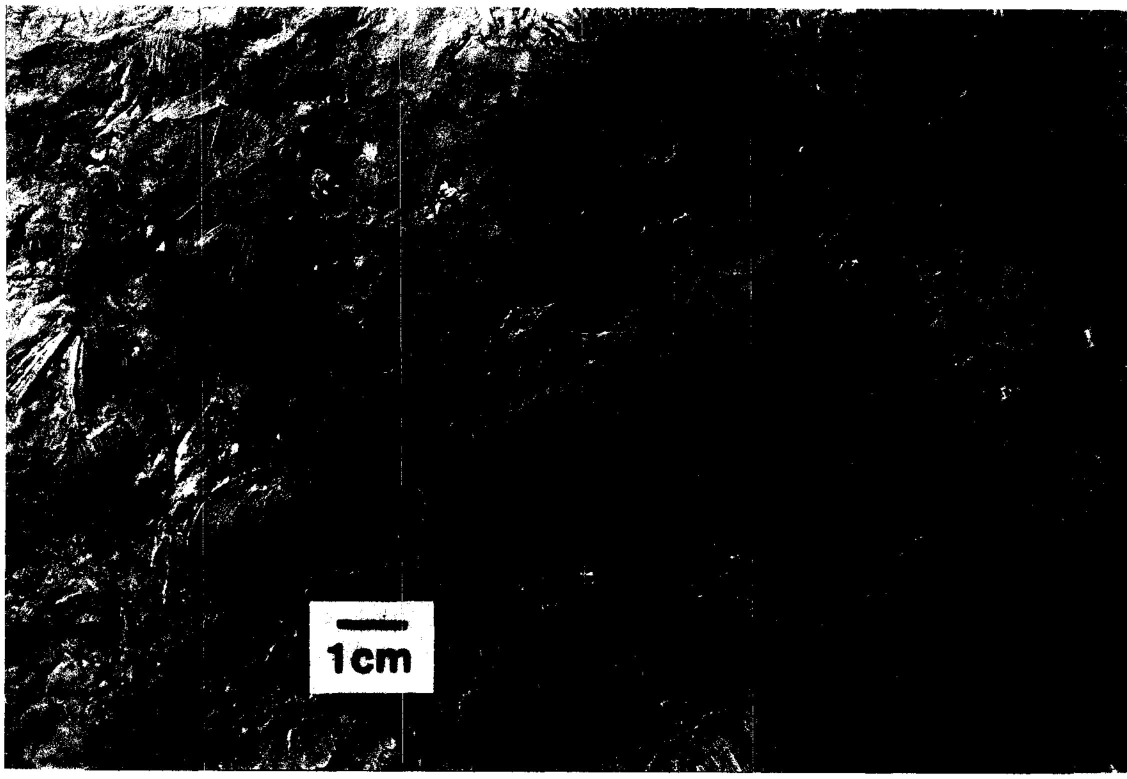

m
9
8
7
6
5
4
3
2
1
0
Zone 1
SH SLT/CS W P G
Group A
Group D
Group B
Group E
Group C
m
19
18
17
16
15
14
13
12
11
10
9
Zone 4
Zone 3
Zone 2
SH SLT/CS W P G

Figure 46 - Photographs of sample 19-1 (CMNH IPS3) and sample 171-2 (CMNH IPS22) from Group D. a) Sample 19-1 contained convex-upward *Platystrophia* sp. (Platy), *Rafinesquina* sp. (Raf), *Caritodens demissa* (Car), and *Zygospira modesta* (Z) and assorted trilobite sclerites (t) and crinoid ossicles (c). Bryozoans encrusted the interior of the *Rafinesquina* brachial valve at the top center of the photograph. A thin layer of calcareous silt covered the bed top . b) Sample 171-2 contained several nearly intact (autochthonous?) bryozoan colonies (B) at the center of a large ideal tempestite. The bryozoans were situated at the center of the bed between a lower well-sorted packstone-grainstone with abundant *Zygospira* and an upper arenaceous calcisiltite that buried and infiltrated the colonies.

a.



b.

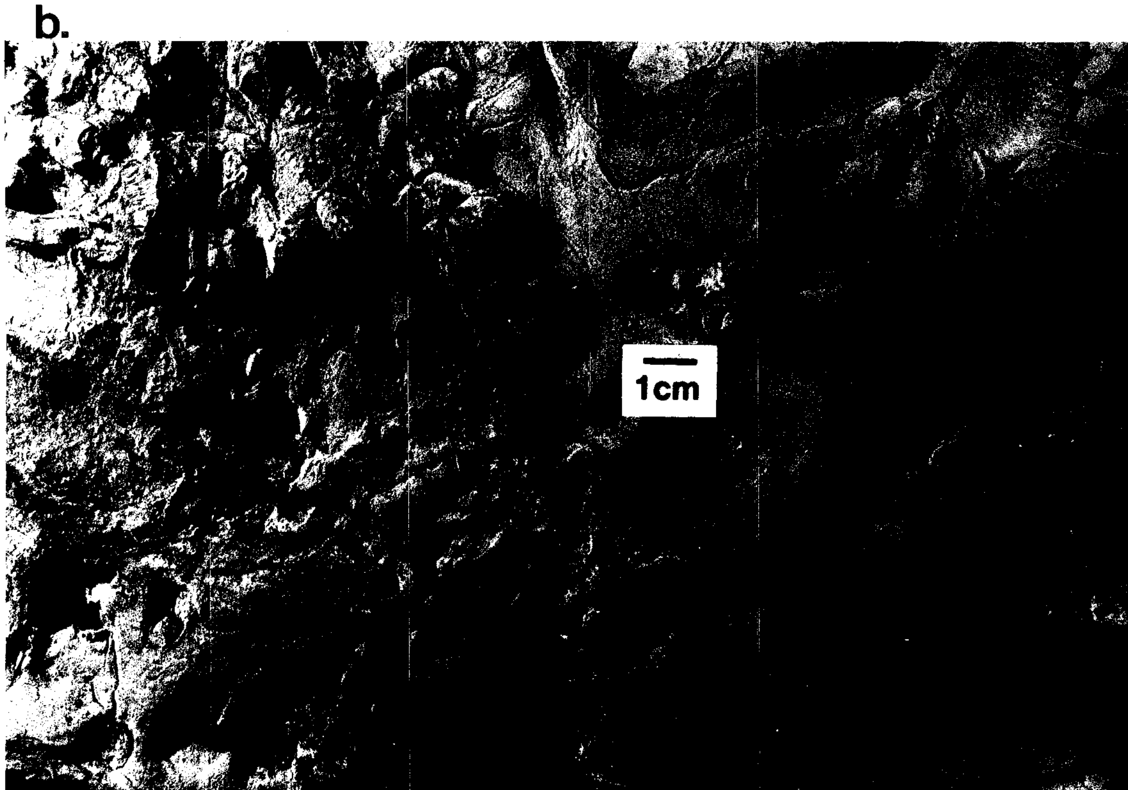


Figure 47 - Sample 27-2 (CMNH IPS7) from factor analysis group C. Sample was a packstone-wackestone with abundant *Rafinesquina nasuta* (Rn), bryozoan fragments (b), trilobite fragments (t), and *Zygospira* (Z). *R. nasuta* were dominantly convex-upward and articulated and displayed mud sheltering. Crinoid material was rare. Note the small *Cyclonema* gastropod (g) at photo center.

Figure 48 - Sample 75-2 (CMNH IPS12) from factor analysis group B. This packstone-wackestone contained large bryozoan fragments (b), disarticulated *Plectorthis* valves (Pl), crinoid ossicles (c), and trilobite fragments, including a pygidium of *Flexicalymene meeki* (F). Note the borings along the exposed surface of the bryozoan in the lower left photo corner.


1cm


1cm

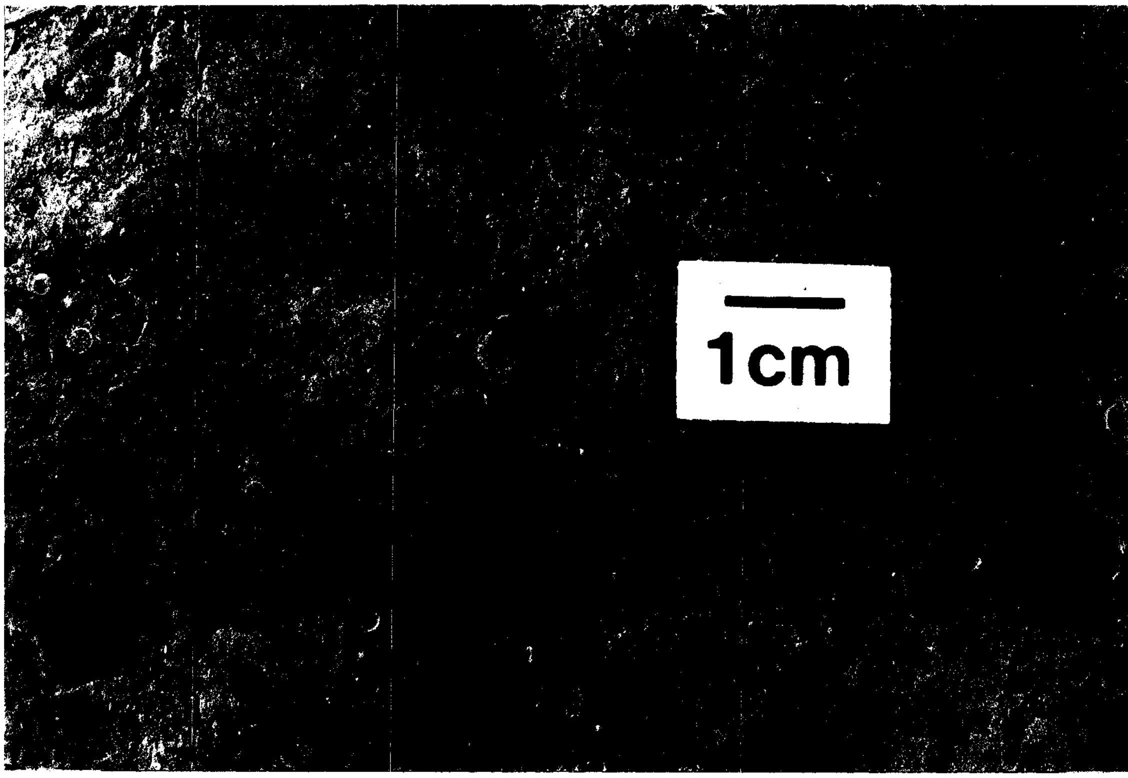
polar analyses that utilized the Cosine θ Coefficient. Samples from group D contained low numbers of *R. nasuta* and *Plectorthis*, implying that it is the abundance of unique taxa more than the presence of those taxa that is the basis for their grouping. Interestingly, the presence of highly abundant taxa other than Rafinesquina, pelecypods, and *Zygospira* in B and C reduced the combined relative abundance of those three common variables in proportion to the composition of the entire sample. This relationship can be seen in Figure 41, where B and C plot to the left or above of A, D, and E. This suggests that the faunal distributions in the samples of groups B and C in the upper half of Zone 1 reflect the actual strong, increased presence of certain taxa within this portion of the section.

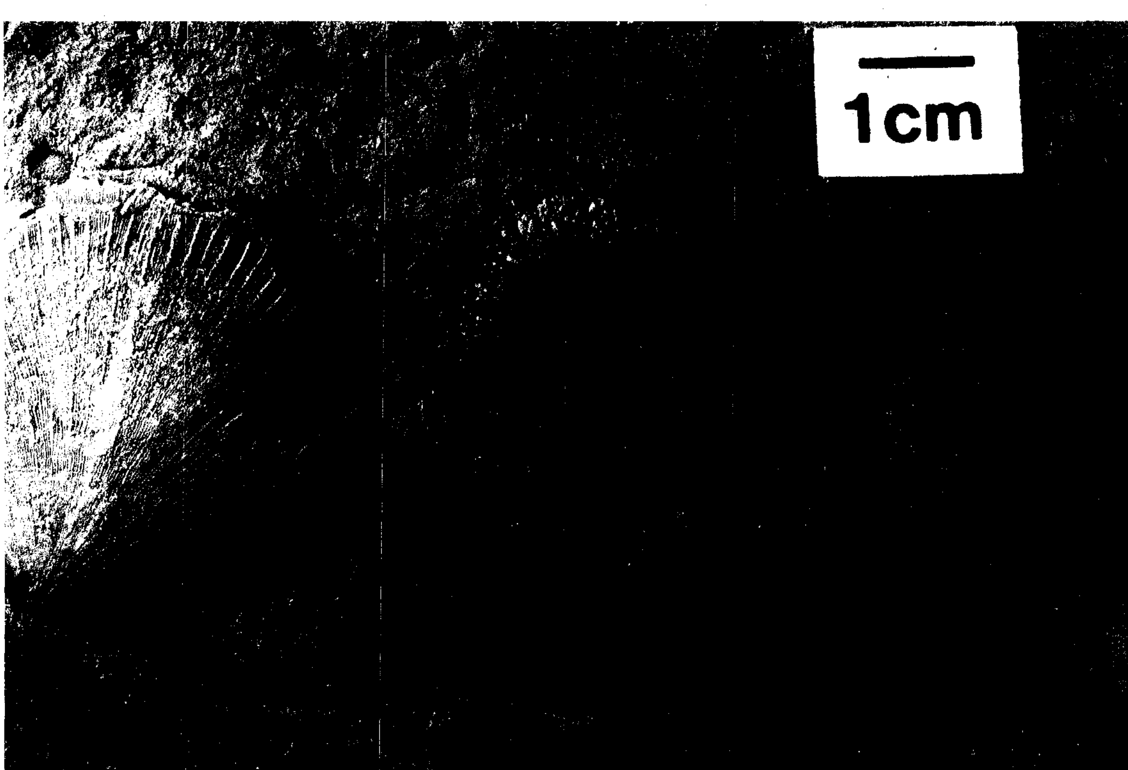
The general compositions of groups A and E were not distinct from D except in the relative abundance of the three most common variables (Fig. 44). Samples from A had few to no *Rafinesquina* sp., high pelecypods, and high *Zygospira* (Fig. 49), and samples from E contained high *Rafinesquina* sp., no pelecypods, and low *Zygospira* (Fig. 50). As with B and C, A and E were samples from specific stratigraphic intervals (Fig. 45), although these were situated in the upper half of the Corryville Member within shale facies of cycles in Zones 3 and 4. Lithologically, A samples are normally-graded calcisiltites and tempestites and one amalgamated calcisiltite and packstone. The fine-grained portions of these beds appear to have enhanced pelecypod preservation. The two E samples were clearly similar and displayed bimodal sorting of skeletal fragments with tiny unidentifiable fragments, large, whole *Rafinesquina* sp. valves, and *Cyclora*; these samples were grouped together in every quantitative analysis performed.

Cyclonema, *Cyclora*, nautiloids, and *Platystrophia* were not definitive variables for any of the five groups, and this appears to be due to the generally

Figure 49 - Sample 147-2 (CMNH IPS19) from factor analysis group A. This packstone contained large pelecypod molds and small fragmented skeletal material, primarily crinoid ossicles (c), small ramose bryozoans (b), and trilobite sclerites (t). Note the large *Ambonychia* mold (Am) in the upper left corner. Modiolopsids were also abundant. *Zygospira*, highly abundant in group A, were most abundant within and at the base of the samples.

Figure 50 - Sample 239-2 (CMNH IPS32) from factor analysis group E. Beds from group B were fine packstones and calcisiltites dominated by large, disarticulated *Rafinesquina* sp. valves (Raf). Note the absence of macroscopic skeletal material. Trilobite fragments (t) and crinoid columnals (c) were rare.


1cm


1cm

low abundances of these taxa. Groups A and B, and to some extent D, were rich in *Zygospira* and pelecypods, but surprisingly lacking in *Rafinesquina* . *Zygospira* was ubiquitous, and its low abundance in group E was the defining factor for that group. The cluster analysis with Cosine θ created clusters equivalent to groups E and B, but did not distinguish group C with the highly abundant *R. nasuta*.

Discussion of Paleoecology

The Corryville Paleocommunity

Faunal distribution analysis indicates that the Corryville Member represents a single biofacies, albeit a biofacies that experienced slight temporal changes in relative abundance and composition. Samples displayed similar faunal components despite variations in skeletal fragmentation, relative abundance, and carbonate mud matrix. The dominant Corryville taxa were *Rafinesquina*, *Zygospira*, pelecypods (primarily *Ambonychia*, *Modiolopsis*, and *Caritodens*), ramose bryozoans, and trilobites (primarily *Isotelus* and *Flexicalymene*). Hinterlong (1981) suggested that the general Corryville population corresponded well to Bretsky's (1970) broadly-defined *Zygospira-Hebertella* Community, but should be renamed the *Zygospira-Rafinesquina* Community because of the dominance of the latter brachiopod species. The abundance of trilobite and crinoid material and strophomenids distinguishes the Corryville community from Bretsky's (1969, 1970) Appalachian community, but the designation of a *Zygospira-Rafinesquina* Community would agree with the results of this study. Although shales were not included in the multivariate analysis, field observations suggest that the faunal elements of the shales were similar to those of the limestone beds.

The three members of the Grant Lake Formation share many of the same macrofossil genera, including *Rafinesquina*, *Zygospira*, *Ambonychia*, *Iocrinus*, and *Pycnocrinus*. However, the dominant faunal components of these members are quite different, and the faunal variation observed within the Corryville section is far less than the variation that exists amongst the members of the Grant Lake Formation. The upper Bellevue Member is dominated by

Platystrophia, *Plectorthis*, *Hebertella*, and thick bryozoans (Diekmeyer, 1992; Jennette and Pryor, in press), and the Mt. Auburn strata contain little trilobite material and an equally rich brachiopod assemblage of *Platystrophia ponderosa* and *Hebertella* (Krumpolz, 1980). The presence of abundant large, thick-shelled brachiopods in these two units has been proposed by several authors as evidence for more turbulent environmental conditions and closer proximity to fairweather wave base (Tobin, 1982; Diekmeyer, 1990, 1992; Holland, 1992). In the Corryville Member at Stonelick Creek, *Hebertella* was absent, *Onniella* was rare, and *Platystrophia*, *R. nasuta*, and *Plectorthis* were present almost exclusively within samples from Zone 1. The general decrease in brachiopod diversity upsection, specifically those brachiopods associated with facies deposited in higher energy environments, suggests that the normal environmental energy may also have decreased slowly over time.

Because of the biases of fossil preservation, it would be nearly impossible to reconstruct the population paleoecology of the Corryville Member, with the exception of certain Lagerstätten (e.g. Meyer, 1990). The preserved benthic biota was dominated by epifaunal and semi-infaunal suspension feeders (bryozoans, pelecypods, brachiopods), and included deposit feeders (pelecypods, gastropods), scavengers/vagrant benthic detritus feeders (trilobites), commensals (bryozoans, edrioasteroids, inarticulate brachiopods, *Cornulites*), and predators (nautiloids). According to Frey (1987a), most Corryville pelecypods were endobyssate and lived with a greater portion of their shells buried within the substrate. Pelecypods displayed large size, and this may have resulted from either a rapid growth rate or optimal environmental conditions (Frey, 1987a). Evidence of predatory activity was rare, although borings were observed in foliate and massive bryozoans and *Rafinesquina* pedicle valves throughout the section; these borers may have been sponges or gastropods. Epizoans included bryozoans, inarticulate brachiopods, and *Cornulites*. The convex surfaces of pelecypods and *Rafinesquina* valves were commonly encrusted, most likely because their broad, relatively flat shells provided adequate settling surfaces for nektonic larvae.

Hinterlong (1981) proposed that Corryville paleocommunities were established through a combination of allogenic and autogenic community succession. This model, however, is difficult to test in storm-deposited beds where the hardpart components of the community are preserved, but the original community structure is not (Fürsich, 1978; Peterson, 1977; Schindel, 1980; Kreisa, 1981a; Miller et al., 1988). Tobin (1982, p. 120-121) stated that authentic examples of Cincinnatian community succession were rare, and he doubted the legitimacy of cited examples of this process because: (1) carbonate muds were present at bed margins rather than at the center of bed where it would have been trapped by baffling bryozoans and crinoids; (2) fossil assemblages contained only low concentrations of sediment bafflers; (3) coeval storm-produced bioclastic shoals would have been preferred sites for community development; and (4) the resolution of the stratigraphic record would have been too coarse to preserve such a sequence. Additionally, fluctuations in short-term species abundances and similar biological processes are generally not preserved in relatively shallow shelf sediments because of the effects of time-averaging and condensation bias (Walker and Bambach, 1973; Fürsich, 1978; Schindel, 1980).

No apparent examples of faunal succession were observed in the study samples, but short-term succession should not be discounted as an important paleoecological process. If the sea floor was composed predominantly of terrigenous and calcareous muds, then some manner of substrate modification must have occurred to support taxa that required stable substrates for life.

Hardgrounds are rare within the stratigraphic section, but the extent to which early cementation may have occurred is not known. Taphonomic feedback (Kidwell and Jablonski, 1983; Kidwell, 1986) could more likely have affected the pace and form of community growth. The abundance of bryozoan and shell material within limestone beds suggests that skeletal debris and shell pavements were common along portions of the sea floor. These would have acted to stabilize the substrate and offer suitable living space for epizoans and pelmatozoans. Although few juvenile pelecypods or brachiopods were observed in samples, this may only reflect a taphonomic bias because the decay rate of smaller shells would be faster than that of large ones (Cummins et al., 1986). *Flexicalymene* sclerites, for instance, were represented by all sizes of individuals in most of the bulk samples; these were probably more resistant to the effects of dissolution (Speyer, 1987).

Diekmeyer (1990, 1992) found that changes in the composition of fossil communities in the upper Kope Formation corresponded well with small-scale bedding cycles. No such strong association was observed within the cyclic bedding sequences of the Corryville Member, but the factor analysis did demonstrate that many of the beds from the "shale facies" displayed similar and unique variations in the relative abundances of taxa. In the samples of group A, taken from the "shale facies" of Zones 3 and 4 (Fig. 45), pelecypods were most abundant and *Rafinesquina* were rare to absent, possibly because 1) the mud-rich environment was less suitable to *Rafinesquina*; or 2) the pelecypods outcompeted the *Rafinesquina* at that particular time. The exceptional preservation of pelecypods suggests a parautochthonous origin for these strata. In the samples of group E, collected from a single shale-rich interval at the center of Zone 4 (Fig. 45), *Rafinesquina* was the dominant genera with a near exclusion of all other taxa. These beds were characterized by extensively reworked and comminuted skeletal remains, and the high degree of fragmentation and sorting suggests that these tempestites had been transported from a higher energy environment.

The intensity of the Bellevue-Corryville transgression cannot be inferred from faunal distribution patterns, but one important large-scale faunal trend was observed within the vertical Corryville section at Stonelick Creek. Many of the Corryville taxa were either stratigraphically restricted to or were most abundant within the lower 9.0 m of the unit, the equivalent of Zone 1. This pattern is well reflected in groups B and C, where samples contained abundant brachiopods of species other than *Zygospira* and *Rafinesquina* sp.. In B, despite differential sorting, fragmentation, and dissolution, samples still contained high abundances of *Plectorthis.* In C, both *Plectorthis* and *R. nasuta* were abundant. In addition, *Platystrophia* and *R. nasuta* were found only within Zone 1, and *Acidaspis*, *Cyclonema*, *Anomalodonta*, ostracods, and bryozoan colonies were more common. The presence of these taxa within the lower half of the Corryville Member does not appear to have been the result of taphonomic bias and may signify a larger ecological response to changing environmental conditions. At the top of the stratigraphic section, *Cyclora* was present. and fragmented skeletal material was less abundant (Fig. 45). Individual event horizons delineated by stratigraphically limited taxa (e.g. the *Heterorthina fairmountensis* bed of Dattilo, 1992) were not discovered during the course of this investigation, but these may lie within the upper Corryville section where bedding is more continuous. Edrioasteroid horizons have been collected within the upper Corryville Member from several geographically distant localities (Meyer et al., 1981; Rassmann, 1984; Meyer, 1990) and this may represent a single horizon.

The analysis of faunal distribution in the Corryville Member relied on observable associations of preservable hardparts that may or may not represent paleocommunities. It should be remembered that all skeletal material has an implicit connection to some form of previously existing community, even when the structure was not preserved. It is important to note here that variations in relative abundance of the same species within different samples may merely reflect an overprint by storm transport or differential preservation. Relative valve abundances must be used carefully in paleoecological investigations because these may be due to differential preservation (Velbel and Brandt, 1989). According to Boucot (1981), the natural fluctuation in dispersal patterns along the sea bottom may also be misleading in distribution analysis. Before recognizing species associations as an ecological "community", patterns of spatial variability must also be objectively evaluated (Springer and Miller, 1990). Multiple samples collected at intervals along single bedding planes would help to distinguish realistic faunal distribution trends (e.g. Lafferty, 1992). In this study, many group D samples varied only slightly from those from the other groups, and so there remains some question as to the validity of these faunal counts. Multiple samples would enable a more complete understanding of intracommunity variation within specific beds and intervals of the vertical section. Because of the stratigraphic relatedness of the samples of B and C, the presence of unique brachiopods does not appear to have been the result of a preservational bias.

Paleoecological Interpretation of Depositional Environment

Reconstruction of the Corryville paleoenvironment would be a difficult task at best because many environmental parameters are not preserved in the rock record. Nonetheless, some pertinent observations have been made as to the general environmental parameters of the Cincinnatian epeiric sea. Conditions were open marine (Osgood, 1970; Tobin, 1982; Jennette, 1986), and water depth was likely below the fair weather wave base but relatively shallow, no more than 30 m (Frey, 1987a). The abundance of trace fossils and the large size of filter feeding organisms indicate well oxygenated sea floor conditions with abundant suspended food resources (Osgood, 1970; Brandt, 1980; Frey, 1987a; Frey, 1987b; Lehman and Pope, 1989). Current energy was low but must have been present because abundant suspension feeders were dependent upon the prevailing circulation patterns for their nourishment (Harrison and Mahan, 1981). Salinity throughout Cincinnatian deposition was normal marine (Frey, 1987b), and the water temperature was probably quite warm considering the estimated paleolatitude. If the temperature did not change much throughout the year, then seasonal variations in faunal populations may have been a minimal factor in population dynamics.

The epeiric sea mud bottom has been interpreted as comparatively firm (Frey, 1987a), with hardgrounds and soft, unconsolidated muds. Many of the bottom-dwelling invertebrates were mobile and adapted for periodically high rates of sedimentation and temporary smothering (Frey, 1987b). Corryville taxa generally display adaptations that are suitable for muddy substrates in normally quiet waters. *Rafinesquina* have a flat, broad shell to reduce density, a broad, flat shape for equal weight distribution, a high commissure to allow feeding even when partially covered by mud, and a reduced size to sustain a low mass to surface area ratio (Richards, 1972; Alexander, 1975; Thayer, 1975; Lehman and Pope, 1989). Corryville *Rafinesquina* are geniculate and occasionally geniculate-alate, two morphotypes associated with habitats that experienced episodic and intensified rates of sedimentation (Alexander, 1975). *Zygospira* survived in muddy environments by attaching itself to a large skeletal fragments or stable, living organism (Richards, 1972). Bryozoan colonies may have adapted to the muddy bottom and high sedimentation rate by adapting the "iceberg strategy" of Thayer (1975), where colonies lay buried with only the living tops exposed above the muddy substrate (Frey, 1987a; Hinterlong, 1981). Crinoids lived either attached by a holdfast to a hard substrate or, in the case of *Pycnocrinus*, with the distal end of the stem coiled around an anchoring object such as a bryozoan colony (Harrison and Mahan, 1981), and bryozoans displayed all forms of morphologic adaptation from encrusting to ramose throughout the vertical section.

Storm events probably had complex effects on the benthic marine fauna. The imprint left by storm activity would have been dependent upon the duration and strength of the storm, the water depth, the proximality to the fairweather and storm wave bases, and the stability of the bottom substrate. Tempestites probably redistributed organic sediments along a vertical and horizontal gradient and altered the consistency and food content of the bottom for a biologically relevant post-storm period (Einsele et al., 1991). Tobin and Pryor (1985) listed seven ways by which Cincinnatian storm events may have affected the benthic ecology: (1) eroding sediments; (2) transporting allochthonous clays and silts into a carbonate ramp; (3) winnowing, transporting and redistributing carbonate sediments; (4) generating downslope gravity flows; (5) mixing benthic fauna from different communities; (6) periodically interrupting the process of community succession; and (7) creating favorable conditions for the evolution and success of opportunistic species. In cases of recolonization, storm bed surfaces could have been softgrounds or scoured firmgrounds and hardgrounds (Aigner, 1982).

In situ burial of communities or individual organisms by storm events appears to have been rare during Corryville time, and evidence of community succession was most likely destroyed by the tropical storms (Hinterlong, 1981; Kreisa and Bambach, 1982; Tobin and Pryor, 1985). However, such storm events may not have obliterated the original faunal associations. A study of molluscan prestorm and poststorm skeletal debris in St. Croix by Miller et al. (1992) demonstrated that, although some transport of shell material had occurred following the passage of Hurricane Hugo in 1989, a wholesale mixing of assemblages had not resulted. This would imply that post-storm community composition was preserved within the same environment, although the structure of that community was not. Because the Zygospira-*Rafinesquina* Community appears to be present throughout the Corryville Member, it does not seem unreasonable to suggest that admixing of taxa from adjacent environments had little affect upon the diversity of the faunal assemblages.

Before further paleoecologic interpretations can be advanced, taphonomic bias must be addressed. Hinterlong (1981) suggested that diversity within the Corryville Member was the result of long periods of environmental stability, but he did not address the relationship between faunal diversity and the preservation potential of the environment. A study by Cummins et al., (1986) along the Texas coast determined that death assemblages do not accumulate at the rate at which organisms die. Although skeletal material is generally preserved only when buried deeply, such as by storm events, the longer a skeleton remains in the environment, the greater its chances of being preserved (Cummins et al., 1986). Therefore an understanding of the duration of skeletal material within an environment is paramount to an assessment of the faunal diversity and distribution. A detailed taphonomic analysis can help to determine the extent to which storm activity affected the development of faunal assemblages, as well as the strength of diagenetic and sedimentologic biases.

Conclusions

1) Corryville fossil assemblages are polytaxic and dominated by epifaunal and semi-infaunal suspension feeders. Many taxa display morphologic adaptations for a normally low energy environment with at least partially muddy sea bottom. The dominant Corryville taxa are *Rafinesquina*, *Zygospira*, pelecypods (primarily *Ambonychia*, *Modiolopsis*, and *Caritodens*), ramose bryozoans, and trilobites (primarily *Isotelus* and *Flexicalymene*).

2) Several Corryville species are range restricted within the vertical stratigraphic section at Stonelick Creek. *R. nasuta* and *Platystrophia* were generally restricted to the lower 9.0 m of the Corryville section, and *Plectorthis* is present only within the lower 9.0 m and the carbonate facies of small-scale bedding sequences in the upper half of the section. These can possibly be used for a generalized stratigraphic correlation.

3) Faunal assemblages differ primarily in the relative abundance of the same species. Five varying faunal compositions were identified through a multivariate analysis of bed samples: (1) *Zygospira*-pelecypod dominated beds, (2) beds with high *Plectorthis-Zygospira* ; (3) beds of high *R. nasuta* and *Plectorthis*, but low *Rafinesquina* sp.; (4) beds dominated by *Rafinesquina* sp.; and (5) beds of moderately high to high amounts of *Rafinesquina* sp., *Zygospira*, bryozoans, and trilobites. Faunal distribution did not correspond well with small-scale bedding cycles, however many of the samples collected from shale facies of cycles did display similar variations in the rank abundance of common taxa and taxonomic groups.

TAPHONOMY

"The utilization of taphonomic information to formulate biostratinomic models for modern and ancient assemblages has become a potentially powerful tool in paleoecologic analysis" (Davies et al., 1990).

Introduction

Taphonomy, the study of fossil preservation, has received considerable attention in the past decade as a means of characterizing fossil death assemblages and evaluating bias in the fossil record (for historical review see Behrensmeyer and Kidwell, 1985; Wilson, 1988). Recent work has emphasized the more positive aspects of taphonomy, in particular the ability of taphonomic indicators to delineate paleodepositional dynamics and parameters (e.g. Brandt, 1985; Kidwell, 1986; Speyer and Brett, 1988). Implicit to taphonomy is the assumption that the taphonomic alteration of skeletal elements varies in a predictable way with depositional setting (Brett and Baird, 1986; Davies et al., 1990). In the mind of the modern taphonomist, fossils are essentially biogenic sedimentary particles that represent the entirety of processes that affected them previous to their discovery as fossils (Seilacher, 1973). Consequently, taphonomic indicators can provide information concerning subtle paleodepositional changes that might not be determined through a purely sedimentologic investigation.

Taphonomy can be conveniently subdivided into biostratinomy, the pre-burial physical processes that affect and alter organic particles, and burial diagenesis, the physical and chemical processes that affect the particles once initial burial has been completed (Brett and Baird, 1986). Biostratinomic information is more closely tied to paleoenvironmental dynamics and can provide information concerning: (1) relative rates of deposition (e.g. Brandt Velbel, 1985; Brett and Baird, 1986); (2) the relative surface residence time of fossil deposits (e.g. Brett and Bordeaux, 1990) (3) the relative paleobathymetry and basinal setting (e.g. Kidwell et al., 1986; Norris, 1986); (4) the relative oxygenation of the bottom waters (e.g. Brandt, 1980b; Brett and Baird, 1986; Brett and Speyer, 1988); (5) relative level of environmental energy, or turbulence (e.g. Brett and Baird, 1986; Brett and Speyer, 1988); (6) the difference between time-averaged and time-specific assemblages (e.g. Brandt, 1989; Meyer, 1990); and (7) the behavioral response of extinct taxa to abrupt changes in environmental conditions (e.g. Morris et al., 1971; Speyer, 1987). Differential fossil preservation can help to clarify changes in the depositional regime with respect to time, and when used in conjunction with sedimentologic information, can result in a more effective, detailed paleoenvironmental description.

Cincinnatian taphonomic investigations have targeted specific taxa (e.g. Brandt Velbel, 1985; Holland, 1988) and smothered assemblages (e.g. Schumacher, 1984; Meyer, 1990), but have rarely focused on the larger stratigraphic intervals. The Corryville Member of the Grant Lake Formation is a poorly known stratigraphic interval well-suited for a detailed taphonomic analysis. In addition to a well-preserved fossil biota with a variety of diverse preservational modes, the Corryville Member was deposited in a normally quiet, low energy environment between normal and storm wave bases (Tobin, 1982), which, according to Speyer and Brett (1988), should provide optimal skeletal preservation. The lower contact of the Corryville Member has been interpreted as an abrupt marine transgression, and taphonomy will be used to examine the extent and intensity of that event.

With the Corryville Member now recognized as a distinct, quiet water lithofacies (Tobin, 1982), further work must be completed to determine whether this interval represents a unique taphonomic facies, or taphofacies. Among other issues, taphonomy must explain the observed variations in limestone thickness and preservational signature, the extent to which storm activity has altered the diversity of fossil assemblages, the relative rate of deposition, and the mode and occurrence of well-preserved assemblages. Comparative taphonomy, the study of differential preservation of fossils both within and between facies (Brett and Baird, 1986; Speyer and Brett, 1986), has been especially effective as a stratigraphic tool to examine inferred environmental gradients (e.g. Aigner, 1985; Norris, 1986; Brett and Speyer, 1986; Brett and Speyer, 1988) and isochronous event horizons (e.g. Parsons et al., 1988). This study will complete a taphonomic description of the Corryville Member through the application of previously developed comparative taphonomic techniques, with an emphasis on a quantitative examination of biostratinomic properties.

Previous Work

The concept of taphonomy has been understood for over half a century (Efremov, 1940), but until the mid 1980s, taphonomy was mainly promoted as a means to demonstrate the general inadequacies of the fossil record in preserving community structure (e.g. Lawrence, 1968). Comparative taphonomy was the first quantitative to semiquantitative method created to describe the particular physical, chemical, and biological signatures associated with the formation of fossil assemblages (Brett and Baird, 1986; Speyer and Brett, 1986). This model operates on the assumption that taphonomic properties are the products of specific environmental conditions (Brett and

Baird, 1986). Various comparative taphonomic features and their implications were summarized by Speyer and Brett (1988, Tables 1-7).

In many cases, the most efficient approach for the description of a facies or stratigraphic interval is to employ a diagnostic system based upon a suite of varying taphonomic attributes. The "taphofacies concept" (Brett and Baird, 1986; Speyer and Brett, 1986; Speyer and Brett, 1988) was introduced to define relative grades of preservation to differentiate facies and environmental gradients. Brett and Speyer (1988) defined a taphofacies as a stratigraphic body of rock with a particular suite of taphonomic properties that distinguishes it from contiguous bodies of rock. However, taphofacies are distributed independently of sedimentary facies and are primarily controlled by sedimentation rate and substrate oxygenation (Speyer and Brett, 1988). Taphofacies analysis is a valuable tool for detecting and describing small-scale environmental changes (Staff and Powell, 1990). An alternative system of "taphonomic grades" was proposed by Brandt (1989) for a high resolution, bed-by-bed analysis of taphonomic and sedimentologic attributes. In contrast to the taphofacies concept, "taphonomic grades" emphasized the amount of relative time represented within a single bed or in larger-scale depositional units. that characterize varying intensities of reworking, transport, and accumulation. Many taphonomic attributes have a less likely chance of being preserved in the fossil record, and a system for describing fossil preservation must be coordinated around those attributes that have the strongest and most variable signals (Staff and Powell, 1990).

Many taphonomic attributes can be used to describe the preservational style of an assemblage, regardless of taxonomic affinities (Brett and Baird, 1986). For the most part, preservational quality is controlled by biostratinomic and early diagenetic processes that are distributed nonrandomly in the fossil record (Brett and Baird, 1986). Key biostratinomic processes include reorientation, disarticulation, fragmentation, sorting, and corrasion, the parameters of which have been summarized by Brett and Baird (1986). These processes occur at or near the sediment-water interface and can reveal information concerning the relative amount of pre-burial transportation and the relative length of time between mortality and initial burial. Staff and Powell (1990) found that taphonomic attributes associated with depth, such as fragmentation and disarticulation, are more likely preserved than attributes such as dissolution that are more closely associated with sediment size. Early diagenetic phenomena are regulated by oxygen levels, bioturbation rates, and chemical saturations (Speyer and Brett, 1986, 1988). Early diagenesis can include exhumation of particles, and their subsequent reburial and different skeletal types will respond differently to the same environmental processes (Speyer and Brett, 1986, 1988). Rapid burial of skeletal material to a depth where the rate of decay is low has been attributed to increased preservation (Cummins et al., 1986).

The preservation of biogenic structures can also be used for the analysis of paleoenvironmental conditions, particularly in the absence of body fossils (Boucot, 1981; Meyer et al., 1981; Brandt Velbel, 1985; Bromley and Ekdale, 1986). Whereas skeletal material can represent multiple episodes of reworking, trace fossils are almost always *in situ* and can reflect temporal changes in environmental conditions as well as changes in the infaunal community (Bromley and Ekdale, 1986). Wetzel and Aigner (1986) used ichnofossil tiering patterns to develop a method of estimating the minimum stratigraphic thickness removed by storm-related sea-floor erosion. This technique, based upon the differential truncation of burrow tiers in sediments below a tempestite bed, may be less effective for Early Paleozoic deposits, where infaunal burrowing did not exceed an approximate depth of 6 cm (Ausich and Bottjer, 1982).

The need for more objective, genetic, and quantitative taphonomic description techniques has been recognized (Kidwell et al., 1986; Droser and Bottjer, 1987; Davies et al., 1990). To compare taphonomic criteria effectively between individual beds and taphofacies, a classification system must be developed that is standardized, reproducible, and statistically testable. In addition, this system must be able to encompass the full range of taphonomic variability observed within a particular fossil assemblage. Early Phanerozoic environments are not precisely analogous to modern and Late Phanerozoic environments because of variations in faunal composition and bioturbation over geological time (Thayer, 1979; Kidwell et al., 1986); therefore the taphonomic characteristics used to describe Miocene pelecypod deposits (as in Kidwell et al., 1986) are not necessarily sufficient to describe Early Paleozoic brachiopod-dominated deposits. This thesis will utilize standard comparative taphonomic terminology (as suggested in Brett and Baird, 1986; Kidwell et al., 1986; Droser and Bottjer, 1987; Davies et al., 1990), but will perforce adapt such terminology for the description of Upper Ordovician skeletal deposits.

Methods

A taphonomic study of the Corryville macrofauna was completed at the proposed Corryville Member type-section (Schumacher et al., 1991) at Stonelick Creek in Stonelick Township, Clermont County, Ohio in the summer and fall of 1990. Eight stream exposures were measured, and the macrofauna of each bed was noted and briefly described. All shale and limestone horizons containing unique and well-preserved fossil deposits were noted. For the comparative taphonomic analysis, thirty-six bulk limestone samples were collected from two separate stream exposures (Fig. 14, exposures 1 and 2) that together represented the entire Corryville interval. These same samples were used for the faunal distribution analysis of this investigation, and preparatory techniques were previously described within that chapter.

In the laboratory, a dissecting microscope was used to examine the taphonomic character of the fossil material on each bulk sample. When obscured by a thin silt layer, bedding surfaces were lightly cleaned using an air abrasive with dolomite grit. Brachiopod, gastropod, pelecypod, and cephalopod shells were identified, when possible, to the generic level. Pelecypod molds were tentatively identified to generic level based on valve shape. Bryozoans were subdivided into the five following macroscopic morphotypes: small ramose (diameter < 2 mm), large ramose (diameter > 2 mm), foliate, encrusting, and massive (colonies displaying near complete preservation). Crinoids and trilobites were commonly represented as disarticulated, unidentifiable skeletal fragments; the taphonomic attributes were necessarily generalized for these two taxonomic groups.

Selected taphonomic attributes, listed in Table 5, were quantitatively or semiquantitatively examined from the identifiable macrofossils (generally > 2

Table 5 - List of taphonomic attributes examined within this study.

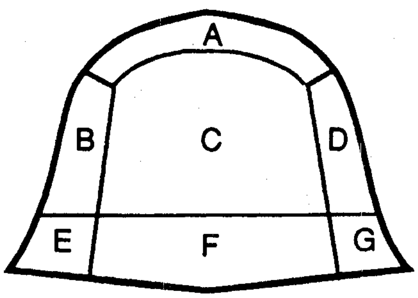
Faunal Group	Taphonomic Attribute
Brachiopods:	Amount of articulated vs. disarticulated material Amount of pedicle vs. brachial valves Shell location of fragments Location of breakage on valve Orientation of anteriomedial axis (degrees) Orientation of hinge (degrees) Hinge inclination (degrees from horizontal) Shell/axis inclination (degrees from horizontal) Relative edge condition Relative amount of corrasion Encrustation (% area) Amount of predational boring Amount of mud sheltering Amount of geopetal structiures
Bryozoans:	Length of fragment (mm) Azimuth of fragment (degrees) Axis of inclination (degrees from horizontal)
Crinoids:	Diameter of columnal (mm) Percentage whole vs. broken columnals Relative amount of corraded columnals
Trilobites:	Maximum Length of exoskeletal fragment (mm) Pyritization of fragment
Pelecypods:	Relative amount of wholeness of specimen Amount of left vs. right valves Hinge length (mm) Orientation of anteriomedial axis (degrees) Mode of preservation Encrustation (% area)

mm in size) observed along bedding surfaces. Most skeletal material within beds was well-cemented and did not survive sample splitting in a condition satisfactory for taphonomic analysis. The abundance of surface skeletal material and the uniformity of preservational states within each bed were considered proof against any possible sampling bias that may have resulted from the selective study of surface specimens. All lengths and diameters were measured with a dial caliper exact to the nearest 0.1 mm. *Rafinesquina* material was subdivided into shell quadrants (see Davies et al., 1990, Fig. 1, for a similar treatment of pelecypods) so that preferential breakage, corrasion, and fragmentation could be located specifically on the shell (Fig. 51). A relative scale system was used to quantify the amount of shell material within individual *Rafinesquina* specimens (Fig. 51). Articulated specimens represent a "1", and the most fragmented specimens are a "6". Azimuthal orientations were measured with a Brunton compass, with readings taken in relation to the bedding surface, normally the horizontal plane.

For this investigation, trends in orientation data were analyzed by plotting directions as two-dimensional orientation vectors (as described in Davis, 1986, Chapter 5; and in Cheeney, 1983, Chapter 8). A distinction is commonly drawn between single "directional" characteristics (e.g. a 173° current direction) and bi-directional "orientation" features (e.g. a north-south trending anticlinal fold) because these two forms of data must be treated separately (Cheeney, 1983). To treat the orientation data in the same manner as the directional data, all orientation measurements were doubled. To standardize all data, doubled measurements > 360° had 360° subtracted. After all calculations were complete, transformed data were halved to return them to their normal state (Davis, 1986). To find the mean direction, θ, of a set of orientations, degree measurements were translated to polar coordinates, and a resultant vector, r,

Figure 51 - Brachiopod shell description and relative scaling system. Valves are divided into seven quadrants to allow for the identification of preferential biostratinomic alteration. The scaling system describes semiquantitatively the relative amount of shell material remaining per specimen.

Brachiopod Shell Description



A	anterior valve margin
B & D	central-lateral valve margins
C	central valve
E & G	posterior-lateral valve margins
F	central-posterior valve margin, beak

Relative Scaling System

Scale	Description
1	articulated valves
2	single, whole disarticulated valve
3	single valve, < 10% missing
4	single valve, 10% - 50% missing
5	single valve, 50% - 90% missing
6	single valve, < 10% remaining

was computed. To calculate the mean resultant length (unit length), R and thus standardize all sample resultants, r was then divided by n, the number of measurements in the sample set. This mean resultant length is a magnitude of the strength of the mean direction and signifies the overall vector distribution. A von Mises distribution was assumed for all data based upon an examination of the single plotted vectors. Error bars (95% confidence) were determined for all resultants > 0.35 using the technique described by Cheeney (1983, p. 100-101, equation 8.10) and the concentration parameter estimates from Davis (1986, Table 5.6).

Results

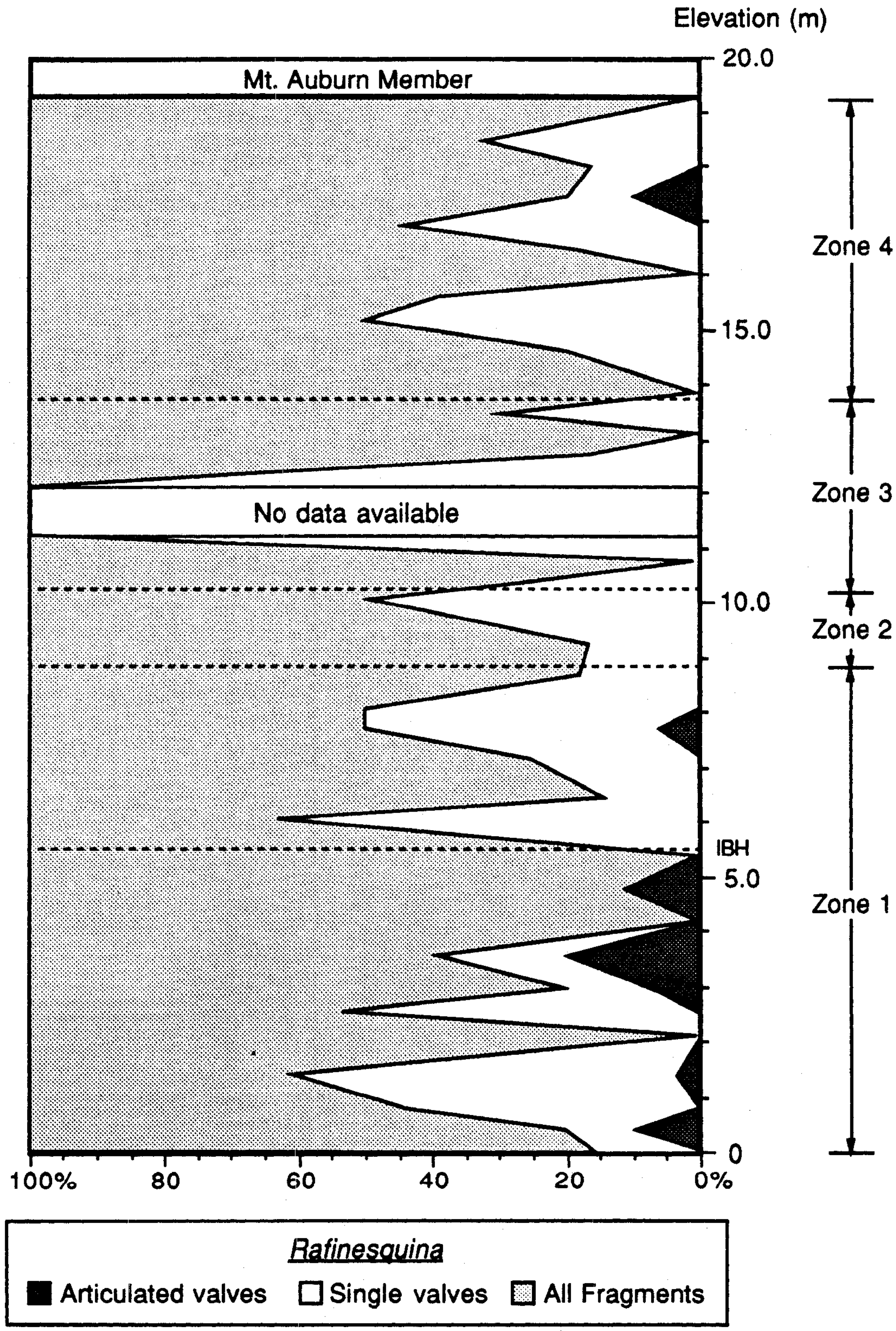
Various taphonomic processes were investigated through the comparative description of macrofossils within the collected bulk samples. As with previous "tapho-stratigraphic" studies (e.g. Krumpolz, 1980; Parsons et al., 1988; Speyer and Brett, 1986, 1988; Brett and Bordeaux, 1990), this thesis utilized both field observations and laboratory analysis; in this case, however, all primary biostratinomic trends within the vertical section were derived from the samples and field observations were supplemental. This emphasis on laboratory examination was preferred because it allowed for more quantifiable, objective results gathered through easily reproduced techniques. Taphonomic details will be described in terms of five broad biostratinomic processes: disarticulation, fragmentation, corrasion, reorientation, and sorting. In addition, fossil diagenesis, ichnofossil occurrence and condition, and fossil Lagerstätten will be discussed within this section. All taphonomic trends will be discussed in relation to the stratigraphic section. Samples, when specifically mentioned, will be referenced by the bed number, exposure number, and the height above the base of that measured exposure. For example, 95-2 (7.7 m) means bed 95 of exposure 2, situated 7.7 m from the base of the exposure.

Disarticulation

Disarticulation was defined by Speyer and Brett (1988, p. 248) as the disintegration of skeletons along natural joints as a result of the bacterial deterioration of connective tissues. Recent studies have shown that modern crinoid and arthropod skeletal material undergoes rapid post-mortem disarticulation in the absence of rapid burial (Meyer and Meyer, 1986; Plotnick, 1986). The differential disarticulation of such material can therefore be used to estimate the relative burial rates and autochthony of fossil assemblages (Speyer and Brett, 1986; Speyer, 1987; Meyer et al., 1989). Most fossil assemblages within the Corryville interval were dominated by disarticulated skeletal parts. The multi-elemental skeletons of echinoderms and trilobites were typically preserved as discrete, disarticulated hardparts and only rarely preserved as articulated specimens. Because no partially articulated echinoderm or trilobite specimens were observed in samples (e.g. isolated calices), these taxa were less suitable for the study of gradational disarticulation. Pelecypods were typically preserved as molds of disarticulated valves, and *Caritodens*, the sole calcitic pelecypod, was always observed in a disarticulated state.

Corryville brachiopods displayed a greater tendency towards articulation. Post-mortem disarticulation of typical bivalved organisms occurs at a rapid pace (Brett and Baird, 1986), suggesting that articulated specimens were buried alive or rapidly after the moment of death. The ratio of articulated to disarticulated specimens varied with different species. In *Zygospira,* approximately half of all described specimens were articulated, but this number represented a minimum estimate; the true proportion was probably much greater The high degree of articulation in *Zygospira* has been attributed to its interlocking hinge dentition (Sheehan, 1978; Schumacher, 1984). Large numbers of single valves of this type of brachiopod are indicative of extremely rough water conditions (Sheehan, 1978). *Rafinesquina* was less commonly articulated, and most articulated specimens were observed in samples from Zone 1 (Fig. 52). The most articulated large brachiopods were observed in sample 27-2 (3.52 m), a wackestone that contained abundant articulated *R. nasuta*. These specimens were pristine and in an inclined to convex-upward orientation.

Figure 52 - Relative preservation and articulation of all Rafinesquina sp. material throughout the Corryville stratigraphic section. Note that articulated specimens are more abundant within Zone 1. The base of the Corryville Member is set at the 0 m elevation.


Elevation (m)
20.0
15.0
10.0
5.0
0
IBH
Mt. Auburn Member
No data available
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Rafinesquina
Articulated valves
Single valves
All Fragments

Fragmentation

When skeletal material is broken by mechanical force without regard for natural joints or articulations, the process is referred to as fragmentation (Speyer and Brett, 1988). Bivalved and univalved organisms are subject to breakage depending upon their robustness and mode of life (Speyer and Brett, 1988). Differential breakage in brachiopods can be due to hinge configuration, valve thickness, and geometry (Sheehan, 1978; Holland, 1988; Velbel and Brandt, 1989). In particular, the taphonomic attributes of smaller shell fragments must be examined because they have a lower preservation potential and so are the source of particularly useful taphonomic aspects (Staff and Powell, 1990). Corryville brachiopods displayed variable degrees of fragmentation and this was an excellent, quantifiable trait for the estimation of environmental energy and reworking. Borings and other evidence for predation and bioerosion were minimal and difficult to identify and may not have been an important factor contributing to fragmentation. All bulk samples contained abundant, tiny (< 1 mm), unidentifiable bioclastic fragments, but material of this size was inadequate for comparative taphonomy.

Both pedicle and brachial *Rafinesquina* valves displayed variable fragmentation (Fig. 53). Articulated and whole *Rafinesquina* were more abundant within samples collected from the lower 9.0 m of the Corryville section (Zone 1). One-third of all specimens were preserved as single or articulated whole valves, and in slightly more than half of all fragments, 25% or less of the original valve remained. No preferential fragmentation of *Rafinesquina* pedicle or brachial valves was observed, although margin fragments were more abundant than fragments from the central or beak area of the shell. Figure 54 displays the relative preservation of *Rafinesquina* specimens by taphonomic

Figure 53 - Relative abundance of various types of *Rafinesquina* sp. fragments. Data represents all specimens described from the bulk samples (n = 469). No single preservational condition was dominant.

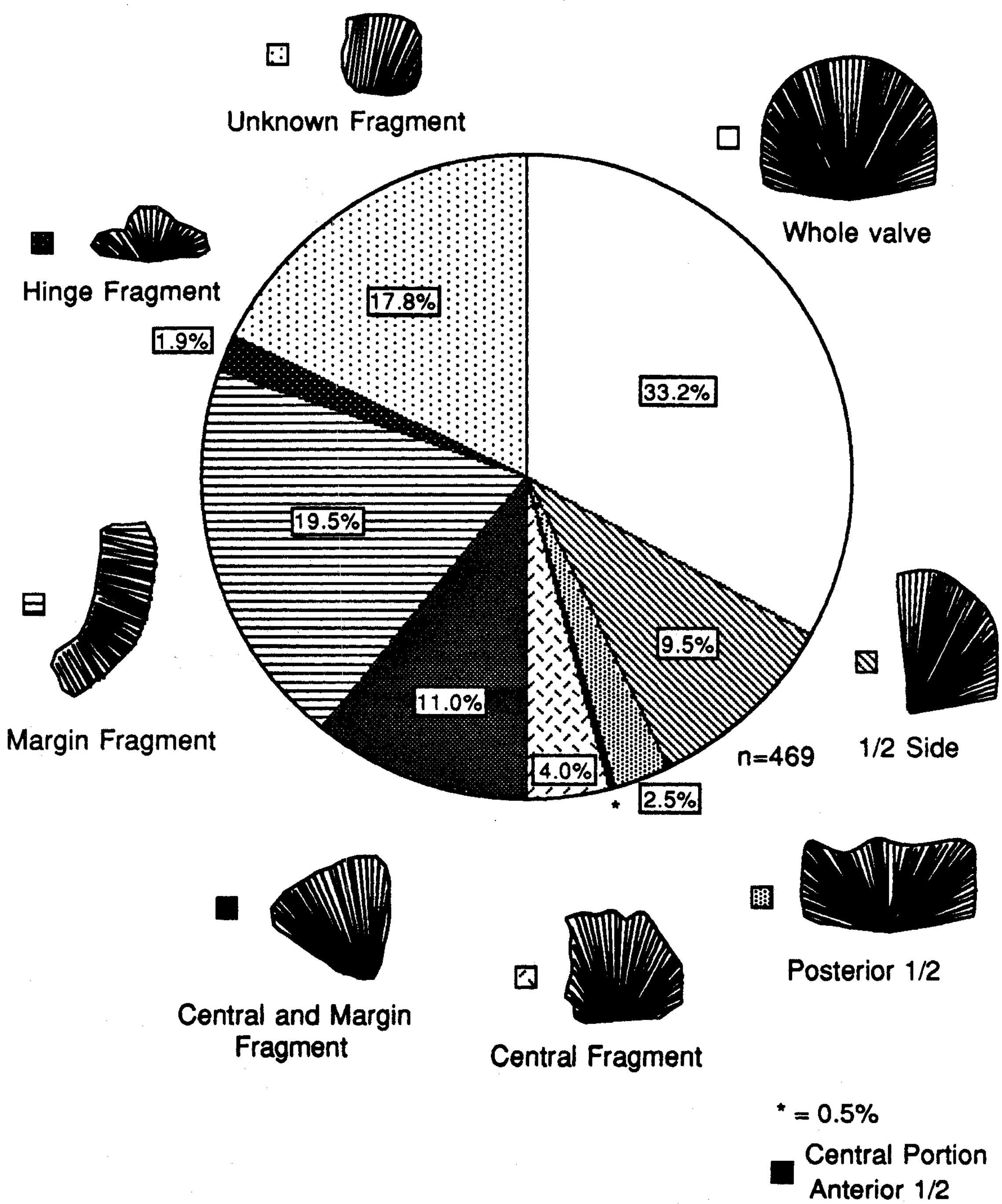
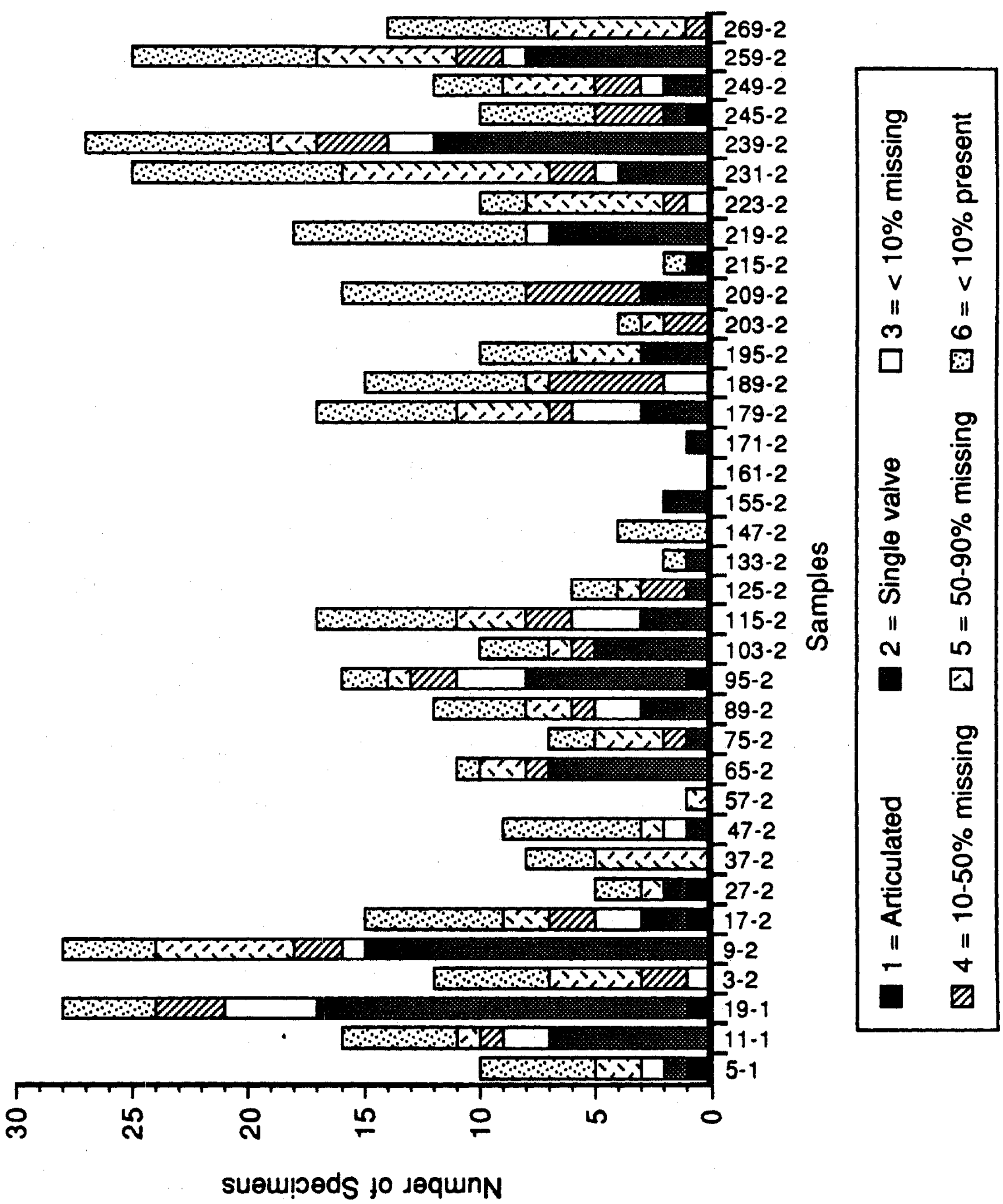

Unknown Fragment
Whole valve
Hinge Fragment
17.8%
1.9%
33.2%
19.5%
Margin Fragment
9.5%
11.0%
4.0%
n=469
1/2 Side
* 2.5%
Posterior 1/2
Central and Margin Fragment
Central Fragment
* = 0.5%
Central Portion Anterior 1/2

Figure 54 - Fragmentation of *Rafinesquina* sp. per sample as defined by the by the relative scaling system for brachiopods. Samples are arranged in ascending stratigraphic order from left to right. Samples with 5 or more specimens all display variable states of fragmentation.

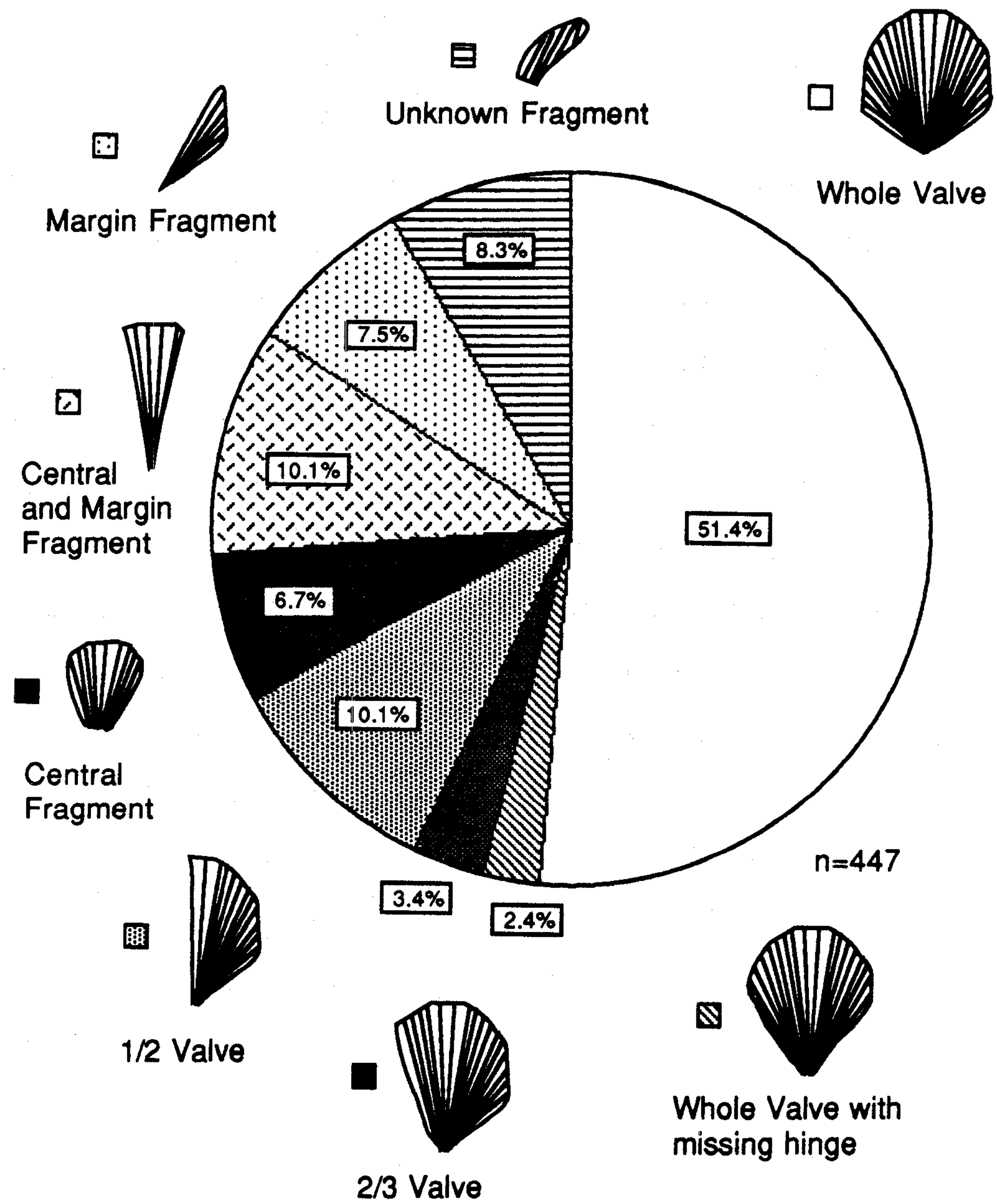

Number of Specimens
Samples
1 = Articulated
2 = Single valve
3 = < 10% missing
4 = 10-50% missing
5 = 50-90% missing
6 = < 10% present
5-1
11-1
19-1
3-2
9-2
17-2
27-2
37-2
47-2
57-2
65-2
75-2
89-2
95-2
103-2
115-2
125-2
133-2
147-2
155-2
161-2
171-2
179-2
189-2
195-2
203-2
209-2
215-2
219-2
223-2
231-2
239-2
245-2
249-2
259-2
269-2
0
5
10
15
20
25
30

scale per sample. Samples are arranged in ascending stratigraphic order from left to right. Samples with abundant to moderate amounts of *Rafinesquina* generally contained a mixed taphonomic signature for fragmentation. Bryozoan encrustation of *Rafinesquina* fragments was common and may have protected larger pieces of shell from advanced fragmentation.

In *Zygospira*, fragmentation tended to occur most often along, rather than across, plications, similar to the fracture pattern noted in *Platystrophia* (Holland, 1988; Velbel and Brandt, 1989). Less than half of the described *Zygospira* material was fragmented, and fragments generally represented less than half of the original valve (Fig. 55). *Zygospira* fragments were most abundant in Zone 1, and in several samples in Zone 4. Smaller, light shells should suffer the least amount of fragmentation, and samples in which *Zygospira* material has been disarticulated and subsequently fragmented indicated higher energy events or a longer span of surface exposure time. Most samples displayed a combination of articulated and fragmented valves. The four bulk samples dominated by fragmented *Zygospira* material did not correspond to a single carbonate texture and were not restricted to a particular interval of the stratigraphic section.

Many complete to nearly complete *Rafinesquina* valves appeared to have undergone *in situ* compaction and fracturing; this phenomena was most apparent in grainstones. Relatively high frequencies of intact shell fractures were observed in grainstones and grainstone-packstones situated at the base of the unit and in the interval from 16.4-16.9 m above the base. This upper interval corresponded with the carbonate facies of a small-scale bedding sequence in Zone 4. Moderate amounts of valve fracturing were seen in packstones collected in the 12.5-16.0 m interval; these fractures were concentrated along the shell margins. No breakage was observed in samples from the remainder of the section. In the samples with relatively high

Figure 55 - Relative abundance of various types of *Zygospira* fragments. Data represents all specimens described from the bulk samples (n = 447). Articulate specimens compose more than half of all identifiable specimens.



Unknown Fragment
Whole Valve
Margin Fragment
8.3%
7.5%
Central
and Margin
Fragment
10.1%
51.4%
6.7%
Central
Fragment
10.1%
n=447
3.4%
2.4%
1/2 Valve
2/3 Valve
Whole Valve with
missing hinge

frequencies of shell fracturing, fractures were located throughout the shell, but somewhat concentrated along the anterior margin and the region of the beak. Neither articulated valves nor isolated disarticulate pedicle and brachial valves appeared to be preferentially fractured.

Bryozoan material was almost always fragmented, however the relative amount of breakage could not be estimated because the original colony structure was not known. Preservation varied from small (< 2 mm), corraded fragments to rare, massive colonies (*Parvohallopora*, *Monticulopora*) preserved within both limestones and shales (Fig. 56). Colonies were particularly abundant within the lowest 9 m of the unit and were generally observed as toppled or overturned with obvious predational boring. Fragment length was measured and will be discussed in the section on sorting processes.

Crinoid skeletons were typically disarticulated, and stem fragments were rare, commonly composed of less than 7 articulated columnals. One crinoid-rich shale bed at the center of Zone 3 in exposure 2 yielded continuous *Pycnocrinus* and *Cincinnaticrinus* stems of 30 cm in length; these stems were fragmented into smaller segments that contained up to 30 or more articulated columnals. The fragmentation of individual columnals suggests higher levels of environmental energy or extended periods of reworking. All broken columnals were corraded, and this suggests that breakage reflects an extended exposure to higher energy environmental conditions. The relative abundances of fragmented and whole columnals within a sample did not correlate with carbonate texture and did not vary systematically within the stratigraphic section (Fig. 57). The sharp spike at 4.15 m is misleading; only three columnals were recovered from this wackestone, and two of those were broken.

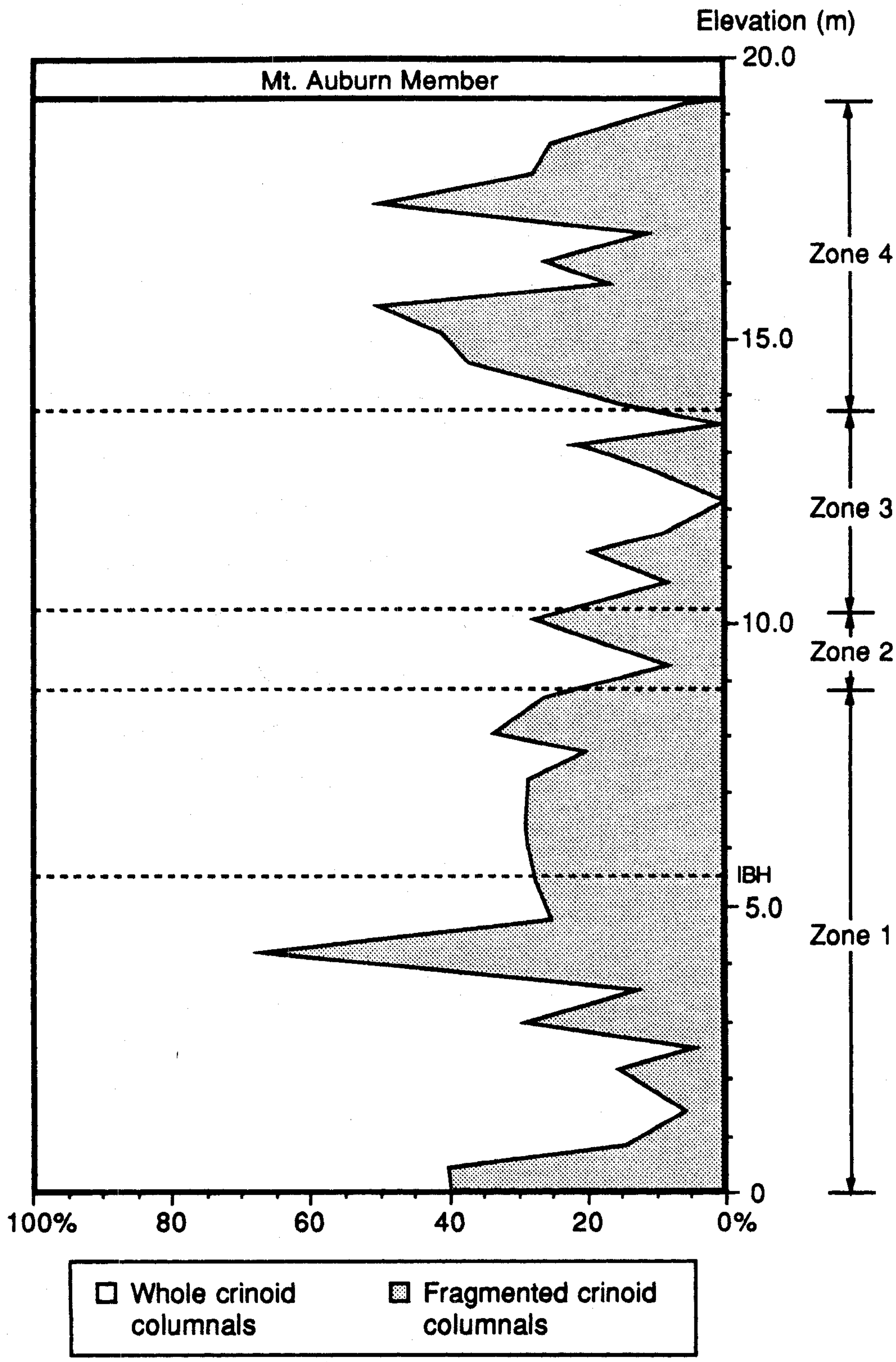
Pelecypod, gastropod, and cephalopod material was neither sufficiently abundant enough nor sufficiently well-preserved for a comparative examination

Figure 56 - Preserved *in situ* bryozoan colonies at Stonelick Creek, Clermont County, Ohio. a) *Parvohallopora* colony was collected from center of 24 cm-thick shale in Zone 4 (Bed 214-2, 13.33 m). Abundant, articulated *Zygospira* were present at the base of this colony. b) *Monticulopora* (?) colony collected from limestone bed in Zone 1 (Bed 75-2, 46.4 m).

A

B

Figure 57 - Relative percentage of broken and unbroken crinoid columnals throughout the Corryville stratigraphic section. The base of the Corryville Member is set at the 0 m elevation. The high percentage of broken columnals at 4.15 m is misleading; only three columnals were present, and two of those were broken. No strong trend in the fragmentation of columnals was identified.



Elevation (m)
20.0
Mt. Auburn Member
15.0
10.0
IBH
5.0
0
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Whole crinoid columnals
Fragmented crinoid columnals

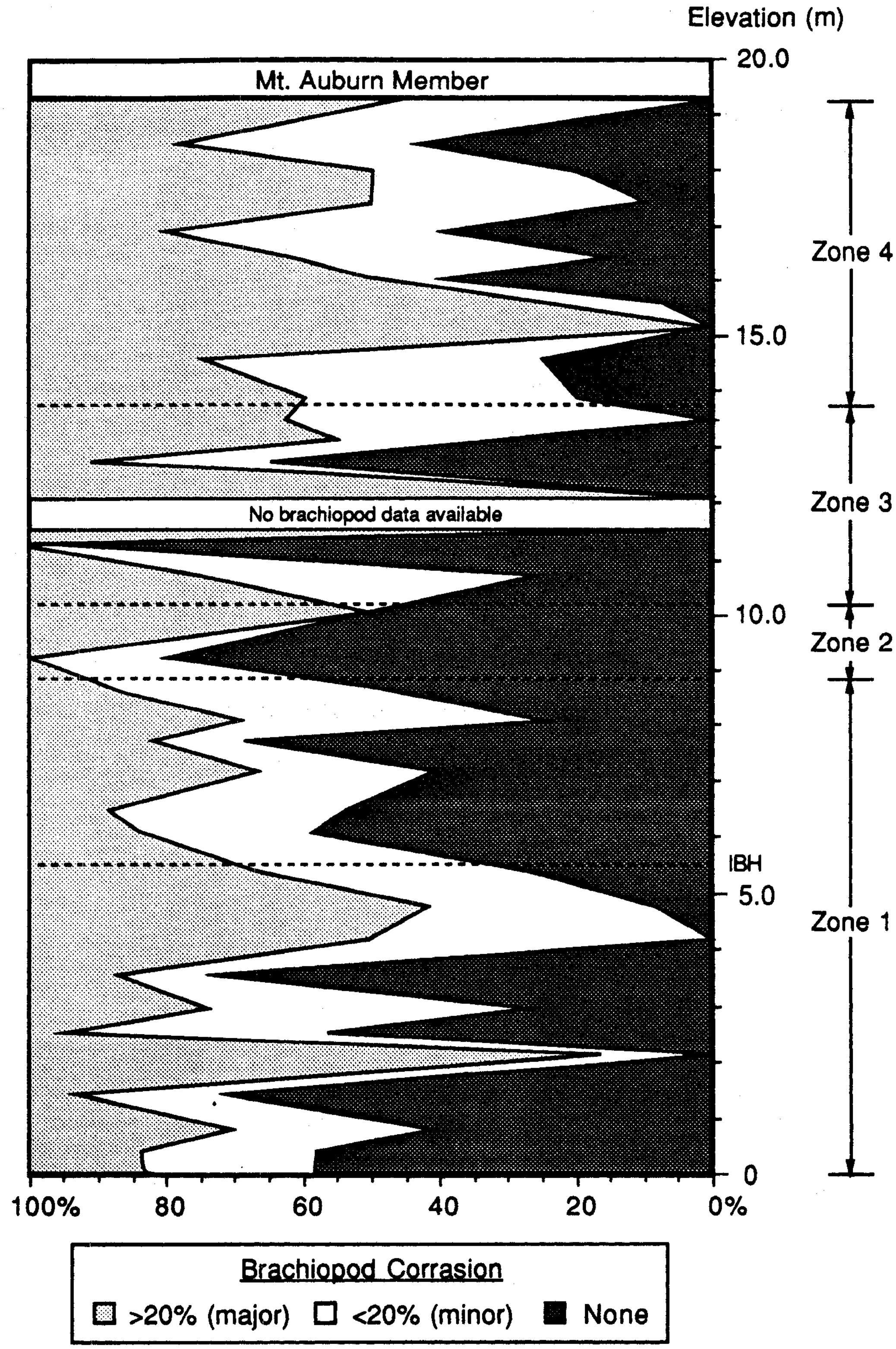
of fragmentation. In cephalopods, preservation was primarily as internal molds where the internal chambers were infilled with silt, mud, and, rarely, fossil debris. The best preserved cephalopods were those that had been encrusted by bryozoans. Phragmocones and living chambers were absent, suggesting preferential breakage of the more fragile and distal areas of the shell and an extended period of pre-burial surface exposure. Most pelecypod material was also moldic, and cross-sections of bivalve molds revealed that all were single valves. Pelecypods were commonly delineated by a thin carbonaceous lining, possibly the remnant of the periostracum, that displayed no sign of pre-dissolution fragmentation or compaction. Preservation was such that only the large and whole impressions were identifiable; smaller pelecypod fragments were either not preserved or simply beyond macroscopic recognition. Estimates of valve ratios and measurements of anterior-posterior lengths could not be completed; approximately 60% of all valves could not be taxonomically identified, but the remainder consisted of equal numbers of right and left valves.

Corrasion

An examination of relative corrasion (the cumulative effect of dissolution, abrasion, and corrosion) can help approximate the amount of time represented by a particular fossil deposit and the surface residence time of the component materials (Brett and Baird, 1986; Davies et al., 1989). Brachiopod shells and crinoid ossicles have fine growth lines and facets, respectively, that were used to determine levels of relative corrasion semiquantitatively. Most corrasion appeared to be a combination of mechanical wear (abrasion) and dissolution, but not advanced corrosion. Etching, enhanced sculpture, granulated texture, and pitting were rare to nonexistent. No instance of differential corrasion on a single specimen were observed (e.g. Brett and Baird, 1986, p. 212). The effects of corrasion were also recognized in bryozoan specimens, but these were difficult to estimate and not as accessible for macroscopic study. Trilobite sclerites were not much corraded; the calcium chitinophosphate exoskeleton of trilobites was probably more resistant to corrasion even over long periods of exposure on the sea floor (Brett and Speyer, 1986, 1988).

Articulate brachiopods, in particular *Rafinesquina*, have many fine costae and growth lines that will reveal minor (< 20%) or major (> 20%) amounts of corrasion. Corrasion greater than 20% was identified as a wearing down of the plications and secondary shell, whereas minor corrasion was simply an indication that some shell removal had occurred. Almost all of the samples displayed a mixture of corraded and pristine shell material, but no positive relationship was established between carbonate texture and relative corrasion. Overall, articulated brachiopod valves displayed little to no corrasion, and strong corrasion was restricted to the smaller skeletal fragments. Corrasion of valve material, where present, was pervasive and not localized along a particular surface or side. In Figure 58, relative corrasion of all large brachiopod shells (*Rafinesquina*, *Plectorthis*, *Platystrophia*, *R. nasuta*, and *Onniella*) was plotted against the stratigraphic section. *Zygospira* was excluded from this data because its small size and robust costae were markedly dissimilar from those of the other taxa. Samples from Zone 4 generally contained more corraded brachiopod material than samples from the other three zones. There appeared to be a rough correspondence between increased corrasion and carbonate cycle facies, except for the sample at 15.2 m. Samples 3-2 (2.1 m) and 37-2 (4.2 m) were a packstone-grainstone and wackestone, respectively, that contained unusually high amounts of fragmented and corraded brachiopod valve material.

Figure 58 - Relative corrasion of articulate brachiopod valve material throughout the Corryville stratigraphic section. The base of the Corryville Member is set at the 0 m elevation. Major corrasion (> 20%), minor corrasion (<20%), and lack of corrasion were observed for all large brachiopods, including Rafinesquina sp., *Rafinesquina nasuta*, *Onniella*, *Platystrophia*, and *Plectorthis*. *Zygospira* was excluded because of its small size and robust costae.



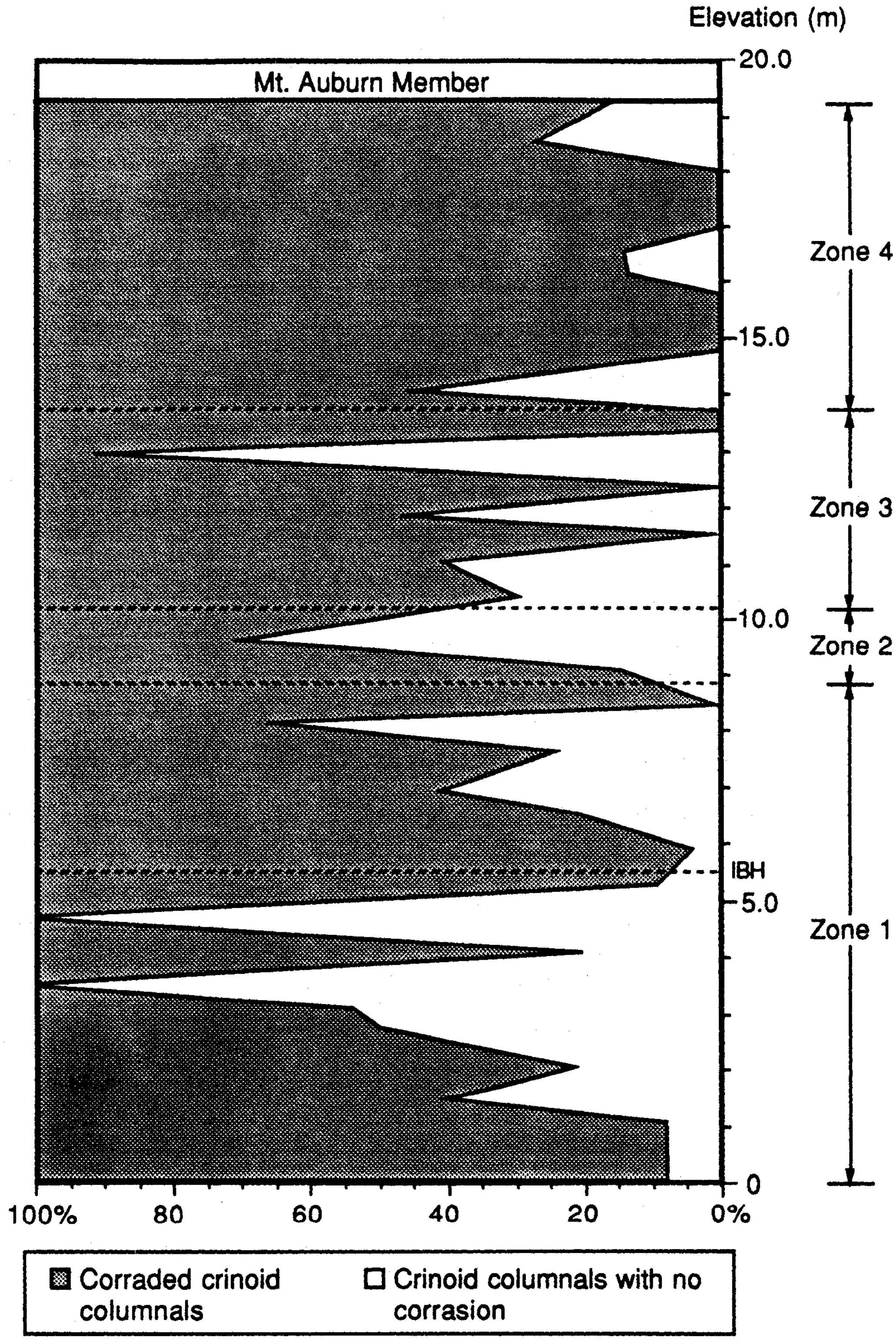
Elevation (m)
20.0
15.0
10.0
5.0
0
Mt. Auburn Member
No brachiopod data available
IBH
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Brachiopod Corrasion
>20% (major)
<20% (minor)
None

Crinoid ossicles, primarily plates and columnals, ranged from pristine to highly corraded. Most skeletal components, including the pinnules, cirri, and plates, were extremely rare and difficult to identify once disassociated from the main body. Although crinoid ossicles consist of porous stereom, Meyer and Meyer (1986) suggested from modern taphonomic studies that prefossilization was not a requirement for the abrasion of crinoid ossicles. *Pycnocrinus* (*Glyptocrinus*), *Iocrinus*, and *Cincinnaticrinus* were the most abundant Corryville columnals, and relative corrasion could be estimated because all three had unique, well-developed articulating crenulae. Most corrasion appeared to have worn down the surface of the columnals and enlarged the central lumen. Etching of facets was rare. Figure 59 displays the relative amount of corraded columnals against the stratigraphic section. No strong trends were apparent, but samples from the upper 4-5 m of section had a consistently high ratio of corraded columnals when compared to the samples from Zone 1.

Reorientation

Skeletal elements are reoriented and transported to varying degrees, dependent upon the energy of the ambient environment and upon their density and shape (Clifton, 1971; Brett and Baird, 1986, Table 2). The stability of the living position of an organism and its relative position in relation to the substrate (e.g., infaunal, epifaunal) will indicate the relative amount of transport or reorientation that has occurred (Brett and Baird, 1986). Reorientation of skeletal material was influenced by unidirectional currents, oscillatory waves, or a combination of both, each of which imparts a characteristic orientation of the available skeletal material (Nagle, 1967). The storm-related nature of Corryville

Figure 59 - Relative corrasion of crinoid columnals throughout the Corryville stratigraphic section. The base of the Corryville Member is set at the 0 m elevation. Note that the amount of corrasion appears to be consistently higher in samples within Zone 4.



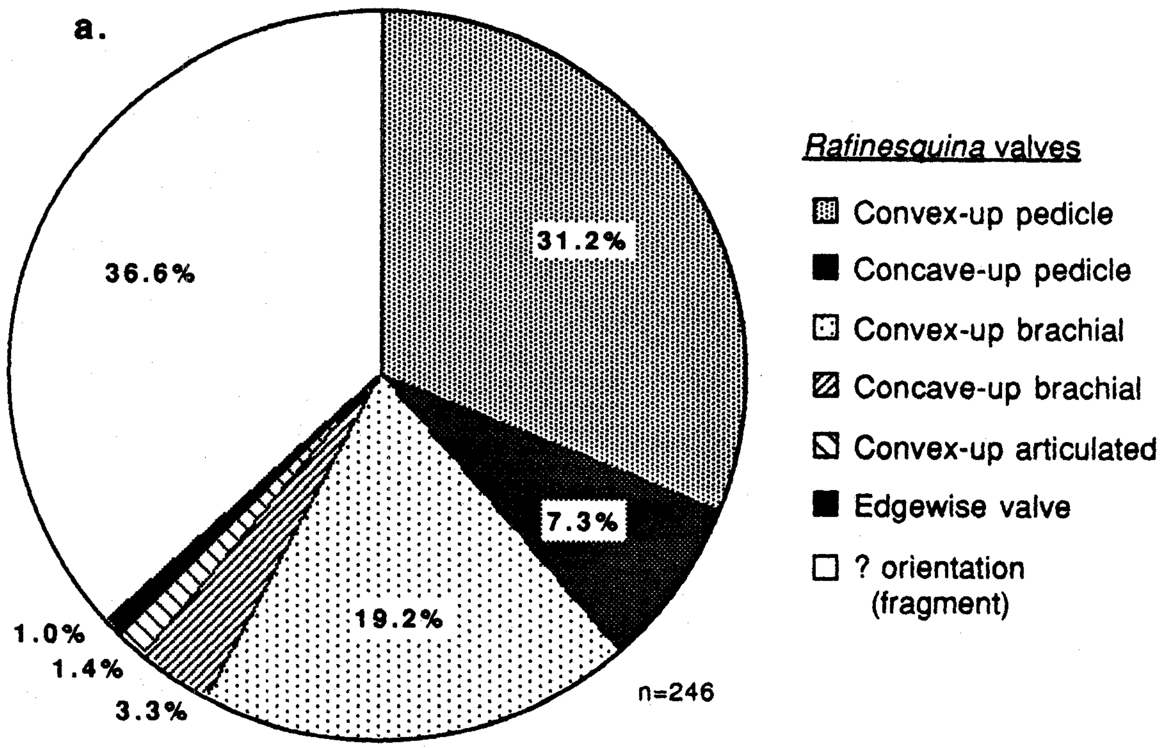
Elevation (m)
20.0
Mt. Auburn Member
15.0
10.0
IBH
5.0
0
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Corraded crinoid columnals
Crinoid columnals with no corrasion

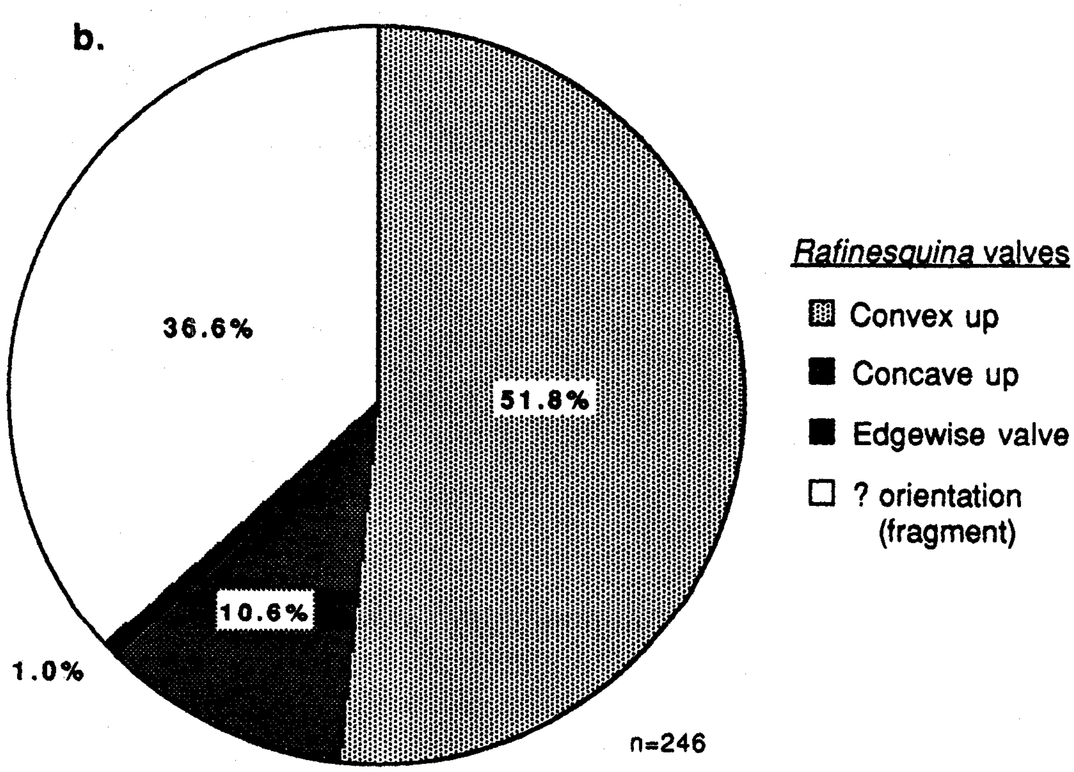
bedding suggests that most fossil material has been reworked at least once. In the bulk samples, specimens were not preserved in the interpreted "life position", and all nonrandom orientation patterns were attributed to reorientation from biostratinomic processes. Two types of orientation were quantified, the orientation of concavo-convex materials and the azimuthal orientation of the longest fragment axis. Inclined axial orientations were also measured, but because most skeletal material was concordant to the bedding surfaces, this information was lacking in taphonomically useful variability.

Concavo-convex orientations

Convex-upward or convex-downward orientations are useful indicators of the relative amount and direction of pre-burial current action (Brett and Baird, 1986; Speyer and Brett, 1988). For this investigation, large and abundant brachiopod valves were utilized, and any material, fragmented or whole, with an obvious curved surface was used to examine the orientation of convexity. Most shell materials displayed a horizontal to subhorizontal, or "concordant" (in the terminology of Kidwell et al., 1986), position in relation to the bedding surfaces, effectively simplifying estimations of concavo-convex orientations. The brachiopod *Rafinesquina* is assumed to have lived semi-infaunally in lower energy, muddy environments with the convex valve downward (Richards, 1972; Alexander, 1975); the concavo-convex orientation of these valves should therefore be an excellent indicator of reorientation. The ratio of identifiably convex-upward to convex-downward *Rafinesquina* material was roughly 5:1, with 1% in an edgewise (oblique to perpendicular) position (Fig. 60). For *Rafinesquina* valves at least 90% complete, this ratio increased to 9:1, with 3% in an edgewise position, Only one sample, 103-2 (8.04 m), displayed

Figure 60 - Concavo-convex orientations in *Rafinesquina* sp. valves. Results represent all specimens described from the bulk samples (n = 246), and orientation data is presented: a) by valve; and b) by overall convexity.


a.
31.2%
36.6%
7.3%
19.2%
1.0%
1.4%
3.3%
n=246
Rafinesquina valves
Convex-up pedicle
Concave-up pedicle
Convex-up brachial
Concave-up brachial
Convex-up articulated
Edgewise valve
? orientation (fragment)

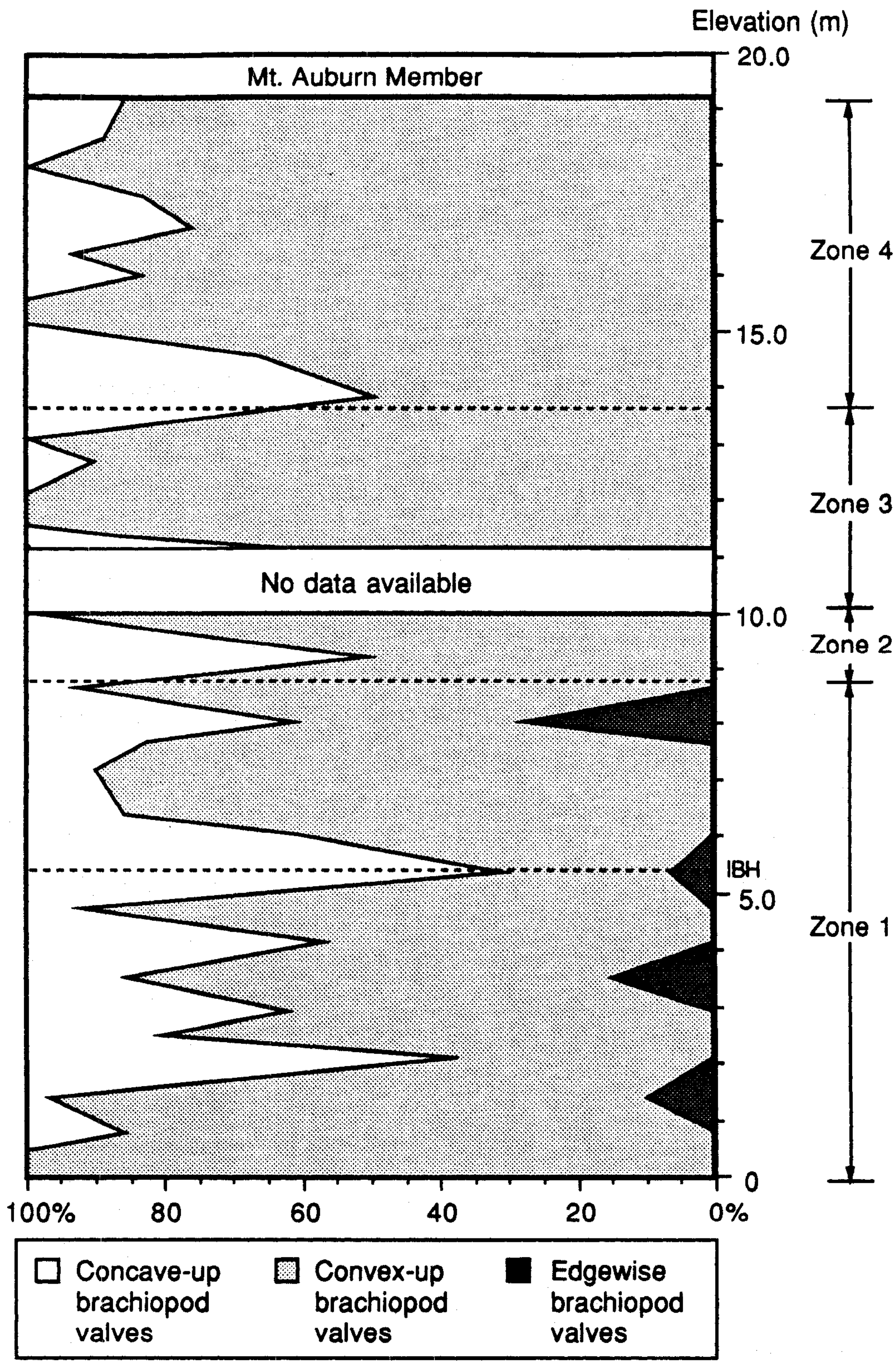

b.
36.6%
51.8%
10.6%
1.0%
n=246
Rafinesquina valves
Convex up
Concave up
Edgewise valve
? orientation (fragment)

edgewise and nested valves. No imbrication or stacking of valves was observed in the samples.

For all large brachiopod concavo-convex shell orientations (*Rafinesquina*, *Plectorthis*, *Platystrophia*, *R. nasuta*, and *Onniella*), the ratio of convex-upward to concave-upward valves was 4:1, with 3% in an edgewise orientation. When examined against the stratigraphic section (Fig. 61), these edgewise brachiopod valves appeared to be restricted to samples from Zone 1. In field exposures, edgewise accumulations of *Rafinesquina* did occur within the upper Corryville Member, but these were rare and localized biofabrics. In Zone 1, concave-upward large brachiopod valves represented 25% of all valve orientations within a single sample, with a maximum of 65%. In Zones 2, 3, and 4, the average amount of concave-upward valves was 15%, with a maximum of 50% in one sample. These results suggest that shell orientation was more variable within the lower half of the Corryville Member. *Zygospira* were excluded from these figures because the average valve area is much smaller than that of other brachiopods, and this implied a different relationship with the hydrologic regime.

Pelecypod valves were generally sparse and poorly preserved, and so were less adequate for the comparison of concavo-convex orientations. Pelecypod abundance was highest within the fine-grained component of tempestite and amalgamated beds. Of the 85 pelecypod specimens examined from all samples, 79 of the shells (93%) were convex-upward. The ratio of convex-upward to concave-upward pelecypod valves was approximately 13:1, and all pelecypod molds displayed a remnant convex-upward orientation.

Figure 61 - Concavo-convex orientation of all articulate brachiopod valves throughout the Corryville stratigraphic section. Data includes all large brachiopods, including Rafinesquina sp., *Rafinesquina nasuta*, *Onniella*, *Platystrophia*, and *Plectorthis*. *Zygospira* was excluded because the average valve area was much smaller than all other species, implying a different relationship with the hydrologic regime. Edgewise valves are more common within Zone 1, and valves within Zone 4 are generally more convex-upward than in Zone 1. The base of the Corryville Member is set at the 0 m elevation.



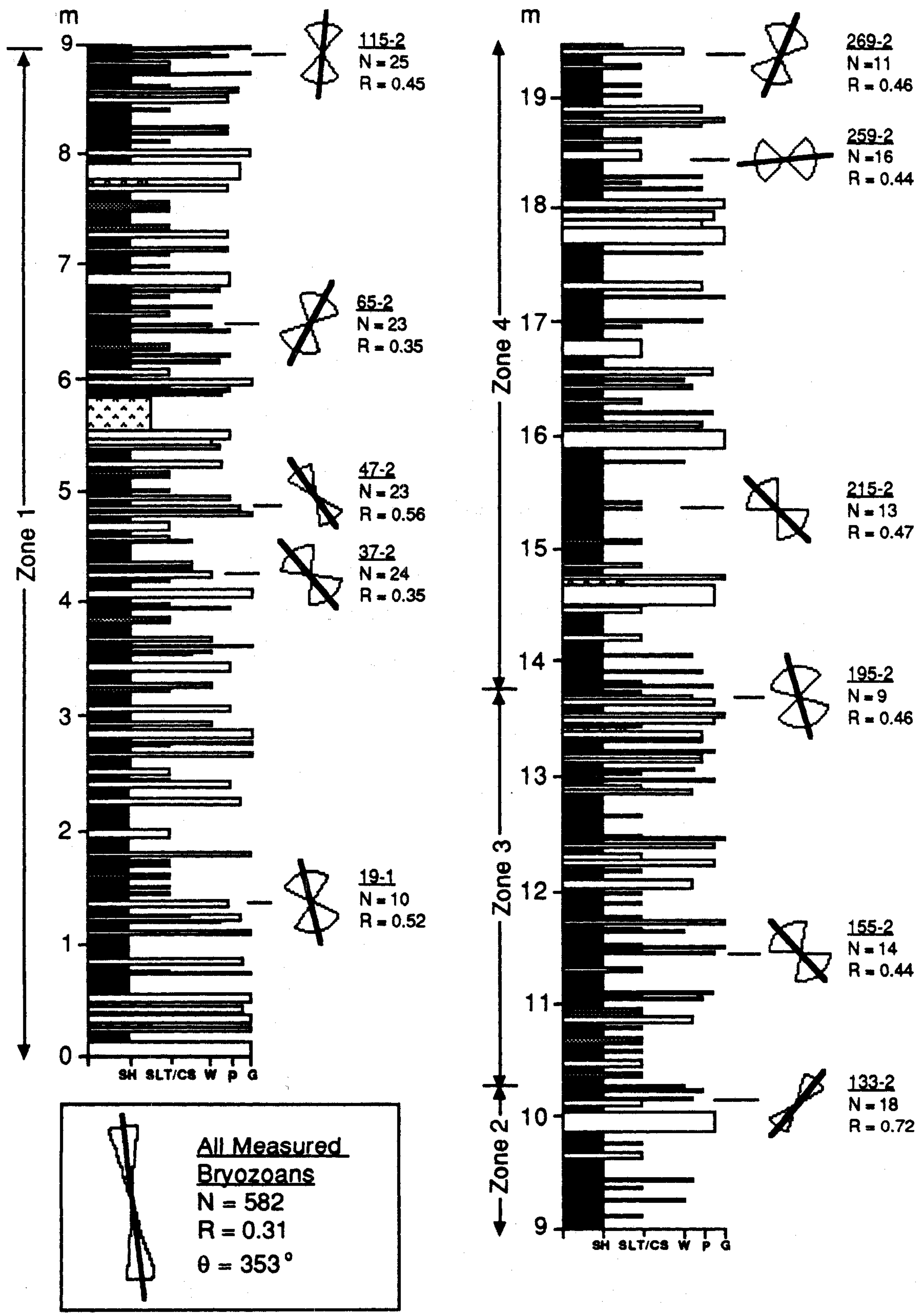
Elevation (m)
20.0
Mt. Auburn Member
15.0
No data available
10.0
IBH
5.0
0
Zone 4
Zone 3
Zone 2
Zone 1
100%
80
60
40
20
0%
Concave-up brachiopod valves
Convex-up brachiopod valves
Edgewise brachiopod valves

Azimuthal orientation

The orientation of the long axis of skeletal material can indicate the velocity, directions, and the relative amount of wave vs. current motion associated with storm deposition (Speyer and Brett, 1988). Morphology and the prevailing current type and current source will affect the degree of reorientation (Nagle, 1967). The longest Corryville skeletal fragments were nautiloid shells, and these displayed strong azimuthal orientation in the large pieces of float along Stonelick Creek. In the bulk samples, however, nautiloid specimens were disappointingly rare and could not be used effectively for azimuthal orientation. The azimuthal orientations of bryozoan fragments and *Rafinesquina* valves were examined because they were abundant within most samples and because their characteristic shapes should have been affected by current or wave action in a predictable manner (see Alexander, 1975; Meyer, 1990).

In theory, loose ramose bryozoan fragments were hydrodynamically stable in an alignment parallel to current direction or normal to the direction of wave propagation (cf. Nagle, 1967). Although ramose bryozoans are roughly cylindrical in shape, the numerous, intact branches may have anchored them in line with a unidirectional current, rather than perpendicular to it such as would be expected in loose crinoid stems. Bryozoan measurements were "orientational" because of the uniformity of their shape along the major fragment axis. Therefore, reorientation could have occurred in one of two possible, though opposite, directions. A majority of the samples did not show a preferred bryozoan orientation. In Figure 62, samples with the strongest bryozoan orientations were plotted against the stratigraphic section. With the exception of samples 65-2 (6.03 m), 133-2 (10.06 m), and 259-2 (18.46 m), mean orientation

Figure 62 - Azimuthal orientation of bryozoan fragments throughout the Corryville stratigraphic section. The thick, oriented lines each represent a mean orientation vector computed from the a variable number (N) of bryozoans within a sample. Because of their uniformity of shape, bryozoan orientations were measured in a single direction and later extended to the opposite direction. All orientation vectors with a mean resultant length (R) $\geq$ 0.35 were plotted, and 95% error bars were computed. Mean orientation was primarily N/NW or S/SE. See Figure 24 for key of stratigraphic section.


m
9
8
7
6
5
4
3
2
1
0
Zone 1
SH SLT/CS W P G
115-2
N = 25
R = 0.45
65-2
N = 23
R = 0.35
47-2
N = 23
R = 0.56
37-2
N = 24
R = 0.35
19-1
N = 10
R = 0.52
All Measured Bryozoans
N = 582
R = 0.31
θ = 353°
m
19
18
17
16
15
14
13
12
11
10
9
Zone 4
Zone 3
Zone 2
SH SLT/CS W P G
269-2
N = 11
R = 0.46
259-2
N = 16
R = 0.44
215-2
N = 13
R = 0.47
195-2
N = 9
R = 0.46
155-2
N = 14
R = 0.44
133-2
N = 18
R = 0.72

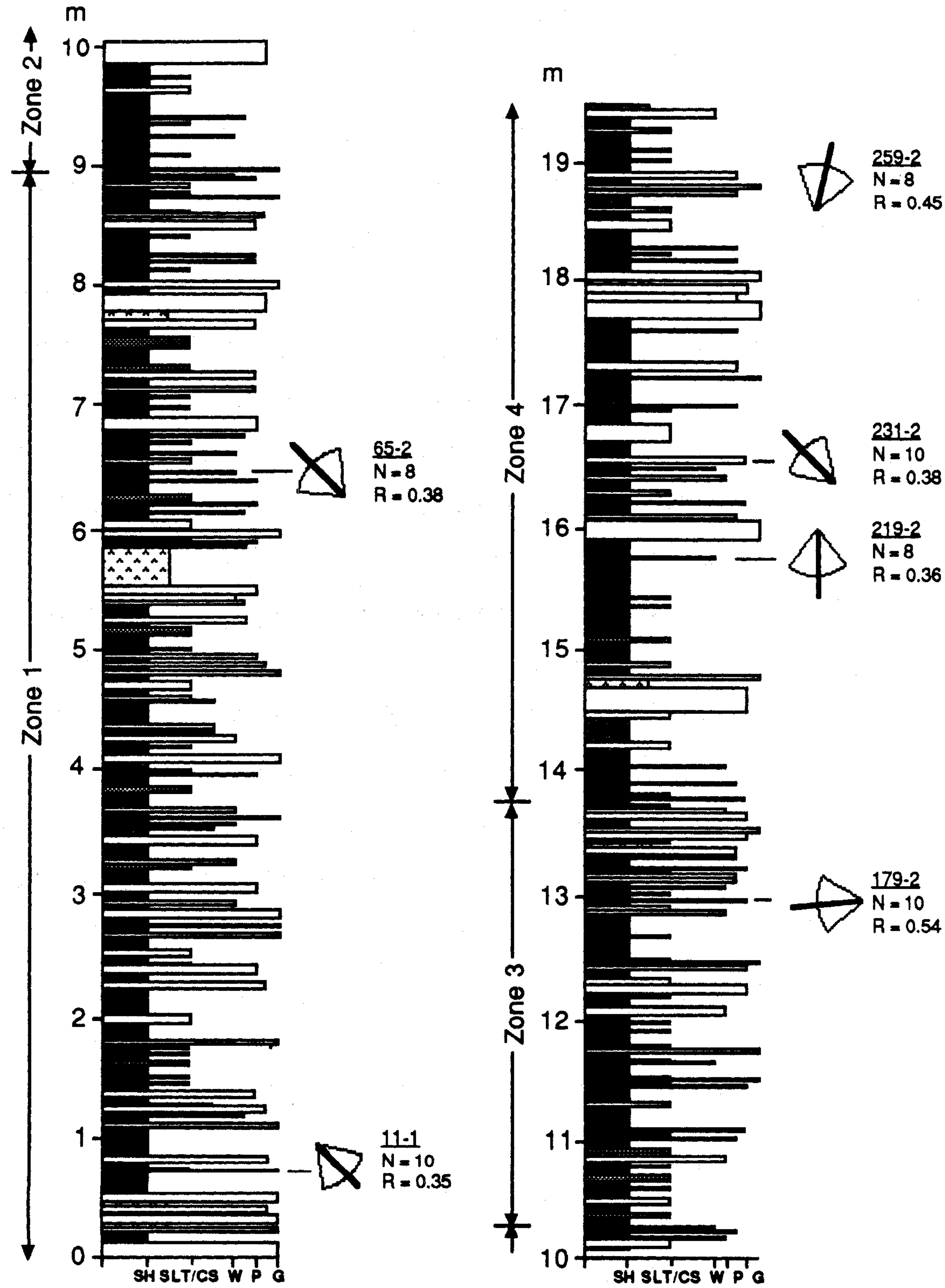
in these samples was generally N/NW or S/SE. Samples containing reoriented bryozoans were amalgamated packstones, calcisiltites, and wackestones that occurred in no systematic sequence within the section. The mean direction for all measured Corryville bryozoans was N/NW (Fig. 62), which compared favorably with orientation measurements taken from flute marks and gutter casts.

The anterior-posterior (or anteriomedial) axis was measured from *Rafinesquina* valves in a direction normal to the hingeline and away from the beak. No directional trends were observed from *Rafinesquina*, but six of the samples did produce resultants > 0.35 (Fig. 63). Five of the six of these samples indicated reorientation to the N/NW or S/SW. Most samples contained too few whole *Rafinesquina* specimens for a proper directional study. Field measurements along extended bedding planes with tens of specimens would provide a more acceptable data set for determining the possibility of reorientation in *Rafinesquina*.

Sorting

The sorting of skeletal materials by size and shape can be used to indicate current intensity and duration, relative amount of transportation, and possibly relative surface residence time (Johnson, 1960; Westrop, 1986; Speyer and Brett, 1988). A study of size sorting was preferable to one of shape sorting because of the abundance of unidentifiable fragmented materials and the ease with which specimen sizes could be compared. Bioclasts in most of the bulk samples, with the exception of the normally-graded tempestites, were well mixed and poorly sorted. The presence of intact silty bed caps and the lack of appreciable or deep bioturbation suggests that sorting from post-storm event

Figure 63 - Azimuthal orientation of the anteriomedial axis of *Rafinesquina* valves throughout the Corryville stratigraphic section. The thick, oriented lines each represent a mean orientation vector computed from the a variable number (N) of valves within a sample. All orientation vectors with a mean resultant length (R) $\geq$ 0.35 were plotted, and 95% error bars were computed. Most samples displayed no strong azimuthal orientation, although a N/NW or S/SW reorientation seems likely for those samples with R $\geq$ 0.35. See Figure 24 for key of stratigraphic section.

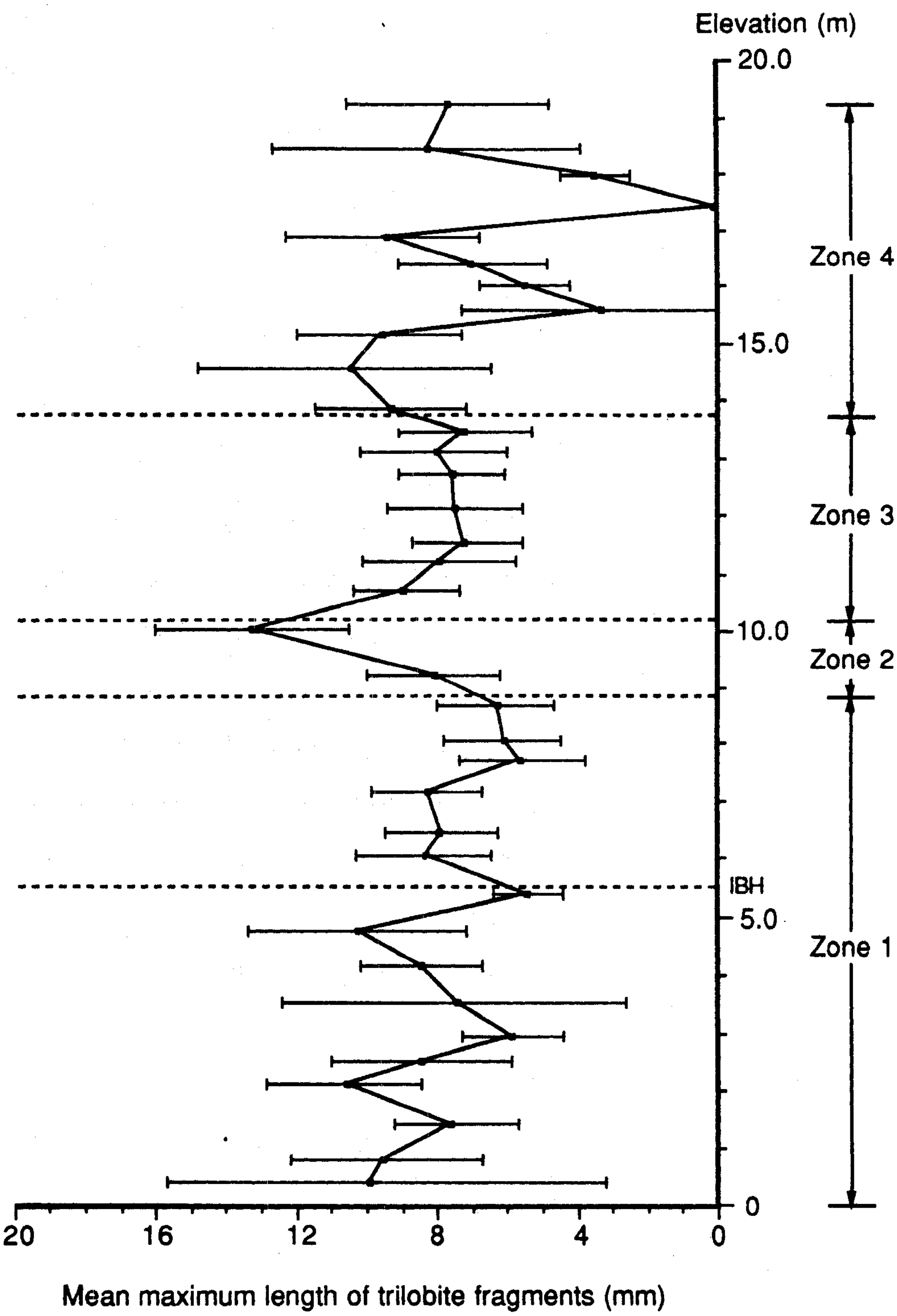

m
Zone 2
Zone 1
65-2
N = 8
R = 0.38
11-1
N = 10
R = 0.35
SH SLT/CS W P G
Zone 4
Zone 3
259-2
N = 8
R = 0.45
231-2
N = 10
R = 0.38
219-2
N = 8
R = 0.36
179-2
N = 10
R = 0.54

reworking or remixing of sediments was negligible. Trilobite and bryozoan fragments were used to test for strong size sorting, and all measurements of length were of the longest axis of a fragment. Crinoid columnals varied in diameter from 1 to 5 mm in most every sample, but did not display any preferential sorting effects. The total number of *Rafinesquina* pedicle and brachial valves from all samples was roughly even, and differential sorting of these valves was not evident.

Trilobite sclerites should be a good indicator of sorting because trilobite cuticle was probably very brittle, but relatively resistant to dissolution (Speyer, 1987). Factors that affected the sorting of trilobite hardparts probably included fragment size and sclerite shape. Trilobite exoskeletal material was typically disarticulated into identifiable free cheeks, cranidia, pygidia, and thoracic segments. These fragments were polygonal, commonly pyritized, and pitted with sharp, linear breakage along the edges. Most of the sclerites may be exuvia but such material can not be distinguished from the "corpse" cuticle (Mutvei, 1981); all trilobite material was treated in the same manner.

Figure 64 displays the average maximum length of trilobite fragments against the stratigraphic section. Average maximum fragment length varied from 4 to 14 mm, with an approximate mean of 8 mm $\pm$ 2 for all samples. Although a study of sorting on a species-by-species basis would have been preferred, a good portion of the skeletal fragments could not be taxonomically identified, and so all trilobite material for a sample was measured and included. All samples contained *Flexicalymene* sclerites that represented individuals of all body sizes. Large *Isotelus* spines, pleura, and doublures were common in grainstones, packstones, and wackestones, and these elements showed little to no wear and fine details (e.g. terrace lines) were preserved. The abundance of large *Isotelus* pleura, spines and free cheeks in sample 133-2 (10.06 m)

Figure 64 - Mean maximum length of trilobite fragments throughout the Corryville stratigraphic section. 95% error bars were computed for each sample. No large-scale sorting trends were detected. The base of the Corryville Member is set at the 0 m elevation.



Elevation (m)
20.0
15.0
10.0
5.0
0
IBH
Zone 4
Zone 3
Zone 2
Zone 1
20
16
12
8
4
0
Mean maximum length of trilobite fragments (mm)

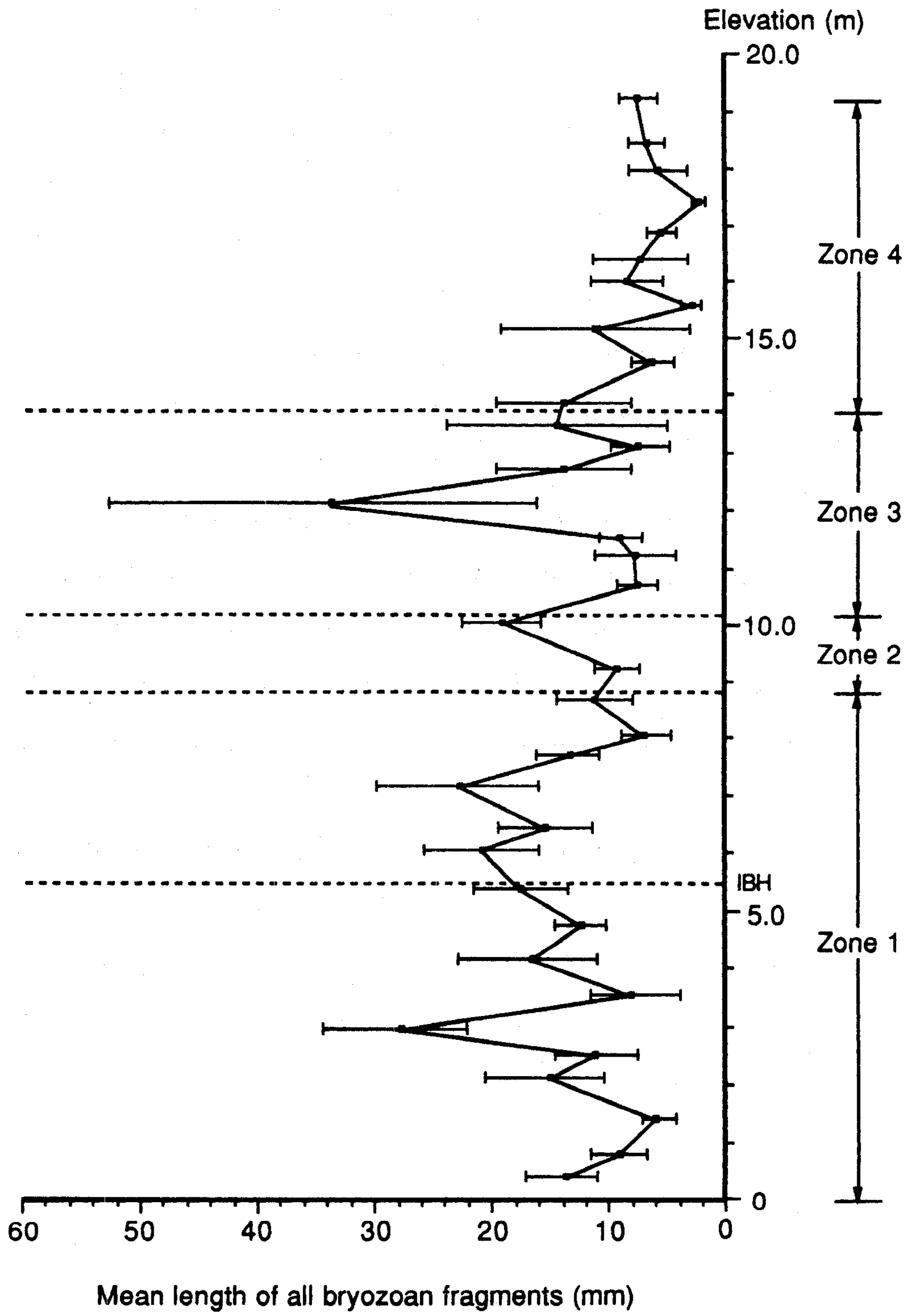
increased the mean fragment length to approximately 13 mm. This would suggest either a fairly autochthonous bed marked by minimal sorting and fragmentation or possibly an environment dominated of *Isotelus* . The two low measurements at 219-2 (15.57 m) and 245-2 (17.42 m) were samples with very few sclerites. Fragment abundance decreased in Zone 4, but no large-scale sorting trends were detected.

Relative sorting was also examined through the size of bryozoan fragments. Fragment abundance generally decreased upsection, and fragments within the beds of Zone 4 were smaller, more corraded, less abundant, and better sorted (Fig. 65). Sample 171-2 (12.11 m), an amalgamated bed with a basal packstone-grainstone and upper arenaceous calcisiltite, contained atypically large fragments (average length 32 mm) of ramose and foliate bryozoans that appeared to have been buried *in situ*, or nearly so. These colonies rested along the upper surface of the basal packstone-grainstone and appeared to have been buried and possibly smothered by an influx of calcareous silt and fine fossil debris.

Early Fossil Diagenesis

The excellent overall condition of fossil deposits in the Corryville Member suggests that early fossil diagenetic processes played a comparatively minor role in the preservation and concentration of these skeletal assemblages. Evidence for burial compaction, pyritization, and diagenetic dissolution was present. Beds were highly cemented and slightly dolomitized, but primary physical and biogenic bedding features were not overprinted. Many of the limestones at Stonelick Creek could be traced laterally for over a kilometer, arguing against a diagenetic overprint of individual horizons.

Figure 65 - Mean maximum length of bryozoan fragments throughout the Corryville stratigraphic section. 95% error bars were computed for each sample. Sorting may be best within a samples from Zone 4 that display generally smaller-sized fragments. The base of the Corryville Member is set at the 0 m elevation.


Elevation (m)
20.0
15.0
10.0
5.0
0
IBH
Zone 4
Zone 3
Zone 2
Zone 1
60
50
40
30
20
10
0
Mean length of all bryozoan fragments (mm)

The effects of burial compaction on the formation of the faunal assemblages were limited, possibly due to early diagenetic cementation. Walker and Diehl (1985) speculated that Early Paleozoic water chemistry facilitated the precipitation of calcite so that marine environments were more subject to early cementation. Enrolled, articulated trilobites recovered from the "trilobite shales" displayed only minor compaction perpendicular to the bedding surface (Brandt, 1980a). Ichnofossils may have been vertically shortened, but not to any great extent. Several articulated and single *Rafinesquina* valves exhibited *in situ* fracturing, and this was attributed to compaction rather than to predation because: 1) the shell material had not been selectively removed from these specimens; and 2) there was no evidence to support post-breakage disturbance or transportation. In addition, abundant preserved shelter porosity below convex-upward shells in many packstones suggests that compaction was minimal. These shelter voids contained internal geopetal structures (possibly late diagenetic calcite spar) with no indication of post-burial reworking and reorientation.

Selective diagenetic dissolution or enhancement (cf. the "diagenetic extinction model" of Fürsich, 1982) had little to no effect on Corryville fossil distribution and preservation. Contacts between the carbonate beds and clastic shales were sharp and the shales appear to have been genuinely nonfossiliferous, except in the cases of lags or event horizons. Evidence for concretions was not found. The excellent preservation of most nautiloid, cephalopod, and gastropod molds implies that the aragonitic shell was removed through early diagenetic dissolution, not prolonged surface exposure. Preservation in nautiloids is predominantly as internal molds with some original shell, where the internal chambers have been infilled with silt, mud, and, rarely, fossil debris. However, these taxa were still present as molds, and so the original faunal components can be recognized, often to a high taxonomic level.

Minor disseminated pyrite was present within calcisiltites, fine grainstones, and arenaceous calcisiltites and associated with trilobite sclerites, pelecypod molds, and isolated burrows. Episodic sedimentation in aerobic conditions has been associated with minor pyrite formation in carbonates (Brett and Baird, 1986, Table 4). Berner (1984) stated that the supply of decomposable organic matter, dissolved sulfate, and reactive detrital iron minerals were essential for the production of authigenic pyrite, with the amount and reactivity of organic matter as the major limiting factor. Allison (1988) found evidence in a modern study that pyrite formation had occurred before appreciable soft part decay just months or weeks after burial. Shallow bioturbation, such as is observed in Corryville fine-grained deposits, can also aid in the production of pyrite by allowing the diffusion of sea water sulfate into bottom sediments (Brett and Baird, 1986).

Ichnofossils

An examination of Corryville trace fossils showed that post-storm event infaunal burrowing was restricted to a relatively shallow portion (< 6 cm) of any silt-rich bed (e.g. calcisiltites, arenaceous calcisiltites, the upper portion of tempestites, and the thinner silt caps). Smaller stream exposures with a greater exposed areal bedding surface exposure are best for the examination of trace fossils. Burrows were not observed in coarser grainstones and were only rarely seen in fine-grained packstones and wackestones. Shales were seldom bioturbated, and then only by *Chondrites*. The exceptional preservation of ichnofossils therefore appears to be linked with carbonate grain size, specifically with silt-sized sediments, and the lack of sediment erosion in a "normally" low energy environment. This phenomena is a feature of other Early Paleozoic storm-dominated marine deposits (e.g. Kreisa and Bambach, 1982).

Burrowing in Corryville strata was abundant, but never intense. In bioturbated beds, laminae and bedding planes were never altered past recognition, and infauna did not rework more than 20 to 30% of the sediments. This level of bioturbation would correspond to Droser and Bottjer's (1987, Fig. 1) ichnofabric index 2 (and rarely 3) for strata deposited in carbonate shelf environments. Ichnofossils existed in what might be interpreted as a minor tiering structure (cf. Bromley and Ekdale, 1986, Fig. 2). Most of the traces (e.g. *Paleophycus*, *Chondrites*, *Trichophycus*) were shallow or along the upper bed surface, but *Diplocraterion* penetrated to a greater depth than the other traces. This subtle tiering, however, occurred within beds deposited by storm events and so was useless for estimating the minimal storm erosion depth (Aigner, 1986).

Most ichnofossils were present in groupings and could be identified to the level of ichnospecies. The most abundant ichnospecies, *Chondrites*, was frequently found in association with *Trichophycus* and *Diplocraterion*. This trio of ichnogenera could be considered the prime Corryville trace fossil community, or ichnocoenosis. Ichnospecies abundances do not vary within the section, and the entire Corryville Member appeared to represent a single "ichnofacies". The sole range-restricted ichnogenus was *Conostichus*, only observed within the upper few meters of the Corryville section and into the lowermost Mt. Auburn Member. Previous workers (Osgood, 1970; Osgood, 1981; Tobin, 1982) have attributed the Corryville Member to the *Cruziana* ichnofacies (Seilacher, 1967), an inner sublittoral, well-lit environment with abundant oxygen and nutrients. The primary Corryville traces represent a collection of Fodinichnia (feeding traces) and Domichnia (dwelling traces), suggesting a post-storm abundance of suspended and buried organics in fairly soft sediments.

Fossil Lagerstätten

Fossil Lagerstätten can provide new insights concerning the paleobiology, necrolysis, biostratinomy, and early diagenesis of a fossil biota (Seilacher et al., 1985). In the broadest sense, any well-preserved assemblage of fossils or "concentration deposit" could be considered a Lagerstätten; this study applies the term to describe only rare assemblages of abundant, articulated skeletons, or "conservation deposits" (see "*Konservat-Lagerstätten* " of Meyer et al., 1981; Seilacher et al., 1985; Allison, 1988). Corryville fossil Lagerstätten are allochthonous and autochthonous horizons, although the most common beds are probably obrution deposits, instances of catastrophic burial by fine sediments (Meyer et al., 1981; Schumacher, 1984; Brandt Velbel, 1985; Meyer, 1990). These deposits are similar to the Lagerstätten reported from other storm-dominated strata (e.g. Fürsich, 1982; Brett, 1983; Brett and Seilacher, 1991), especially those from the well-described Middle Devonian Hamilton Group of New York State (Speyer and Brett, 1986; Speyer, 1987; Brett and Seilacher, 1991).

No Lagerstätten were observed within the bulk samples of this study, but this investigation has determined that such deposits occur only within specific stratigraphic intervals at Stonelick Creek. Corryville Lagerstätten have been recovered from two separate intervals within the Corryville section, the first near the center of the unit, and the second at the top of the section below the Mt. Auburn-Corryville contact. These two intervals contain markedly different forms of Lagerstätten. The lower consists of "trilobite shales" and tempestites with rare, articulated individual specimens, and the upper interval contains smothered, autochthonous and current-transported echinoderm assemblages. While Lagerstätten may yet be preserved in alternate stratigraphic horizons, all previously documented deposits have been attributed to these two intervals. This suggests that, with few exceptions, the preservation potential for Lagerstätten throughout Corryville deposition was fairly low, and that optimal preservational conditions were less common than has been previously thought.

The lower Lagerstätten were found within the tempestites and soft shales of Zone 2 and the lower portion of Zone 3. The presence of the "trilobite shales" was verified by the recovery of several articulated, enrolled and elongate *Isotelus* and *Flexicalymene* specimens from the shales of Zone 2 (CMNH P911 through CMNH 915, and CMNH P920). In these specimens, orientation was consistently dorsal up with no dominant azimuthal orientation, deformation was minor, and all sizes of individuals were present. The enrollment of trilobites has been attributed to an instinctive response to deep and abrupt burial, after which the organisms, unable to escape, were preserved articulated and *in situ* (Brandt, 1980; Brandt Velbel, 1985; Speyer and Brett, 1986). Brandt Velbel (1985) determined that trilobite specimens from Corryville "trilobite shales" (or "butter shales") were more elongate and partially enrolled than completely enrolled. The size range, excellent preservation, and partial to lack of enrollment in the "trilobite shales" were interpreted by Brandt Velbel (1985) as evidence for an instantaneous kill and a lack of appreciable transport. The thick shales displayed no lamination or bedding, some normal grading, minor *Chondrites* - "type B", and low organic content, and probably represent more than one depositional event. Trilobite Lagerstätten within the other units of the Cincinnatian Series displayed similar taphonomic signatures (Brandt Velbel, 1985).

Detailed locality information from older studies (Caster, 1942, 1952; Caster and Macke, 1952) indicated that the tempestites within the lower Lagerstätten interval were the source of fragile, articulated echinoderms and arthropods and of rare trace fossils. These tempestites might not be considered true Lagerstätten, but the anomaly of many well-preserved specimens from this interval implies a unique set of taphonomic conditions. In each situation, the specimen was preserved in the fine sediments in the upper portion of the bed. It does not seem unrealistic that these organisms survived the direct storm effects only to succumb from suffocation during the deposition of silts with waning storm energy. If death had occurred at the onset of the storm, the corpses might have settled out of the water column more quickly and then been deposited within the fossiliferous basal packstone of the tempestite.

The upper Lagerstätten interval has been the source of the smothered edrioasteroid populations (Meyer et al., 1981; Meyer, 1990) and *Iocrinus* beds (Meyer et al., 1981; Schumacher, 1984). The edrioasteroid horizons have been collected from several geographically distant localities. A study of the calcite cements of one of these beds concluded that the layer was an incipient hardground, formed as a result of early cementation (Rassmann, 1981). Meyer (1990) suggested that the edrioasteroids were epizoans living at the top of an already condensed, time-averaged shell accumulation, and that their death resulted from an abrupt, storm-related smothering event. Preservation of the edrioasteroids was excellent (some specimens still displayed an inflated theca) and this permitted a detailed study of the dynamics of these populations (Meyer, 1990). A gutter cast bed with abundant *Iocrinus* was collected just below the Mt. Auburn Member contact and was interpreted as a transported assemblage (or thanatocoenosis) (Meyer et al, 1981; Schumacher, 1984). Crinoid material was dislodged, transported, and then redeposited by a storm-generated, roughly NW-SE unidirectional density current (Schumacher, 1984). Abraded and fragmented skeletal material was included within this assemblage, indicating that a combination of live and dead material was transported from the original crinoid colony site (Schumacher, 1984).

Discussion of Comparative Taphonomy

One goal of this investigation was to identify the taphonomic attributes best suited for the study of Upper Ordovician fossil assemblages. The most versatile biostratinomic indicators proved to be fragmentation, reorientation, and corrasion, all of which displayed variable states that could be used to estimate grades of environmental change. The least effective indicators for a comprehensive comparative study were articulation and sorting. Horizons dominated by articulated taxa were excellent evidence for episodic sedimentation, yet these were rare within the stratigraphic section in comparison to deposits dominated by disarticulated and fragmented skeletal material. Many potentially useful taphonomic attributes were not sufficiently variable or widespread enough to merit a comprehensive intersample comparison. For example, pelecypod valve ratios could not be used to estimate the effects of differential transport or sorting because of the generally poor level of pelecypod preservation. Bedding planes with well-preserved and articulated pelecypods do exist within the Corryville interval, but these were not common. The best taxonomic groups for comparative study were bryozoans and brachiopods because they displayed a wide variety of quantifiable taxonomic signatures. Crinoid, cephalopod, and gastropod materials were less effective tools for taphonomic resolution.

Most Corryville Member limestones would be described as elongate, thin lenses or as three-dimensional "beds" in the terminology of Kidwell et al. (1986, Fig. 3). Corryville tempestites appear to represent the terminal storm event, but the taphonomic signature of these beds indicates that the component bioclasts reflect variable amounts of post-mortem reworking and exposure. Study samples displayed variable taphonomic signatures, but many were similar enough to allow for the construction of a "typical" Corryville limestone bed. This bed is a packstone that varies laterally in its carbonate texture and has at least a thin veneer of bioturbated silt along the upper bedding surface. Fossil material is abundant, generally disarticulated, and poorly sorted. In no cases were shell beds seen that indicate *in situ* preservation of a community in life position. Trilobite, crinoid, brachiopod, and bryozoan hardparts display variable corrasion and fragmentation. Pelecypods, when present, are generally molds associated with silt layers along the bedding surfaces. Curved shells are dominantly convex-upward, lie concordant with the planar bed surfaces, and commonly form pavements along the upper bedding contact. Elongate skeletal material may be preferentially oriented, although some fragments will diverge from this orientation.

No comprehensive relationship was established between carbonate lithology and taphonomy. The taphonomic character of many beds appeared to be consistent despite a lateral gradation in texture from bioclast-supported to matrix-supported. Brandt (1989) stated that certain textures were associated with taphonomic attributes, but this may not entirely be the case for Corryville storm beds. According to the concept of taphonomic grades (Brandt, 1989), wackestones should have shown less fragmentation, orientation, and corrasion, and more articulation, yet in the Corryville Member, several packstones and wackestones displayed the same taphonomic character. It appears then that the relative amount of carbonate matrix present is less related to taphonomic character. Skeletal beds with little or no carbonate matrix and finer grain size do generally display increased fragmentation, sorting, and corrasion (Tobin, 1982; Jennette, 1986), but fine grainstones were rare within the Corryville Member and the bioclastic material within calcisiltite beds was usually too minute for comparative biostratinomy. For the remaining wackestones, packstones, and poorly-washed grainstones, variations in relative corrasion, fragmentation, and articulation may simply reflect differences in the surface residence time of the material before it was incorporated and buried by the terminal storm event.

Storm Deposition

Taphonomic indicators support the assertion that the Corryville strata were subject to the processes of storm deposition. The overall pattern seems to be that of sedimentologic concentrations due to hydraulic processes, and reorientation and fragmentation appeared to be the best taphonomic indicators for Ordovician storm activity. In the Corryville Member, preserved distal tempestites, shales, and arenaceous calcisiltites were most abundant, indicating deeper water conditions (cf. Aigner, 1985; Jennette, 1986). The general absence of skeletal material, bioturbation, and lamination in the shales suggests that many of these beds were deposited quickly by storms rather than by slow "background" sedimentation (Tobin, 1982; Jennette and Pryor, in press).

The pervasive concordant, concavo-convex orientation of brachiopods and other shell materials has been reported from other storm-dominated strata (Kreisa and Bambach, 1982; Norris, 1986; Parsons et al., 1988). In Ordovician storm-deposited strata in Virginia, Kreisa and Bambach (1982) found that shells were oriented dominantly parallel to bedding (75%) and convex up (2:1). The convex-up position is the more hydrodynamically stable position for shells in a muddy substrate, and once normally concave-up shells have been inverted in a unidirectional current, they do not reinvert or move an appreciable distance (Brenchley and Newall, 1970). Current velocities needed to overturn

Rafinesquina resting concave-upward atop fine sediments have been broadly estimated from flume studies at 1 m/s or greater (Alexander, 1975, p. 615) , and once in the convex-up, horizontal position *Rafinesquina* could resist scouring currents of at least 26-27 cm/s (Alexander, 1984).

Two exceptions to current-related convex-upward shell orientation are overturning through bioturbation and *in situ* burial associated with community succession. Emery (1968) and Clifton (1971) both demonstrated that in modern quiet water environments, bioturbation and predation can produce a predominantly concave-up orientation in pelecypod shells. In the absence of bioturbation, physical processes are the primary force of reorientation (Salazar-Jiménez et al., 1982). During the Late Ordovician, infaunal burrowing was restricted to shallow depths (Ausich and Bottjer, 1982). The preserved laminated silt cap of most Corryville tempestites indicates that they record the terminal storm event bed and that reworking of sediments by post-storm scavenging, predational boring, and bioturbation was minimal to nonexistent. If faunal succession were preserved within a bed, then concave-upward shells might be more abundant, especially at the base of the bed where *Rafinesquina* settled in the mud in a concave-upward position (Walker and Alberstadt, 1975; Harris and Martin, 1979). No sample, however, contained the characteristics of faunal succession or displayed shells in a dominantly concave-upward position. Samples with a nearly equal ratio of convex-upward to concave-upward valves generally contained small numbers of valves or valves with various degrees of hinge or axial inclination other than horizontal. These latter valves may indicate a reduced effect of current reorientation or an increased effect of post-storm wave action.

The long axes of fossil materials were oriented predominantly to the N-NW/S-SE, an orientation consistent with measurements from previous studies of the Corryville Member (Hinterlong, 1981, Fig. 8; Meyer, 1990, Figs. 7 and 8). Bimodal orientations were not observed. Tobin (1982, Appendix 7) estimated a general NW current orientation for the Corryville Member using cephalopods and gutter casts. This would suggest an offshore unidirectional storm surge to the N/NW that reoriented the long axes of skeletal fragments to that direction. Beds that lack a preferred azimuthal orientation can signify *in situ* reworking and lack of transportation or a more complex combination of current forces. The few beds with strong bryozoan orientations to the NE/SW may have resulted from a stronger wave current action following storm deposition. These beds were not closely spaced in the stratigraphic section and probably do not represent a temporal change in the local ramp orientation or unidirectional current direction. Imbricated shells, which can be used to indicate the direction of offshore-directed flows (Aigner, 1985), were not observed. Azimuthal orientations were derived solely from Stonelick Creek samples, and further measurements of bryozoan and nautiloid orientations at other field localities may produce a better sense of the regional current orientation.

Although storms may destroy or disperse skeletal material, they paradoxically are the mechanism that buries and preserves such assemblages (Kreisa, 1981b). Rapid storm burial and sedimentation rates have been frequently associated with articulation and hardpart preservation (Fürsich, 1978). Taphonomic evidence from Corryville Lagerstätten has shown that storm deposition was at times sudden and episodic and that burial in muds could be quite deep (Brandt, 1980b; Schumacher, 1984; Brandt Velbel, 1985; Meyer, 1990). Storm energy could be high, as with the deposition of proximal tempestites, or low, as in the blanketing of hardpart deposits by transported muds (cf. Jennette and Pryor, in press). Davies et al. (1989) argued that the sole manner in which carbonate shell materials could be preserved from dissolution was through rapid deposition in areas of high productivity.

Yet even in cases of rapid burial, decay can occur at depth (Cummins et al., 1986). Allison (1988) stated that, for some fossil Lagerstätten, early diagenetic mineralization impeded this decay and was the process most responsible for preservation. The general absence of diagenetic alteration in Corryville interval suggests that either synsedimentary cementation or early diagenetic lithification was an important factor in post-burial fossil preservation. Walker and Diehl (1985) suggested that Early Paleozoic fossil assemblages were subject to early cementation and therefore were better preserved and more likely to represent the original biota.

Given that storms caused a final burial of fossil material, then the taphonomic condition of an assemblage will be related to the timing of the storm relative to the age and death of the assemblage (Holland, 1988). Most Corryville tempestites contained an assemblage that displayed variable amounts of disarticulation, corrasion, fragmentation, and shell orientation. Similar storm deposits from epicontinental sequences have been attributed to multiple episodes of winnowing, condensation, and periods of non-deposition (Fürsich, 1982; Seilacher, 1982; Parsons et al., 1988; Brett and Bordeaux, 1990; Diekmeyer, 1992; Jennette and Pryor, in press). Such deposits would be akin to Johnson's (1960, Table 1) "Model II" of fossil assemblage formation.

Parsons et al. (1988) suggested that this preservational mélange represented several generations of taxa as relatively fresh, unworn material was continuously admixed with older, time-averaged skeletal materials. That such a process occurred is supported by 1) the absence of size and shape sorting in most samples, and 2) the abundance of whole articulated and disarticulated brachiopod valves in samples primarily composed of worn, smaller-sized skeletal fragments. In the Corryville strata, most limestone beds appeared to represent the terminal storm event, and so the reworking and remixing of the skeletal material probably occurred during previous storm events within an indeterminate period of time before the final storm. The thinner tempestites within the distal facies of small-scale bedding cycles may be the least reworked of any strata (cf. Norris, 1986). Thickness of limestone beds appears to have been dependent upon the amount of available carbonate material rather than the intensity of the storm event.

Corryville Paleoenvironment

In the periods in between major storm events, the Corryville paleoenvironment was probably below the normal (fairweather) wave base and must have been fairly quiet and stable (Tobin, 1982). Large bryozoan colonies evidently prospered during early Corryville time, and may have grown upward from the base to keep pace with slow, fairweather sedimentation. The presence of hardgrounds in the upper Corryville section suggests that the rate of sedimentation between episodic depositional events could be relatively low (Meyer, 1990), and the abundance of thick mud layers implies that post-storm exhumation and reworking by bottom currents was minimal. No obvious condensed beds with authigenic materials (e.g. phosphatic pebbles) signifying prolonged subareal or subaqueous exposure were observed or have been previously reported from within the Corryville Member. Therefore, storm deposition must have been a fairly continuous, though intermittent, process.

In this type of low energy marine environment, skeletal debris that was exposed on the bottom surface for extended periods of time should have a taphonomic signature distinct from that of rapidly buried material. For this reason, variability between samples can be the result of variation of exposure time rather than environmental intensity (Holland, 1988). Disarticulation should increase with increased surface exposure, especially in environments with lower net sedimentation rates. Normal, slow to moderate rates of burial (1-10 cm/100 yrs) would permit a complete disarticulation of skeletal elements (Brett and Baird, 1986, p. 212). Modern decay experiments have demonstrated that multielement skeletons can decay within a matter of days after death (Meyer and Meyer, 1986; Allison, 1988; Greenstein, 1991). In this study, no articulated echinoderms, trilobites, or even trilobite moults were observed outside of the rare Lagerstätten. This would suggest that fairweather marine sedimentation rates and bottom current activity were insufficient to preserve post-mortem multiskeletal remains.

Instances of encrustation were observed throughout the section, and no single stratigraphic interval displayed more encrusted material than any other. Encrustation is further evidence of extended exposure of fossil material, but this feature alone may not be reliable for determining the surface residence time (Brett and Bordeaux, 1990). Encrustation was observed on orthoconic nautiloid shells (> 90% in one specimen), pelecypods, articulated brachiopods, articulated crinoids stems, other bryozoans, and a variety of trilobite sclerites, including spines, cranidia, and unidentifiable platy fragments. Corryville bryozoan encrustation occurred predominantly on the convex side of single pelecypod and *Rafinesquina* valves. In comparison, beds of the Bellevue Member contained a much greater amount of bryozoan-encrusted material than those of the Corryville Member. Diekmeyer (1990, 1992) noted that encrusting bryozoans were more plentiful in the shallow-water Bellevue facies than in the deeper water Kope facies. In the Corryville Member, erect ramose bryozoans are more common than the encrusting morphotypes, a relationship that has been associated with increased water depth in modern marine environments (Schopf, 1969).

Corrasion and fragmentation were significant processes in the alteration of skeletal materials during fairweather conditions. Davies et al. (1989) found in modern sediments that dissolution was responsible for most taphonomic loss of carbonate shell material, more so than abrasion or bioerosion. Abrasion is considered to have been less important in deeper water, quiet environments like the Corryville facies (Brett and Baird, 1986), and bioclasts from the samples were not much abraded. Kreisa (1981b) suggested that daily, fairweather processes were more responsible for shell fragmentation than episodic storm turbulence, however, breakage can be high when skeletal remains are transported together by bottom storm currents (Harrison and Makan, 1981). More robust shells and other skeletal remains may remain at the surface for longer periods and involve complex paleoecological relationships (Holland, 1988). Small skeletal fragments in the bulk samples were highly corraded and displayed rounded, thinned edges, and this condition was likely related to dissolution from extended exposure. Conversely, larger, whole shells mostly displayed little to no corrasion, implying that all skeletal materials were not subjected to biostratinomic processes of the same duration and intensity. It thus appears that fairweather processes were a primary means for taphonomic alteration, while burial due to storm events was the means of final preservation.

Corryville trace fossils can be used to interpret some general information concerning the environmental conditions present following the high energy phase of episodic storm events. The restriction of burrows at the tops of storm event beds suggests a rapid post-storm substrate recolonization (Meyer et al., 1981, p. 52), perhaps in response to an introduction or remixing of detrital organics. Even where most abundant, ichnofossils represent a relatively low amount of reworking; post-storm mud accumulation must have been rapid enough to leave little time for a thorough biological churning of the sediment. Brandt (1980b) observed a limited development of bioturbation within Corryville trilobite shales and also attributed this phenomena to recurrent, rapid influxes of silt and clay. *Chondrites* has been commonly associated with sediments that contained abundant unoxidized organic matter (Ekdale, 1992, p. 163), and this implies that the bottom water may have been dysaerobic or, at the very least, that the sediment pore waters were oxygen depleted.

Large-scale Taphonomic Patterns

Despite the variety of taphonomic signatures that exists within the Corryville Member, this unit is most conveniently described as a single taphofacies. In this taphofacies, fossil assemblages were mostly restricted to carbonate beds and contained abundant, polytaxic skeletal material. Taxa with multielement skeletons were disarticulated unless preserved *in situ* by rapid storm burial; the latter phenomenon was rare and apparently occurred only during certain periods of Corryville deposition. Fossil assemblages contained molds and variable ratios of whole and fragmented hardparts. Bioclastic material displayed variable amounts of corrasion and fragmentation, and these were attributed to extended fairweather exposure and to unrecorded storm activity. Episodic storm events remixed and reoriented bioclasts and deposited them as tempestites that reflected the storm intensity and relative water depth. The effects of early diagenetic processes on the formation of the fossil assemblages were minimal, although aragonitic shells were differentially dissolved. A more detailed taphofacies description would be possible through a qualitative, comparative taphonomic study of the Mt. Auburn and Bellevue intervals.

Differential preservation appeared to reflect limited variations in the intensity of biostratinomic processes rather than large-scale shifts in the environmental parameters. There was no strong taphonomic evidence to support a protracted transgression, although the abundance of thick grainstones at the base of the Corryville Member suggested that winnowing and reworking of bioclastic material may have been greater at that time. Taphonomic attributes varied unsystematically within the Corryville section, and the four "zones" could not be differentiated solely by taphonomic signature. When compared to the rest of the samples, however, those from Zone 4 generally displayed smaller-sized fragments, fewer trilobite fragments, fewer pelecypods, increased bryozoan fragmentation and sorting, few articulated brachiopods, higher relative amounts of corrasion, and a higher relative percentage of concordant, convex-upward shells. Additionally, *Conostichus* and rare "shingled" *Rafinesquina* valves were observed in field exposures near the upper unit contact. This wedging of valves occurred when an abundance of disk- or blade-shaped fragments was subjected to continued wave agitation (Seilacher, 1973, Fig. 5; Sanderson and Donovan, 1974). These apparent taphonomic trends closely resemble taphonomic attributes reported by Krumpolz (1980) from the Mt. Auburn Member; this suggests that the upward shoaling from the Corryville Member to Mt. Auburn Member may have begun within the upper Corryville section three or four meters below the unit contact. This result is not surprising in light of the gradational nature of the Corryville-Mt. Auburn contact (Tobin, 1982; Schumacher et al., 1991).

The variability of preservation between the limestone facies and shale facies of the small-scale upper Corryville bedding sequences could not be adequately tested in this study. Samples were not collected with the intention of quantifying the taphonomy of cycles, but because the tight sampling interval, a few patterns were recognized in the shale facies. Tempestites were normally graded with either a bimodal distribution of small skeletal fragments and large brachiopod valves or simply small skeletal fragments. In the beds from the shale facies in Zone 3, pelecypods were preserved within the fine-grained portions of samples. Pelecypod abundance was highest within this interval, but whether this was a function of enhanced preservation or paleocommunity dynamics could not be determined. A more in-depth taphonomic examination is needed to determine the nature of the Corryville cycles. The cycle represented in Zone 2 is present for nearly a kilometer along Stonelick Creek and offers an excellent opportunity to examine lateral variation within a specific cyclic interval.

Very few large-scale patterns were seen in the quantified taphonomic data, suggesting that either the dominant biostratinomic processes did not vary greatly throughout Corryville deposition or that sampling procedures needed to be revised. A potential shortcoming of this type of taphonomic study was that it did not take into account within-habitat variation, which may be potentially as great as between-habitat variation (Staff and Powell, 1990). Sample collection was limited by the width of accessible exposures, and an investigation of within-habitat taphonomic variation would require multiple samples collected from along a single bedding plane. An optimal sampling method would also include a larger sample size and a sampling strategy concentrated along significant lithostratigraphic features (i.e. cycles and unit contacts). In this investigation, the vertical sampling interval was set at a relatively close range so that any large, taphonomically distinct intervals should have been detected. While no strong signatures were revealed, this sampling method allowed for the description of the general, recurring taphonomic attributes of Corryville faunal assemblages.

By identifying the typical preservational style of a facies, the more taphonomically unique strata can be more easily identified in future studies.

Conclusions

1) Taphonomic evidence supports the assertion that Corryville Member deposition occurred in a normally low energy environment dominated by episodic storm processes. Post-storm deposition of suspended skeletal material and muds was relatively rapid with little size sorting. Unidirectional storm currents flowing to the N/NW reworked and reoriented skeletal fragments into a dominantly convex-upward position. Most beds displayed minimal post-storm reworking by bottom currents or burrowers.

2) The Corryville Member contains diverse and abundant of trace fossils, but these are present throughout the section and probably represent a single trace fossil assemblage, or "ichnofacies". Several ichnospecies occur in association, and most ichnofossils are present in beds with abundant silt-sized sediment. Shales are rarely bioturbated. *Conostichus*, a conical hyporelief also common within the Mt. Auburn Member, was restricted to limestones within the upper 3 meters of the Corryville section.

3) The Corryville Member appears to be a single taphofacies. Most limestone beds within the Corryville Member contain a variety of taphonomic modes, possibly due to a remixing of several generations of skeletal materials by storm events. Macrofossils were rarely articulated, and differential disarticulation, fragmentation, and dissolution were probably the result of fairweather biostratinomic processes. Early diagenetic alteration of fossil assemblages was minimal.

4) No new taphonomic event horizons were discovered in this investigation, but previously described trilobite and echinoderm Lagerstätten appeared to be distributed nonrandomly within the Corryville section at Stonelick Creek. One horizon was situated at the center of the section, and another occurred just below the upper unit contact. In general, Lagerstätten were rare and not representative of the typical mode of preservation in the Corryville Member.

5. Limestone beds in the upper 3 to 4 meters of the Corryville section contain less and smaller skeletal material that exhibits increased corrasion and fragmentation. These trends are thought to be associated with the upward shallowing from the deeper-water environment of the Corryville Member into the more proximal conditions represented by the Mt. Auburn Member.

INTERPRETATION OF CORRYVILLE DEPOSITION

The following section is a summary discussion of the details described within the preceding three chapters. Quantitative methods were utilized throughout this investigation with the intent of creating an objective, reproducible data set, and all interpretations presented herein are those of the author as based upon the results of the data. It is the hope of the author that, as additional information is gathered in future studies, these interpretations will be further refined or perhaps replaced by improved models.

Depositional Mechanism

Tobin (1982) maintained that the Corryville facies was a quiet-water, marine setting. This observation is verified by the following evidence: (1) the high abundance of thick, nonfossiliferous shales; (2) the excellent preservation of trace fossils, sedimentary structures, and graded tempestites; (3) the presence of abundant carbonate matrix within limestone beds; (4) the abundance of whole, unabraded, thin-shelled, and delicate invertebrate macrofossils; (5) the abundance of organisms morphologically adapted for muddy substrates; and (6) the absence of reworking of storm deposits and other relatively high-energy environmental processes. These factors all indicate deposition in low energy, probably within a lower shoreface to transitional zone environment, but above storm wave base. The abundance of shales and distal tempestites (arenaceous calcisiltites) suggests that the Corryville environment was often deep and far enough away from the carbonate source that only the finer material was transported in by unidirectional currents (cf. Aigner, 1985). The sea floor bottom was probably patchy, a mix of skeletal shoals, firmgrounds, soft mud, and rare hardgrounds (Walker and Diehl, 1985). Various benthic organisms displayed morphologic adaptations for life in or on each of these substrates.

The concept of a storm-related origin of the Cincinnatian Series has received broad support and acceptance amongst Cincinnatian workers (Meyer et al., 1981; Tobin and Pryor, 1981; Tobin, 1982; Jennette, 1986; Schumacher, 1984; Diekmeyer, 1990; Jennette and Pryor, in press; and others). Sedimentary structures, carbonate petrology, and taphonomy all indicate that storm activity was an equally significant process during Corryville time. Most of the sedimentary features depicted within this investigation resemble those described by Jennette (1986) and Jennette and Pryor (in press) from storm-related deposits in the lower Cincinnatian. Jennette and Pryor (in press) proposed that storm-induced, offshore-directed bottom currents were mainly responsible for sediment transportation and suspension. Reoriented skeletal material and gutter casts suggest that Corryville storm currents flowed downslope to the N/NW, a direction normal to the ramp slope. Shales were probably brought in by periodic pulses from the east, where the source was the Taconic Highlands (Tobin, 1982). Most limestones displayed structures associated with distal deposition (cf. Aigner, 1982, 1985; Jennette and Pryor, in press), and limestones represented parautochthonous deposits of biogenic materials.

Davies et al. (1989) observed in modern environments that the preservation of carbonate material from the destructive effects of dissolution involved high rates of deposition; taphonomic evidence from the fossil Lagerstätten indicates that Corryville storm deposition was both rapid and episodic (Brandt, 1980; Tobin and Pryor, 1981; Brandt Velbel, 1985; Meyer, 1990). Tobin (1982) suggested that depositional rates for the Cincinnatian were comparable to those in modern carbonate environments, but that accumulation rates were far lower because most Cincinnatian storms were erosional by nature. These events commonly reworked or removed accumulated storm and background sediments and interrupted carbonate production for indefinite periods of time (Tobin, 1982). Thus net sedimentation during the Cincinnatian was not the equivalent of net accumulation (Schindel, 1980; Tobin, 1982), and the accumulation rate for single beds could have varied from hours or days (distal tempestites) to tens of years (amalgamated beds). This condition indicates that overall depositional rates within the Corryville section can not be determined simply by dividing unit thickness by time and rates of relative background deposition could not be determined.

Many of the Corryville beds that superficially appeared homogeneous were actually highly complex, multi-event deposits. Given a mechanism of storm deposition wherein one limestone and shale couplet equals one storm event (Tobin, 1982), then graded tempestites with an intact upper silt component probably represented a single episode of storm disturbance. In shale beds, however, multiple layers of silt, fossil hash, or fossil stringers were frequently observed, especially within Zone 1. This heterogeneity implies that a single shale "bed" was actually deposited in several intermittent episodes of either low environmental energy or minimal amounts of sediments larger than mud size. "Background" (fairweather) muds could not be differentiated from storm-deposited muds, further obscuring the relative amount of time represented by thick shale horizons or cycle facies.

The absence of condensed beds, subaerial exposure surfaces, or concentrations of authigenic minerals suggests that no large-scale diastems were present within the stratigraphic section or at the bases of small-scale cycles. Hofmann (1964) noted the presence of so-called "mud cracks" from a

Corryville bed at Stonelick Creek and attributed these polygonal fractures to subaerial exposure. No other subaerial features were reported by Hofmann (1964). These cracks are similar to those seen in the upper Corryville edrioasteroid hardgrounds (Rassmann, 1984; Meyer, 1990) and may be related to extended subaqueous surface exposure, weathering patterns, or more likely, subaqueously-formed syneresis cracks.

Although no primary omission surfaces were discovered, Corryville deposition was not entirely continuous. The erosional base of each tempestite bed implies a small diastem where material has been removed from the record of deposition (Kreisa, 1981b; Aigner, 1982). The relative amount of erosion that occurred at these horizons would be difficult to determine, primarily because the shales lacked any type of lamination or depth-related structures. Moreover, the average frequency of erosion was related to many factors, including water depth, storm strength, paleolatitude, local topography, and general climatic regime (Speyer and Brett, 1988), that cannot be easily assessed. A second type of diastem is represented by proximal tempestites such as those within the carbonate cycle facies. These commonly amalgamated beds contain fossil materials with complex taphonomic signatures that suggest multiple episodes of reworking and cannibalization of previous storm or "background" deposits (Aigner, 1982, 1985; Seilacher and Aigner, 1991). In addition, the abundant discontinuous shale interlayers within proximal tempestites imply a nearly complete storm erosion of former, possibly thick, mud deposits.

Both autocyclic and allocyclic models have been proposed to explain the origin of small-scale cyclicity in the Cincinnatian Series. Tobin (1982) attributed the formation of megacycles to fluctuations in the terrigenous sediment supply, either as a result of climatic fluctuation or from a shifting source area (i.e. delta switching). From field observations, Tobin (1982) qualitatively figured that cycle duration was approximately 57,000 yrs, which is comparable to cycles from other epicontinental sequences (Aigner, 1985). Alternatively, Jennette (1986) and Jennette and Pryor (in press) suggested that glacio-eustacy was responsible for cycles within the Kope through Bellevue transition zone. Jennette and Pryor (in press) cited the following reasons to support their model: 1) a coeval glaciation of Gondwanaland in the Upper Ordovician (Sheehan, 1973; Lenz, 1976; Brenchley and Newall, 1980; Hambrey, 1985); 2) the asymmetry of the cycles indicating a fast transgression and slow regression, a signal similar to what would be expected from glacial oscillations; and 3) the cycle duration of 57,000 yrs from Tobin (1982) fit well within the limits dictated by the Milankovitch theory of orbital cyclicity (20,000-400,000 yrs). Aigner (1985) described similar small-scale cycles from the Triassic Upper Muschelkalk epeiric sea deposits and postulated that only a minor sea level change of approximately 1 m would be required for their creation.

The process model of Jennette and Pryor (in press) appears to explain Corryville cyclicity more plausibly than the model of Tobin (1982). Allocyclic mechanisms such as eustacy would have affected a greater area of the carbonate ramp, would have been active for longer durations, and would have reflected proximality trends (Aigner, 1985; Einsele et al., 1991). Tectono-eustacy was dismissed as a possible cycle mechanism because coeval Taconic thrusting probably occurred several hundred miles east of the ramp and on a time scale exceeding that predicted by cycle thickness (Jennette and Pryor, in press). The lateral continuity of Corryville cycles within southwestern Ohio implies a regional variation in environmental conditions rather than the more local effects of autocyclic deposition, and the asymmetry of Corryville cycles is adequately explained by a glacially-driven mechanism as described by Jennette and Pryor (in press). Although the individual Milankovitch orbital parameters have constant amplitudes and time periods, the combined effects of these parameters can become complex (Einsele et al., 1991), and this may explain why Corryville cycles are of varying thickness and character.

Depositional Patterns and Relationship to Cyclicity

Previous lithostratigraphic studies (Tobin, 1982; Holland, 1990; Schumacher et al., 1991) have tended to regard the Corryville Member as a homogeneous section, but a high-resolution stratigraphic analysis of this interval has clearly proven that assumption to be incorrect. Shale and limestone beds within the vertical Corryville section were distributed in a heterogeneous and systematic manner, with small-scale depositional cycles restricted to the upper half of the unit. Shale-rich and limestone-rich intervals were traced laterally in mean shale percentage logs along a transect of approximately 50 km; the persistence of these trends in both proximal and distal portions of the ancient carbonate ramp suggests that these patterns represent significant temporal variability in the regional depositional environment. Based upon the results of this investigation, the Corryville section at Stonelick Creek can be divided into two roughly equal portions: a "lower" Corryville Member, the basal 9 m of section, and an "upper" Corryville Member, the overlying 10.5 m of section. The contact between the "lower" and "upper" Corryville Member was arbitrarily placed at the base of the first thick shale in the stratigraphically lowest shale cycle facies, the equivalent of the previous Zone 1/Zone 2 contact. This horizon represents a general shift in carbonate petrology and distribution, and to a minor extent, in taphonomy and faunal distribution.

The "lower" Corryville Member at Stonelick Creek, the equivalent of Zone 1, is distinguished by the following characteristics: 1) abundant bryozoan colonies and a rich articulate brachiopod fauna including *Plectorthis*, *Rafinesquina nasuta*, and *Platystrophia* sp., the latter two of which appear to be stratigraphically restricted to this interval; 2) a lack of preserved cycles; 3) a higher abundance of grainstones, packstones, wackestones, and amalgamated beds; 4) predominantly discontinuous bedding; 5) a more uniform vertical spacing of limestone beds; 6) an increased number of gutter casts; 7) shales and limestones of the same average thickness (6 cm for both); 8) a mean shale percentage that ranges between 45% and 61%; 9) frequent fossil stringers and discontinuous silt and carbonate lenses in shales; 10) a mixed taphonomic signature in most limestone beds; and 11) several horizons of irregular-bedded packstones, grainstones, and fossiliferous shales (IBHs). The haphazard fossil orientation, increased corrasion and fragmentation, starved ripples, and absence of *Rafinesquina* associated with the IBHs strongly suggest that environmental energy was higher at these horizons than in the surrounding strata.

The "upper" Corryville Member at Stonelick Creek, which is the combined Zones 2, 3, and 4, can be recognized by the following characteristics: 1) distinct cyclic bedding sequences with a proximal carbonate facies and a distal shale facies; 2) a higher abundance of packstones, fine packstones, calcisiltites, arenaceous calcisiltites, and "ideal" storm bed couplets; 3) discontinuous to continuous bedding; 4) a dichotomous distribution of carbonate lithotypes, with arenaceous calcisiltites, calcisiltites, and thin packstones in the shale cycle facies and packstones and grainstones in the carbonate cycle facies; 5) limestone beds that are either thin (in shale facies) or thick (in carbonate facies); 6) shales that are generally thicker than limestones, except in the carbonate cycle facies; 7) a typically higher mean shale percentage (59%-72%) that can range from 31% to 90%; 8) sparsely fossiliferous shales, except within the carbonate facies of cycles; 9) Lagerstätten at the base ("trilobite shales") and at the top (echinoderm deposits) of the interval; 10) increased fragmentation, corrasion, and shell reorientation in the upper 3 m; and 11) *Conostichus*, *Cyclora*, and rare hardgrounds in the 3 m below the upper unit contact.

The ordered distribution of cycles within the Corryville Member suggests that either the mechanisms responsible for cyclic deposition were inactive in the "lower" Corryville Member or that environmental conditions were such that cycles were simply not preserved. The first assumption appears to be at least partially invalidated by evidence from the distal portion of the study transect. In core 868, two well-defined cycles were present in the upper half of the "lower" Corryville Member (Appendix 2), with the thickest IBH as the carbonate shale facies of the lower of the two cycles. Corryville strata in the bottom 5 m of core 868 yielded no sign of cyclicity and were typical of the "lower" Corryville bedding style. If these two shale-rich intervals in the "lower" Corryville Member are indeed bedding cycles, then their absence in field exposures and cores to the southwest can be explained as a lack of preservation in more shallow, proximal ramp settings (cf. Aigner, 1985). A study of additional cores from the "distal" portion of the carbonate ramp can further resolve this relationship.

The shale facies of Zone 2 at the base of the "upper" Corryville Member was the lowest shale-rich interval to have been preserved in the three cores and at Stonelick Creek. This interval has therefore been interpreted as a bedding sequence of regional significance. Given the assumptions that Cincinnatian shale cycle facies represent deposition in deeper water conditions (Tobin, 1982; Jennette, 1986; Jennette and Pryor, in press) and that such a mud-rich facies would be preserved only within low energy, distal environments, then the Zone 2 cycle must have been deposited when conditions along the carbonate ramp were, for the first time during Corryville deposition, universally "deep". If so, then the base of the "upper" Corryville Member (base of Zone 2) could be defined as the point of maximum water depth or flooding, with the "lower" Corryville Member representing slightly shallower environmental conditions.

It would seem reasonable to suggest then that the Bellevue-Corryville transgression was initially abrupt, but was not complete until some time later during Corryville deposition. There exists no positive way to discern whether or not the transgression continued above the base of the "upper" Corryville Member, but the continued preservation of similar cycles implies that conditions did not grow markedly deeper. In an earlier study of the Corryville interval, Hinterlong (1981) likewise suggested that the lower section was transgressive, but his rationale lacked a regional or taphonomic perspective and relied primarily upon minor changes in paleocommunity composition.

Because the paleoramp slope was gentle and fairly uniform (Tobin, 1982; Jennette, 1986), only minor variations in relative sea level would have been needed to create significant shifts in the positions of the normal and storm wave bases (Irwin, 1965). It is possible that, although the Corryville facies represented comparatively distal water conditions, there existed some threshold water depth above which cycle definition was not clearly preserved. Individual limestone beds would have been deposited, but mud deposits were either less thick or more frequently eroded in proximal settings. If such a threshold did exist, then it was not reached in more proximal environments until the time represented by the base of the "upper" Corryville Member. Interestingly, tempestites and shales with well preserved, articulated arthropods and echinoderms occurred stratigraphically just above the point of maximum flooding. The "trilobite shales" have been interpreted as horizons where trilobites were smothered by thick, rapid influxes of mud (Brandt Velbel, 1985);

their preservational condition suggests that the Corryville sea floor may have been at or just below storm wave base where scouring and erosion were minimal and distal tempestites were composed dominantly of suspended muds or mud flows. Deeper water conditions beyond storm wave base are more liable to preserve obrution deposits (Brett and Seilacher, 1991).

Hinterlong (1981) found that, in the Corryville section at Stonelick Creek, "zones where changes in diversity occur coincide with zones where sedimentologic evidence indicates changes in energy and sedimentologic regimes" (p. 68). Although Hinterlong's (1981) observations were based upon a qualitative assessment of the section, the faunal distribution of the Corryville Member at Stonelick Creek did broadly reflect the upward deepening trend. Diversity appeared to be greatest within the "lower" Corryville Member, where bryozoan colonies and unusual gastropod, trilobite, brachiopod, and pelecypod taxa were abundant. Brachiopods endemic to the "lower" Corryville Member, specifically *Platystrophia*, *Rafinesquina nasuta*, and *Plectorthis*, were also common in the Fairview, Bellevue, and Mt. Auburn units, Cincinnatian intervals interpreted as more proximal, higher energy facies than the Corryville Member (Tobin, 1982; Dattilo, 1992; Diekmeyer, 1990, 1992). The disappearance of these taxa coincided with the preservation of cycles and supposedly quieter water conditions. *Plectorthis* reappeared upsection within a carbonate cycle facies in Zone 4, suggesting that this genus may have migrated with more turbulent environmental conditions. Abundances of pelecypods, trilobites, brachiopods, and gastropods were less in the "upper" Corryville Member. Many of the beds in this portion of the Corryville section were either nonfossiliferous arenaceous calcisiltites or packstones and calcisiltites with fine, unidentifiable fossil hash.

The regression from the Corryville Member to the Mt. Auburn Member likewise appears to have been a gradational event. In the upper 3-4 m of the Corryville section at Stonelick Creek, limestones and fossils displayed characteristics that more closely resembled those observed from the strata of the Mt. Auburn Member by Tobin (1982). Packstones became increasingly fine-grained and well-sorted upsection, with an increase in phosphatic steinkerns (*Cyclora*), fragmentation, and corrasion. The ichnofossil *Conostichus* was present in the uppermost Corryville Member and lowermost Mt. Auburn Member, suggesting that both intervals were favorable environments for the trace maker. Bored hardgrounds were present within the Mt. Auburn strata along Stonelick Creek, and similar surfaces have also been recovered from near the top of the Corryville Member at other localities (Meyer et al., 1981; Rassmann, 1984; Meyer, 1990). These surfaces could have resulted from a reduced sediment supply, an increased time of exposure to the bottom waters, an early marine cementation, or a combination of these. Meyer (1990) suggested that *in situ* edrioasteroid populations within the upper Corryville Member contained multiple generations and therefore represented a greater time span during which the sea floor was exposed and available for colonization.

Sequence Stratigraphy: An alternative View

Van Wagoner et al. (1988) defined sequence stratigraphy as the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities. Recent Cincinnatian studies have begun to employ sequence stratigraphy to address the question of depositional timing for small-scale cycles and the large-scale shoaling-upward sequences (Holland, 1992; Jennette and Pryor, in press). In the Kopè through Bellevue sequence, Jennette and Pryor (in press) documented regionally continuous fifth order, glacio-eustatic cycles, or bedding sequences. Each bedding sequence was interpreted as a single storm-deposited parasequence (Jennette and Pryor, in press) with a duration of 57 Ka. A parasequence is a relatively conformable succession of genetically related beds or bedsets bounded by marine-flooding surfaces and their correlative surfaces (Van Wagoner et al., 1988). Fifth order bedding sequences generally represent deposition on the Milankovitch scale, from 0.01-0.1 Ma (Einsele et al., 1991).

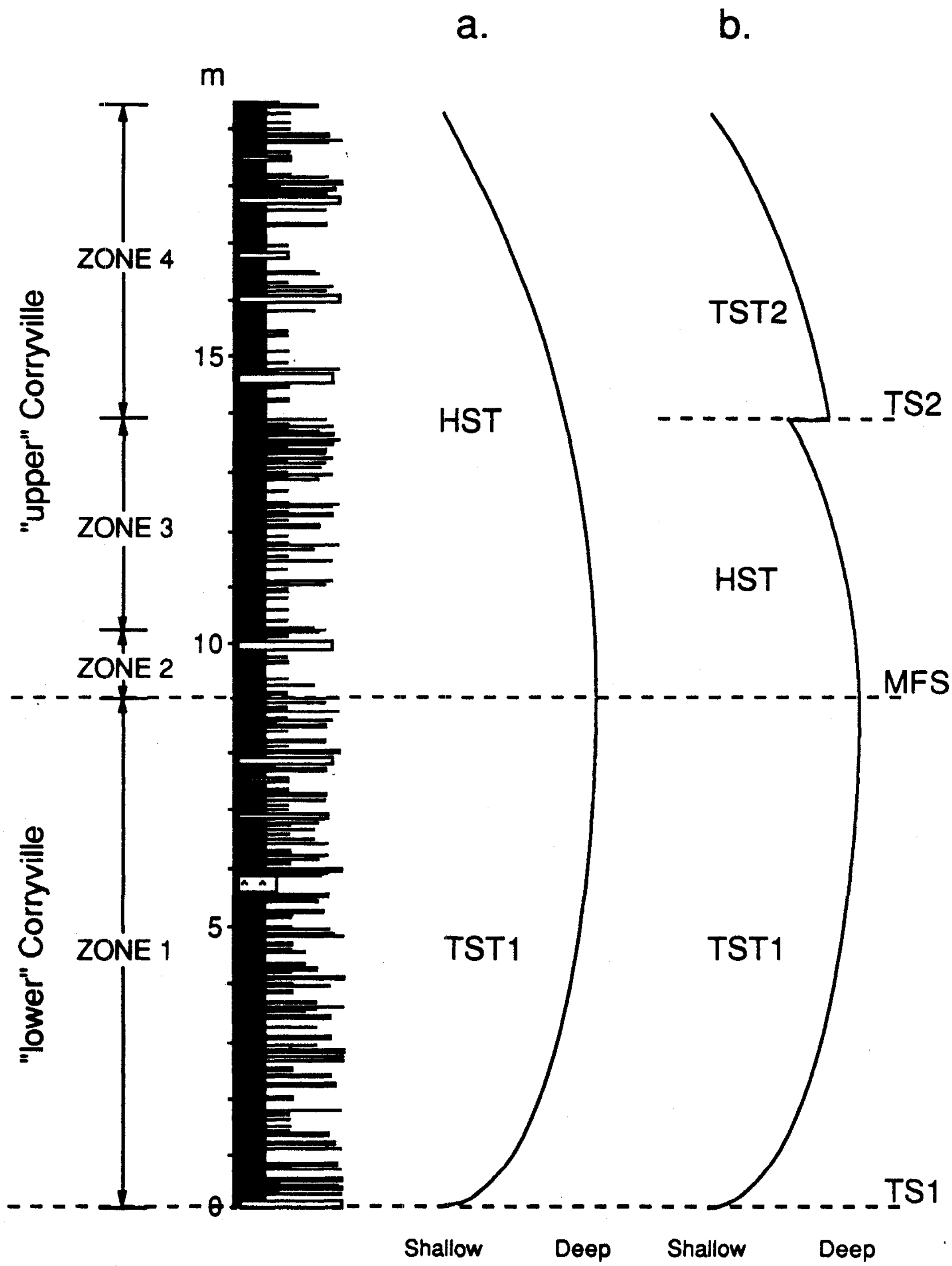
Holland (1990, 1992) completed a sequence stratigraphic study for the entire Cincinnatian Series in southwestern Ohio, northern Kentucky, and southeastern Indiana. Holland interpreted the Corryville and Mt. Auburn units as the lower and upper portions, respectively, of the "C2" sequence, an interval representing 1 Ma of deposition. The Bellevue-Corryville contact was interpreted as a transgressive system tract (TST), where the transgressive surface and maximum flooding surface were essentially the same (Holland, 1990, 1992). Therefore the Corryville and Mt. Auburn units were interpreted as a highstand systems tract (HST), the portion of the sequence that overlies the maximum flooding surface (MFS) and underlies the sequence boundary (Holland, 1990, 1992). The character of the combined lower transgressive and maximum flooding surface varied geographically from hardgrounds and gradational bedding in Ohio to a sharp contact in Kentucky (Holland, 1990, 1992).

Holland's (1990, 1992) study utilized only partial exposures from the base and top of the Corryville section, and as a consequence, lacked the detail necessary for a thorough sequence stratigraphic description of the full interval.

As described in the preceding section, the maximum flooding surface was established just below the center of the Corryville Member at the base of Zone 2. This flooding surface was regional in extent and was distinguished by a relatively sharp increase in shale content. The Bellevue-Corryville contact is still representative of the initial transgressive surface, but now the "lower" Corryville Member (Zone 1) must be interpreted as a relatively thick TST (Fig. 66a). This does not resemble Holland's (1992, p. 209) description of a Cincinnatian transgressive facies, but it does fit the essential definition of a transgressive unit situated between two highstand facies. The "upper" Corryville Member is interpreted as the HST that continued upwards in to the Mt. Auburn Member (Fig. 66a). The highstand facies for the Corryville Member is characterized by increased shales and regionally correlative bedding sequences. These bedding sequences appear to be fifth order cycles or parasequences similar to those reported by Jennette and Pryor (in press). The two system tracts compare favorably with Jennette and Pryor's (in press) description of fourth-order stratal units.

An alternative sequence stratigraphic interpretation is presented in Figure 66b. The limestone content of Zones 2 and 3 increases upward through to the base of Zone 4, where thick shales are again dominant. The upper third of Zone 3 consists of thick, amalgamated grainstones and packstones that exhibit a bedding style similar to that seen in the "lower" Corryville Member, and it is possible that this interval represents a significant regressive interval. If so, then the Zone 3/Zone 4 contact would represent a second transgressive surface, although probably less intense the initial transgression at the base of the Corryville Member (Fig. 66b). Zone 4 would therefore represent a second transgressive system tract (TST2) above the HST. The presence of the three

Figure 66 - Sequence stratigraphic interpretation of the Corryville Member. Stratigraphic column is composite from Stonelick Creek. The general trend appears to be a transgressive surface (TS1) at the Corryville-Bellevue contact followed by a transgressive systems tract (TST1) represented by the "lower" Corryville. The maximum flooding surface (MFS) is placed at the base of Zone 2, the first thick shale interval of regional extent. The "upper" Corryville appears to be either: a) a single highstand systems tract (HST); or b) an HST followed by a small transgression at the top of Zone 3 (TS2), and then a second transgression systems tract (TST2).



a.
b.
m
ZONE 4
ZONE 3
ZONE 2
ZONE 1
"upper" Corryville
"lower" Corryville
15
10
5
0
HST
TST1
TST2
HST
TST1
TS2
MFS
TS1
Shallow
Deep
Shallow
Deep

system tracts is apparent in the mean shale percentage logs of Stonelick Creek and core 2620 (Fig. 31).

Suggestions for Further Research

It is the hope of the author that the conclusions reached within this study will form a solid foundation upon which future investigations of the Corryville Member can build. While it is tempting to believe that the Corryville Member is now well-understood, many important aspects of this unit have yet to be satisfactorily resolved. For instance, little is still known concerning the early and late diagenesis of the Corryville Member, the details of shale petrography in relation to the depositional trends (e.g. cycles), and the persistence of the cyclicity to the S/SE within the stratigraphically-equivalent Grant Lake Limestone. Strata within the "upper" Corryville Member appear to be the laterally continuous, and the potential of discovering distinct, isochronous event horizons within this interval remains high. High-resolution analyses of additional rock cores and field exposures would add further detail to the variability of cyclic sequences and the relationship of that variability to proximality gradients.

In addition, much work remains to be done concerning the paleontology of the Corryville Member. First, the taxonomy of this unit must be reworked in detail so as to afford future studies a well-documented, reliable faunal description. For example, twelve species of *Platystrophia* were found in the University of Cincinnati fossil collections. Most of these Corryville taxa lack a holotype or proper documentation, and therefore need to be reexamined. A reassessment of taxonomy would also greatly facilitate the identification of rare and problematic species. The search for new species should continue, and the potential for such discoveries seems to be highest within the tempestite beds at the center of the unit. This thesis did not attempt to quantify the effects of lateral transport on faunal distribution, however the recurring exposure of specific

Corryville intervals (e.g. Zone 2) along Stonelick Creek implies that such a study is feasible. Finally, a comparison of the Corryville Member to similar shale-rich Cincinnatian lithofacies (e.g. Corryville, Kope, Waynesville) would aid the understanding of the nature and tempo of transgressions and of how such events affected faunal composition, distribution, and preservation.

CONCLUSIONS

1) The Corryville Member of the Grant Lake Formation is a single shale-rich (63% regional average) facies deposited in an epeiric sea along a shallow carbonate ramp. The Corryville Member contains abundant packstones, arenaceous calcisiltites, calcisiltites that are dominantly planar, continuous to discontinuous. Shales are terrigenous and sparsely fossiliferous. Evidence suggests that Corryville Member was a low energy, deeper water environment subject to the effects of periodic, high energy storm events. Amalgamated beds and tempestites display diagnostic sedimentary features consistent with those observed in modern storm dominated settings. Taphonomic evidence indicates that the deposition of suspended skeletal material and muds was relatively rapid, with minimal post-storm reworking by bottom currents or burrowing organisms. Unidirectional storm currents flowing to the N/NW reoriented skeletal fragments into hydrodynamically stable positions.

2) The distribution of lithologies within the Corryville Member interval is heterogeneous and systematic, and any assessment of this stratigraphic interval must take this variability into account. The thickness and mean shale percentage of the Corryville Member vary geographically as predicted by proximality relationships; both increase to the north and northwest, the distal portions of the inferred paleoramp slope. On the basis of field observations, the internal stratigraphy of the Corryville Member can be subdivided into four "zones" that vary in mean shale percentage, bedding character, and dominant carbonate lithotype. These zones are laterally persistent within southwestern Ohio and can be used to correlate local and distant field exposures and rock cores.

3) Small-scale cyclic bedding sequences are identifiable in the Corryville Member at Stonelick Creek, but not within the lower half of the section. These asymmetric cycles are composed of a proximal "carbonate facies" and a distal "shale facies" that display sedimentary structures and carbonate textures consistent with proximality relationships from modern storm environments. Cycle thickness varies from 1-3 m, and the "shale facies" is approximately twice as thick as the "carbonate facies". These cyclic bedding sequences are similar to sequences described from other Cincinnatian stratigraphic units. An allocyclic, glacio-eustatic model is endorsed as the probable mechanism responsible for the formation of these small-scale cycles.

4) On the basis of faunal distribution, dominant carbonate lithology, and cycle preservation, the Corryville Member can be divided into a "lower" portion of 9.0 m and an "upper" portion of 10.5 m. The lowest small-scale cycle at the base of the "upper" Corryville Member appears to represent the first widespread shale-rich interval present throughout southwestern Ohio. The base of the shale facies of this cycle is interpreted as the maximum flooding surface, suggesting that the transgression that occurred at the base of the Corryville Member was less abrupt than has been thought. In sequence stratigraphic terms, the "lower" Corryville Member would represent a transgressive systems tract with transgressive surface at the contact of the Corryville and Bellevue Members. The "upper" Corryville Member is interpreted as a highstand systems tract that may possibly be overlain by a second, smaller transgressive systems tract.

5) Corryville fossil assemblages are polytaxic and dominated by epifaunal and semi-infaunal suspension feeders. The most abundant taxa are *Rafinesquina*,

Zygospira, pelecypods (primarily *Ambonychia*, *Modiolopsis*, and *Caritodens*), ramose bryozoans, and trilobites (primarily *Isotelus* and *Flexicalymene*). Many macrofossils display morphologic adaptations for a normally low energy environment with a mud-rich substrate. Trace fossils are abundant throughout the section, and several ichnospecies commonly occur in association. Most ichnofossils are present in beds with abundant silt-sized sediment. *Conostichus*, a conical hyporelief also common within the Mt. Auburn Member, is restricted to the upper 3 meters of the Corryville section. The Corryville Member appears to represent a single ichnofacies.

6). The Corryville Member is interpreted as representing a single biofacies and paleocommunity. Five varying faunal compositions were identified through a multivariate analysis of bed samples, and faunal assemblages differed primarily in the relative abundance of individuals per species. The most common Corryville assemblage contained abundant bryozoans, *Zygospira*, *Rafinesquina*, and trilobites, with lesser amounts of pelecypods and crinoid fragments. Several Corryville brachiopod species (*R. nasuta*, *Platystrophia*, and *Plectorthis*) are abundant within and generally restricted to the lower 9.0 m of the vertical Corryville section at Stonelick Creek. Pelecypods achieve their highest abundance in distal tempestites at the center of the Corryville Member. These faunal distributions can potentially be used for a generalized stratigraphic correlation.

7) The Corryville Member appears to be a single taphofacies. Most limestone beds within the Corryville Member contain a variety of taphonomic modes, possibly due to a remixing of several generations of skeletal materials by storm events. Macrofossils are rarely articulated, and differential disarticulation,

fragmentation, and dissolution probably resulted from fairweather biostratinomic processes. Early diagenetic alteration had minimal effect upon the formation of fossil assemblages. Limestone beds in the upper 3 to 4 meters of the Corryville section contain less and smaller skeletal material that displays increased corrasion and fragmentation. These trends are thought to be associated with the upward shallowing from the deeper-water environment of the Corryville Member into the more proximal conditions represented by the Mt. Auburn Member.

8) No new taphonomic event horizons were discovered in this investigation, but previously described deposits of articulated trilobite and echinoderm specimens appear not to be randomly distributed within the Corryville section at Stonelick Creek. These Lagerstätten are situated at the center of the section and in the interval just below the upper unit contact. In general, fossil Lagerstätten are rare and do not represent the typical mode of preservation in the Corryville Member.

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Appendix 1

Corryville Exposures in the Tristate Area

The following list is a compilation of known and previously cited exposures of the Corryville Member of the Grant Lake Formation and Grant Lake Limestone within the area of southwestern Ohio, southeastern Indiana, and northern Kentucky. This appendix does not attempt to document all exposures within this broad region, but represents a significant number of the more accessible and well-documented localities. Additional detail for most of these localities can be found in Davis and Cuffey (1992).

Corryville Member of the Grant Lake Formation

Armco Steel: Hill and roadcut on Armco Steel Company property in Middleton, Ohio. Mt. Auburn and approximately 3 m (10 ft) of Corryville reported present at this exposure. Butler County, Ohio (Trenton, Ohio 7.5-minute quadrangle).

Backbone Creek: Streamcuts along Backbone Creek, 0.43 km (0.27 mi) east of Ohio Route 32 entrance ramp on Ohio Route 132 (Meyer et al, 1985). Corryville may be present at very top of section. Batavia Township, Clermont County, Ohio (39°05'20"N; 84°10'10"W; Batavia, Ohio 7.5-minute quadrangle).

Bellevue Hill Park: Partial exposure at top of cliff at southwestern corner of park. the Bellevue-Corryville contact is present at this site and is set at a prominent limestone bed which forms a small ledge near the cliff edge (Ford, 1974). Corryville limestones display a distinctive silt covering on the bed top and convex-up brachiopods. Most shales are recessed or eroded. This is also the "Clifton Hill" site of Ford, 1967. Cincinnati, Hamilton County, Ohio (39°07'17"N; 84°31'14"W; Covington, KY.-Ohio 7.5-minute quadrangle).

Blue Rock Road: Roadcut 0.5 km (0.3 mi) southeast of junction of Interstate 275 (Exit 31) and Blue Rock Road (Ford, 1967; Krumpolz, 1980; Meyer, et al., 1981; measured section in Tobin, 1982; Rassman, 1984; Schumacher, 1984; Tobin, 1986; Meyer, 1990; Holland, 1992). Between 1.0 m (3.3 ft) and 3.9 m (12.8 ft) of Corryville is present, but mostly buried, at base of cut. The upper 7.6 m (25.0 ft) of section is composed of the Mt. Auburn Member and the Sunset Formation. Both a shell pavement with abundant edrioasteroids (Meyer, 1990) and a horizon containing abundant specimens of the crinoid *Iocrinus subcrassus* (Schumacher, 1984) have been excavated from the Corryville section at this site. Colerain Township, Hamilton County, Ohio (39°13'47"N; 84°37'16"W; Cincinnati West, Ohio 7.5-minute quadrangle).

"Big 4" Railroad Cut ("Maud Cut"): Exposures located along the railroad line between Maud and Westchester, Ohio, and east of the Interstate 75 overpass (Krumpolz, 1980). This exposure is difficult to access; no local paths or roads lead directly to this section of the tracks. Caution must be exercised as the tracks are still in use. Most of this exposure is the Mt. Auburn; there may be some part of the unit that overlies the Mt. Auburn, but the exposures are steep and were not examined above the typical Mt. Auburn strata. Much of the Corryville is buried in talus and the interval thickness at this exposure could not be determined. Union Township, Butler County, Ohio (39°20'25"N; 84°23'30"W; Glendale, Ohio 7.5-minute quadrangle).

Brookville Dam: Exposure along Brookville Dam spillway south of Brookville Lake, 1.5 miles (2.5 km) north of Brookville, Indiana (Hay, 1981; Tobin, 1982; Tobin, 1986). Approximately 13.8 m of Corryville and a contact with the overlying Sunset Formation. Brookville, Franklin County, Indiana (39°26'13"N; 85°00'19"W; Brookville, Indiana 7.5-minute quadrangle).

Dornbusch: Exposure in west-flowing stream just north of town of Dornbusch, Ohio, and south-southeast of the steam's intersection with Interstate 275 (Ford, 1974; measured section in OGS File 16873). This section contains 11.2 m (36.7 ft) of the Corryville Member. Colerain Township, Hamilton County, Ohio (39°14'52"N; 84°36'30"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Elk Creek: Stream exposure along east bank of Elk Creek at first meander bend of Elk Creek 460 m (1500 ft) north of Howe Road bridge (measured section in OGS File 16893). This cut has 5.5 m (18.0 ft) of the Corryville Member. Madison Township, Butler County, Ohio (39°30'20"N; 84°27'36"W; Middletown, Ohio 7.5-minute quadrangle).

Emming St.: Partial exposure on hill north of Emming Street, between Wheeler and Stratford, and just below the transmitting tower (Forsyth, 1946; Ford, 1974). The Bellevue-Corryville contact is present, but partially buried. Corryville limestones are exposed in a small clearing on top of the small west-facing cliff exposure at this site. Cincinnati, Hamilton County, Ohio. (39°07'22"N; 84°31'21"W; Covington, KY.-Ohio 7.5-minute quadrangle).

Galbraith Rd.: Exposure located 0.5 km (0.3 mi) east of intersection of Galbraith Road and Vine Street (Forsyth, 1946; Van Fossen, 1951). No longer exposed. Springfield Township, Hamilton County, Ohio (Cincinnati East, Ohio 7.5-minute quadrangle).

Highland Ave: "Most SE exposure" on Highland Street (University of Cincinnati Museum Files). No longer exposed. Cincinnati, Hamilton County, Ohio (Cincinnati West, Ohio 7.5-minute quadrangle).

Hunts Creek: Exposure along Hunts Creek 460 m (1500 ft) west of junction of Princeton and Yankee Roads (measured section in OGS File 16889). the exposure begins at the intersection of a south flowing stream and Hunts Creek and continues upstream as a series of low cuts on alternating sides of the creek. This locality contains the upper 7.4 m (24.2 ft) portion of the Corryville Member, the Corryville-Mt. Auburn contact, and 1.3 m (4.3 ft) of the Mt. Auburn member. Liberty Township, Butler County, Ohio (39°23'25"N; 84°23'25"W; Trenton, Ohio 7.5 -minute quadrangle).

Lawrenceburg: Roadcuts on either side of I-275 in Kentucky, 0.7 km ((0.4 mi) south of the Ohio River across from Lawrenceburg, Indiana (Tobin, 1980). May be small section of Corryville at top of exposure. Boone County, Kentucky (39°05'46"N; 84°49'04"W; Lawrenceburg, Indiana-Kentucky-Ohio 7.5-minute quadrangle).

Lick Run: Stream exposures along Lick Run west of State Route 132 bridge, and 760 m (2500 ft) north of Blackhawk, Ohio at the junction of State Route 132 and State Route 123 (measured section in Krumpolz, 1980). The contact with overlying Mt. Auburn is present and sharp; this contact is best seen in the westernmost exposure. Harlan Township, Warren County, Ohio (39°20'02"N; 84°04'41"W; Pleasant Plain, Ohio 7.5-minute quadrangle).

McMillan St.: Exposure in empty lot west of 16 McMillan Street and approximately 66 m (200 ft) northwest of the junction of McMillan and Vine Streets (Ford, 1974). The base of this 3-meter (12-foot) exposure lies at about 845 ft above sea level; the section most likely represents the middle to upper portions of the Corryville. Cincinnati, Hamilton County, Ohio (39°07'39"N; 84°30'52"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Middletown: Roadcuts along both sides of State Route 4, just south of bridge across Dick's Creek, and about 0.5 km (0.3 mi) south of junction with State Route 73 (Krumpolz, 1980; Hay, 1981; Tobin, 1982, 1986). This is the type-section for Hay's (1981) Excello Member of the Brookville Formation, and is sometimes referred to as the "Excello" locality (Krumpolz, 1980; Hay, 1981). The lower half of this section and the Corryville-Mt. Auburn contact are present, but buried under a pile of talus at the base of the exposure. The Corryville is present in the lower 5.0 m (16.4 ft) of the roadcut. Lemon Township, Butler County, Ohio (39°28'40"N; 84°24'58"W; Trenton, Ohio 7.5-minute quadrangle).

Mt. Airy Forest: Series of large roadcuts on both sides of I-74 where it passes through Mt. Airy Forest northwest of Cincinnati, Ohio. These exposures are steep, and permission to examine them must be obtained first from the Ohio Department of Transportation. Green Township, Hamilton County, Ohio (39°10'05"N; 84°34'52"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Muddy Creek: Streamcut just south of Muddy Creek Road bridge 1.0 km (0.6 mi) east of junction of Muddy Creek Road and Ebeneezer Road (Ford, 1967; Jennette, 1986). Most of this exposure is the Bellevue member, but the Bellevue-Corryville contact occurs near the very top of the exposure. Be advised that this creek is polluted and may contain raw sewage. Green Township, Hamilton County, Ohio (39°08'00"N; 84°38'28"W; Addyston, Ohio-Kentucky 7.5-minute quadrangle).

Neeb Road: Exposure north of Rapid Run Road and along Rapid Run Creek (University of Cincinnati Museum Files). No longer exposed. Delhi Township, Hamilton County, Ohio (Burlington, KY.-Ohio 7.5-minute quadrangle).

O'Bannon Creek: Gully along east-facing stream exposure 365 m (1200 ft) south of Gaynor Farm Road bridge (measured section in OGS File 16834). The Bellevue-Corryville contact is present about 4 m (13 ft) above the stream bed and is sharp. This exposure contains nearly all of the lowest Corryville "zone". The 0.5 m (1.6 ft) thick irregular-bedded horizon is located at 5.5 m (18.0 ft) above the Bellevue-Corryville contact. Goshen Township, Clermont county, Ohio (39°14'07"N; 84°11'03"W; Goshen, Ohio 7.5-minute quadrangle).

Ravine Street: Poor, mostly buried exposure behind Seminole Apartments southwest of intersection of Ravine and McMillan Streets (Forsyth, 1946; Caster, 1952; Ford, 1974). A few small, loose Corryville slabs are still present at this site. Cincinnati, Hamilton County, Ohio (39°07'43"N; 84°31'36"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Rumpke Landfill: Inaccessible exposure in field east of State Route 27 N (Colerain Avenue), 2.5 km (1.5 mi) north of Interstate 275 (measured section in Tobin, 1982; Velbel, 1985; Tobin, 1986). This exposure once contained almost 14 m (46 ft) of Corryville and the Corryville-Mt. Auburn contact, but may have been buried as a result of landfill activity. Colerain Township, Hamilton County, Ohio (39°16'33"N; 84°36'03"W; Greenhills, Ohio 7.5-minute quadrangle).

Second Creek: Streamcuts along Second Creek below and west of Cozzandale Road bridge (Osgood, 1970). The uppermost portion of the Corryville and the Corryville-Mt. Auburn contact are present at a small waterfall close to the bridge. An excellent Mt. Auburn exposure occurs northeast of the bridge just around the first stream meander. Harlan Township, Warren County, Ohio (39°19'25"N; 84°05'31"W; Pleasant Plain, Ohio 7.5-minute quadrangle).

Sharonville: Exposure in upper half of field at Sharonville industrial park, situated at end of a 243-meter (800-foot) lane north of Hauck Road and 0.7 km (0.4 mi) east of intersection of Hauck and Reading Roads. This shallow field exposure also contains the underlying Fairview Formation, Bellevue Member, and Miamitown Shale. The Corryville can best be seen at the eastern side of the field just above the highest zone of light gray, sparsely fossiliferous Miamitown Shale. Sycamore Township, Hamilton County, Ohio (39°17'38"N; 84°24'07"W; Glendale, Ohio 7.5-minute quadrangle).

Sheits Road: Exposures along unnamed stream that follows Sheits Road, just west of intersection of stream and Interstate 275 near Dornbusch, Ohio (measured section in OGS File 16872). This locality contains 6.2 m (20.3 ft) of the Bellevue Member, the Bellevue-Corryville contact, and 5.6 m (18.4 ft) of the Corryville member. Colerain Township, Hamilton, Ohio (39°14'50"N; 84°37'24"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Stonelick Creek: Proposed type-section for the Corryville Member of the Grant Lake Formation and Grant Lake Limestone (Schumacher et al., 1991). Stonelick Creek is situated about 2.2 km (1.3 mi) west from the center of Newtonsville and roughly 15.5 km (9.3 mi) east of the city limits of Milford. The entire Corryville Member is present as a series of discontinuous streamcuts upstream and downstream from the Ohio State Route 131 bridge (Hinterlong, 1981; Meyer et al., 1981; Schumacher, 1984; Tobin, 1986; OGS Files 16836 and 16837). Stonelick Township, Clermont County, Ohio (84°6'43"W, 39°10'40"N; Newtonsville, Ohio 7.5-minute quadrangle).

Taylor Creek: Exposure between Miamitown and Dent, Ohio (Osgood, 1970). Could not be located. Colerain Township, Hamilton County, Ohio (Addyston, OH.-KY. 7.5-minute quadrangle).

Todd Run: Streamcut 60 m (200 ft) west of State Route 133 bridge (measured section in OGS File 16853). Bridge is situated 1.3 km (0.8 mi) south of the junction of Ohio State Routes 133 and 32. Streamcut contains 6.4 m (21.0 ft) of the Corryville Member. Williamsburg Township, Clermont County, Ohio (39°02'23"N; 84°02'38"W; Williamsburg, Ohio 7.5-minute quadrangle).

West Middletown: Exposure along unnamed northern tributary of unnamed stream situated 152 m (500 ft) north of driveway on west side of Trenton-Franklin Road. Driveway is 0.8 km (0.5 mi) north of West Middletown, Ohio (measured section in OGS File 16885). Exposure contains 5.0 m (16.4 ft) of Corryville section at base, overlain by 5.2 m (17.1 ft) of Mt. Auburn Member. Madison Township, Butler County, Ohio (39°31'55"N; 84°25'05"W; Middletown, Ohio 7.5-minute quadrangle).

Westwood-Northern Boulevard: Partial exposure in gully northwest of junction of Westwood-Northern Boulevard and Gobel Street (Ford, 1974). The north end of Gobel Street has been closed off. Many of the beds are thick calcisiltites, and this interval may represent the upper portion of the Corryville member. Another exposure was reported on the south side of same junction (Forsyth, 1946). Cincinnati, Hamilton County, Ohio (39°08'50"N; 84°39'45"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Wynbrook Apartments: Partially buried exposure in cliff behind Wynbrook Apartments on the east side of Winton Avenue just north of the intersection with Dutch Colony Drive (Ford, 1974). Dutch Colony Drive is about 6.6 km (2.0 mi) north of the intersection of Spring Grove Avenue and Winton Ave. This exposure contains the Miamitown Shale, and the Bellevue, Corryville, and Mt. Auburn Members of the Grant Lake Formation. The Corryville begins at the first bench up from the parking lot level. Cincinnati, Hamilton County, Ohio (39°11'25"N; 84°31'10"W; Cincinnati West, Ohio 7.5-minute quadrangle).

Corryville Member of the Grant Lake Limestone

Eagle Creek: Exposures along unnamed tributary of West Fork of Eagle Creek, about 365 m (1200 ft) west of junction of Ohio State Route 125 and Faul Road (measured section in OGS File 16912). This section begins at stream level approximately 795 ft above sea-level. The exposure contains 3.4 m (11.2 ft) of the Corryville Member, the contact of the Corryville and the overlying Straight Creek Member, and 5.5 m (18.0 ft) of the Straight Creek Member. Jefferson Township, Brown County, Ohio (38°51'02"N; 83°45'10"W; Russellville, Kentucky-Ohio 7.5-minute quadrangle).

Florence Mall (Mall Road): South end of Mall Road, Florence, Kentucky in area now covered by the Florence Shopping Mall. Source of an edrioasteroid pavement in uppermost Corryville (Meyer et al, 1981; Rassmann, 1981; Meyer, 1990). Boone County, Kentucky (Union, Kentucky 7.5-minute quadrangle).

Georgetown: Roadcuts along both sides of Ohio Route 125 (White Oak Creek valley) approximately 1.3 km (0.8 mi) west of intersection of Ohio Route 125 and U.S. Route 125 near Georgetown, Ohio (Lee, 1974; Holland, 1992). This contains the lowermost Corryville, Bellevue and Fairview Formations. Lewis Township, Brown County, Ohio (38°52'33"N; 83°55'53"W; Hamersville, Ohio and Higginsport, Ohio-Kentucky 7.5-minute quadrangles).

Goose Run: Exposure along stream 91 m (300 ft) west of White Oak Station Road on Goose Run (measured section in OGS File 16906). This series of streamcuts contains the uppermost 4.0 m (13.1 ft) of the Corryville Member, the contact of Corryville and overlying Straight Creek Member, and 5.5 m (18.0 ft) of the Straight Creek member. Scott Township, Brown County, Ohio (38°58'47"N; 83°53'38"W; Hamersville, Ohio 7.5-minute quadrangle).

Manchester: Exposure on west-facing hill on east side of State Route 136 near the intersection of Route 136 and Brown Hill Road approximately 2.4 km (1.5 mi) north of Manchester, Ohio. Outcrop contains Grant Lake Limestone and contact with overlying Bull Fork Formation (Lee, 1974). This roadcut is the same as the "Isaacs Creek" locality of Sweet (1979), or else they are located within a few hundred meters range along the road. Sprigg Township, Adams County, Ohio. (38°44'07"N; 83°03'09"W; Manchester Islands, Kentucky-Ohio 7.5-minute quadrangle).

Maysville Bryozoan Reef Mounds: Roadcut on the west side of U.S. Route 68 and 0.2 km (0.1 mi) south of the U.S. Route 62 and U.S. Route 68 junction and at south edge of the village of Washington, Kentucky (Cuffey, 1992). Bryooan reef mounds located in meter below the Corryville-Mt. Auburn contact. Corryville Member is approximately 8 m thick. Mason County, Kentucky (38°36'36"N; 83°48'39"W; Mays Lick, Kentucky 7.5-minute quadrangle).

Ripley: Roadcut located 4.2 km (2.4 mi) north of city limits of Ripley, Ohio along the west side of US Route 62-68 (Lee, 1974). This exposure reportedly contains a sharp and obvious contact between the even-bedded limestones and shales of the underlying Fairview Formation and the overlying 19.7 m (64.6 ft) of irregular-bedded Grant Lake Limestone (Lee, 1974). Union Township, Brown County, Ohio (38°46'30"N; 83°49'08"W; Russellville, Ohio-Kentucky 7.5-minute quadrangle).

Sleepy Hollow: Roadcut on Kentucky Route 1449, about 6.4 km (4.0 mi) north-northwest of Orangeburg, Kentucky (Peck, 1966; Lee, 1974). This is the type-section of the Grant Lake Limestone, where it is reported to be 33.4 m (109.6 ft) thick. The upper contact with the Bull Fork Formation and the lower contact with the Fairview Formation are gradational within a 3-meter (10-foot) interval (Lee, 1974). Mason County, Kentucky (38°37'10"N; 83°42'51"W; Orangeburg, Kentucky 7.5-minute quadrangle).

Thomas More Parkway: Tiered exposures in field at Chancellor Center,1.0 km (0.6 mi) east on Thomas More Parkway from junction with Turkeyfoot Road. Uncovered in 1989, this exposure contains three broad benches bounded by several 2-3 m (6-10 ft) west-facing exposures. Approximately 10 m of Corryville is present (Dave Meyer, personal communication). Kenton County, Kentucky (39°01'20"N; 84°33'57"W; Covington, Kentucky-Ohio 7.5-minute quadrangle).

White Oak Creek: Streamcut along White Oak Creek, approximately 304 m (1000 ft) north of New Hope, Ohio (measured section in OGS File 16910). The section contains 6.5 m (21.3 ft) of the Corryville Member and begins at stream level approximately 860 ft above sea-level. Scott Township, Brown County, Ohio (38°57'57"N; 83°54'36"W; Hamersville, Ohio 7.5-minute quadrangle).

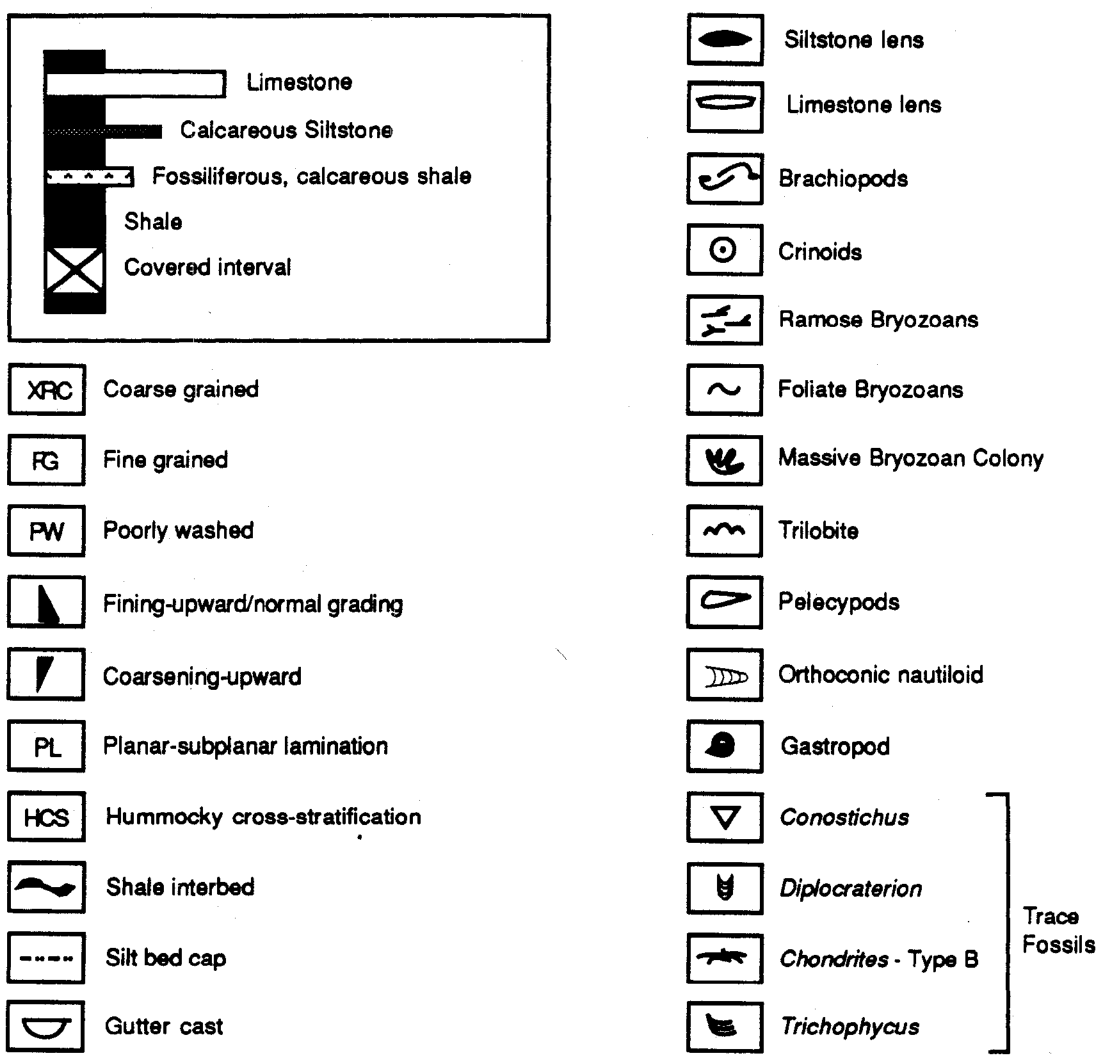
Appendix 2

Description of Outcrops and Cores

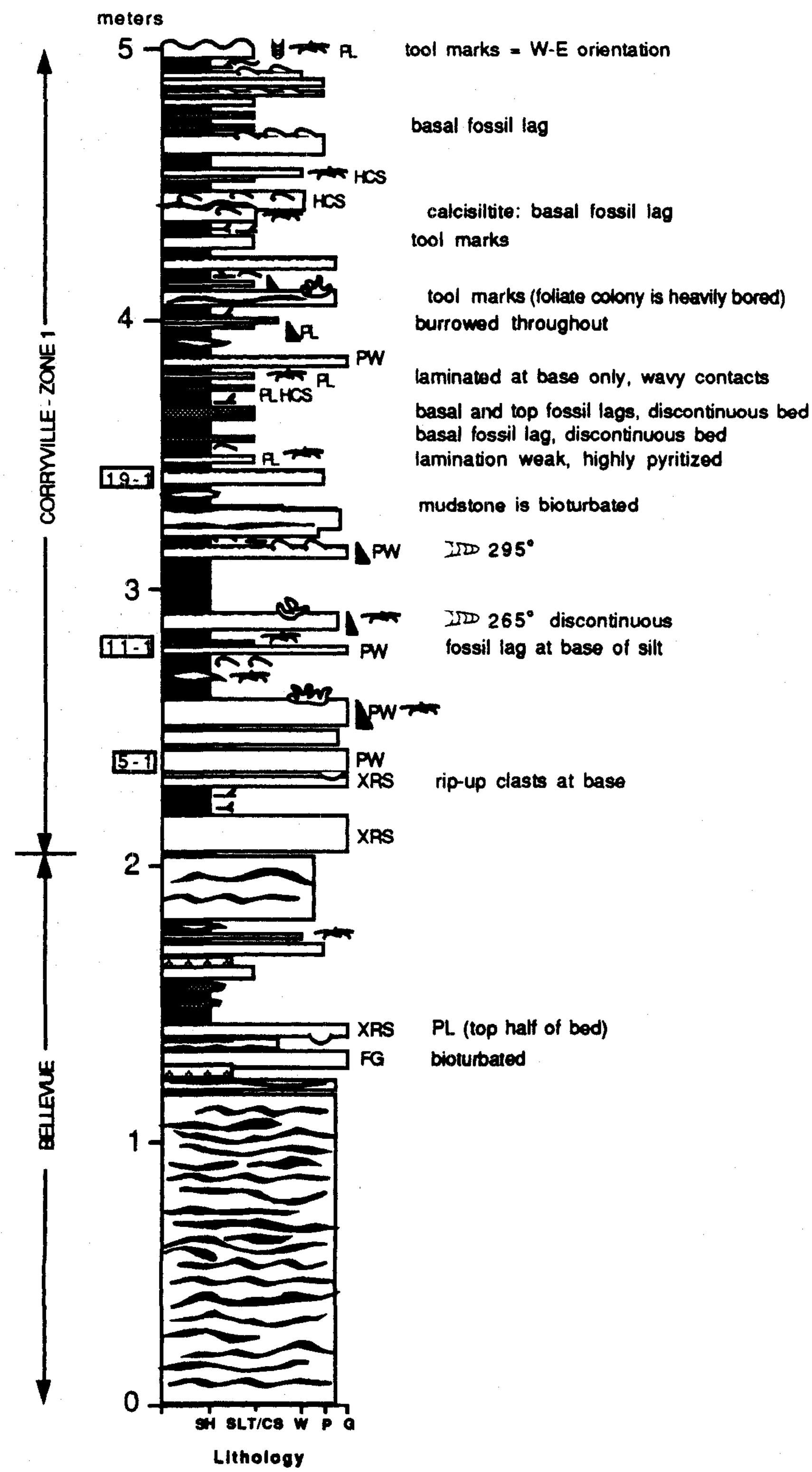
Appendix 2

Description of Outcrops and Cores

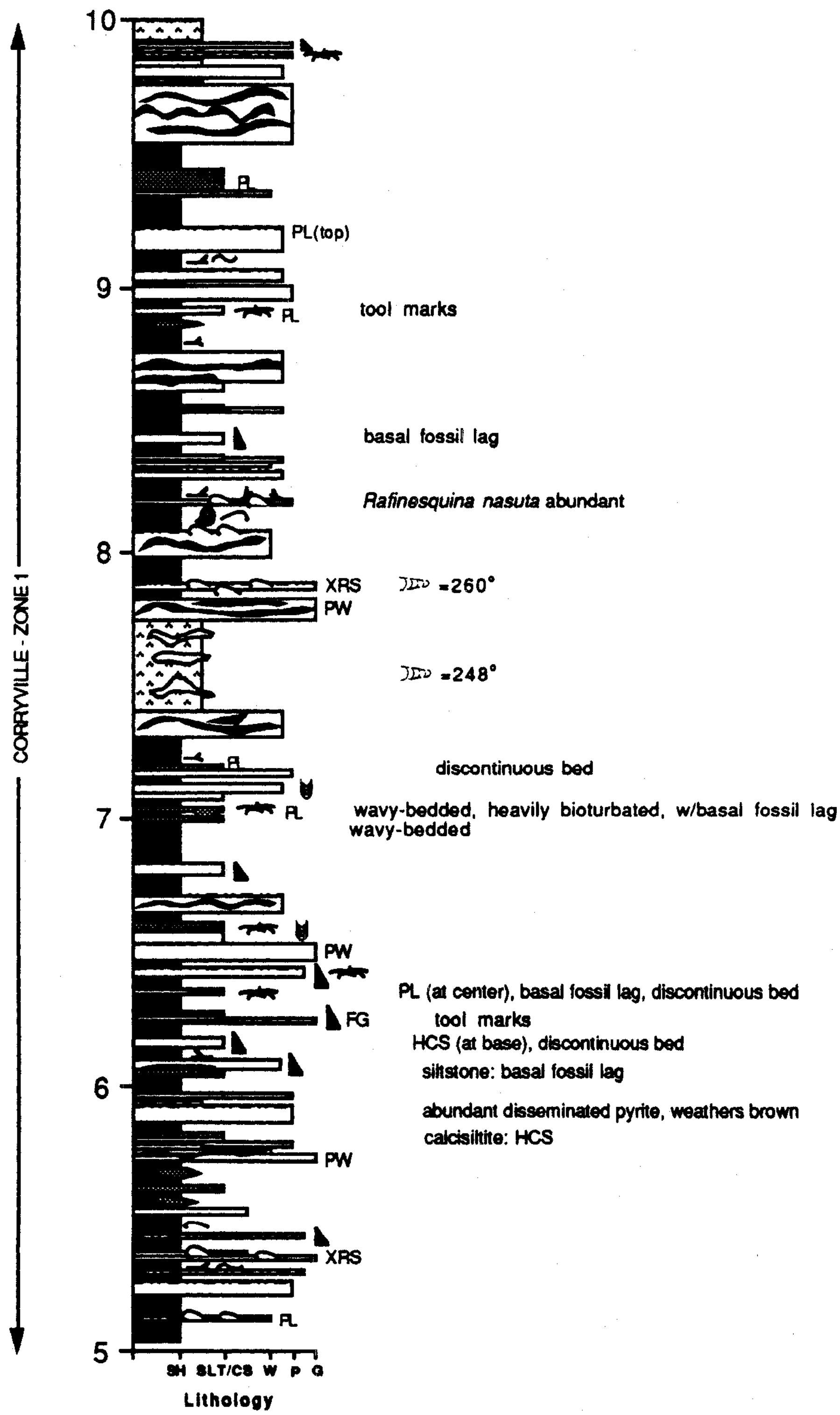
Key to Symbols



LOCATION: STONELICK CREEK, EXPOSURE #1 (PG 1 OF 3)



LOCATION: STONELICK CREEK, EXPOSURE #1 (PG 2 OF 3)



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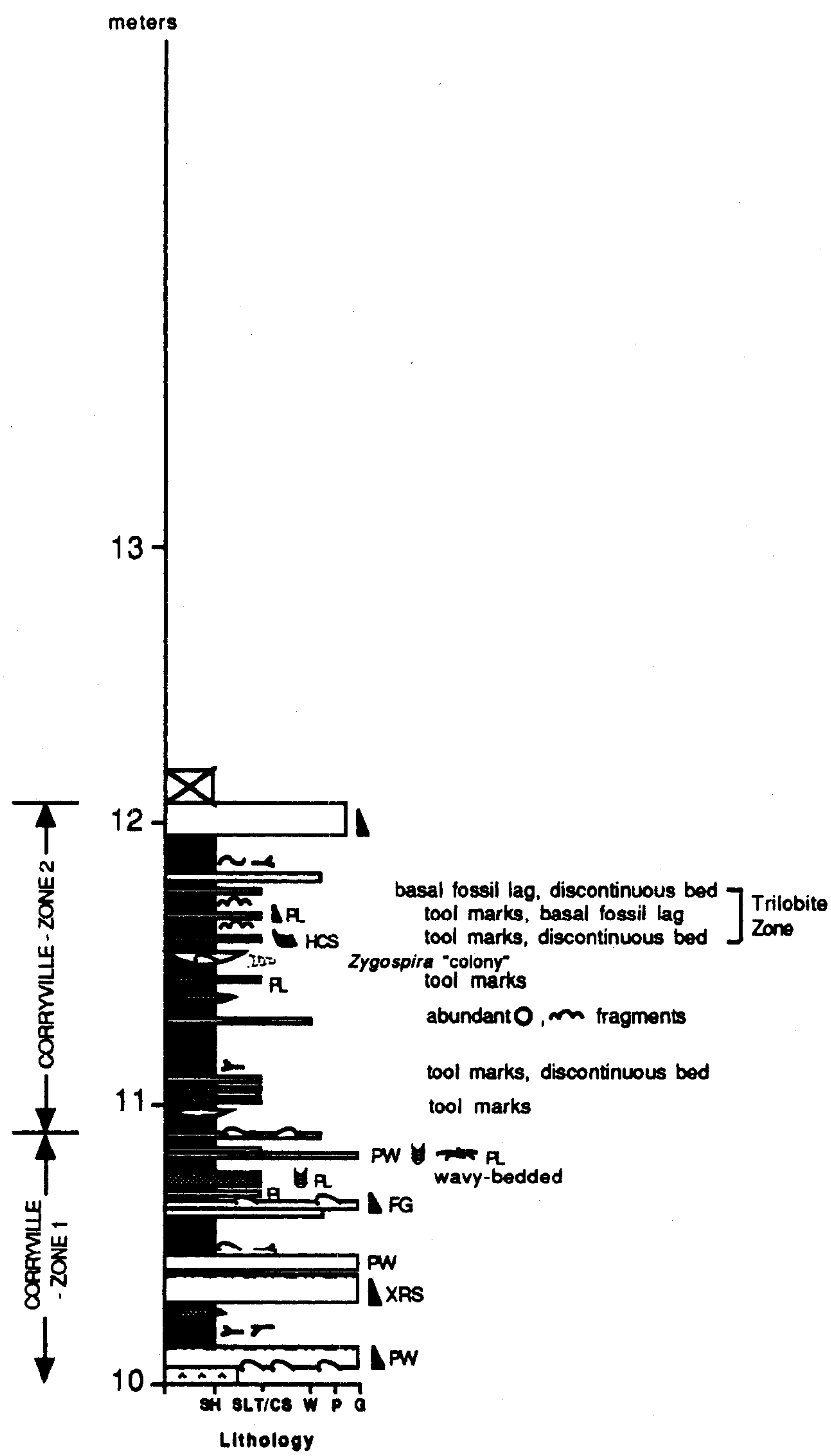
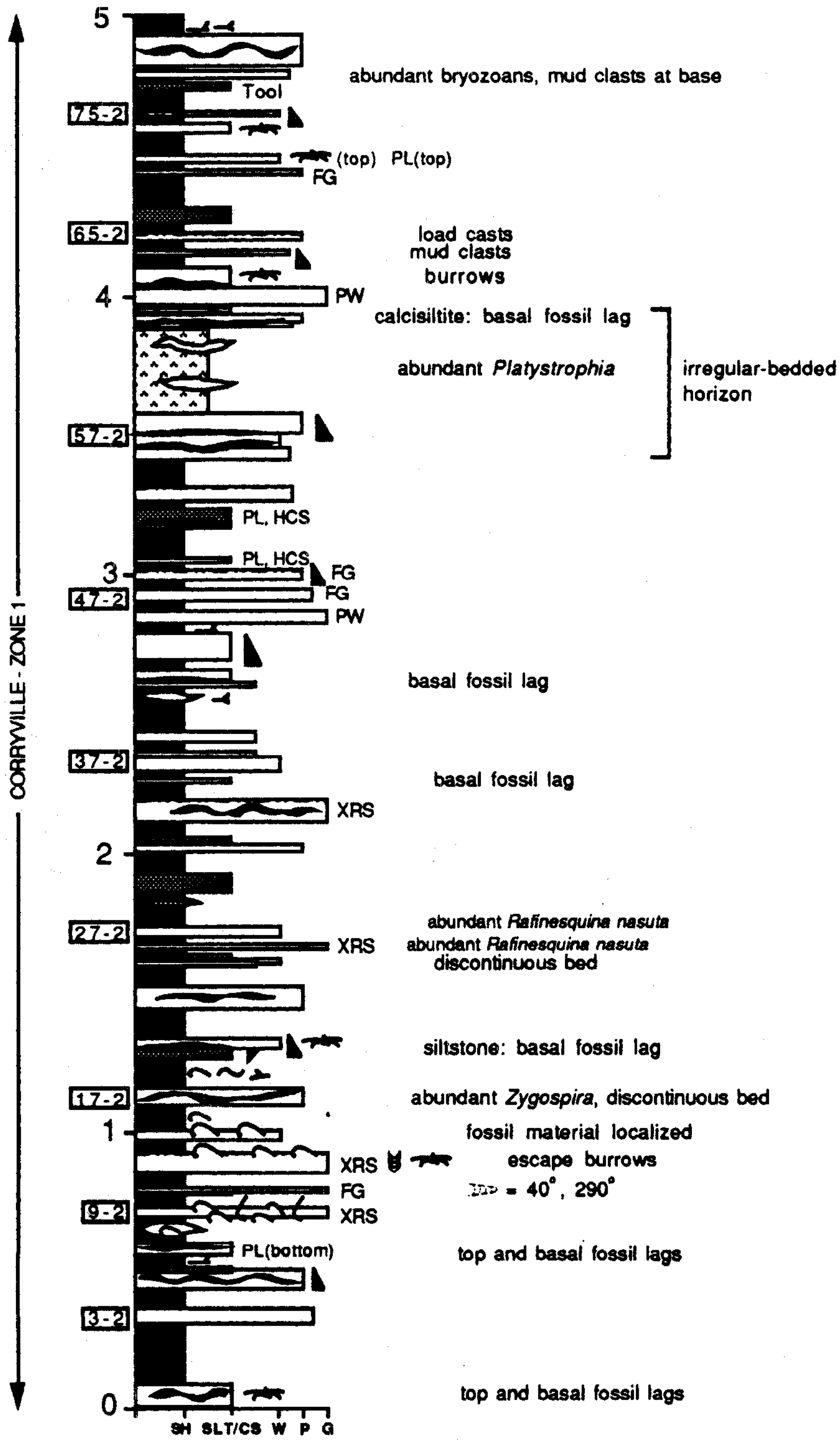


LOCATION: STONELICK CREEK, EXPOSURE #2 (PG 1 OF 4)



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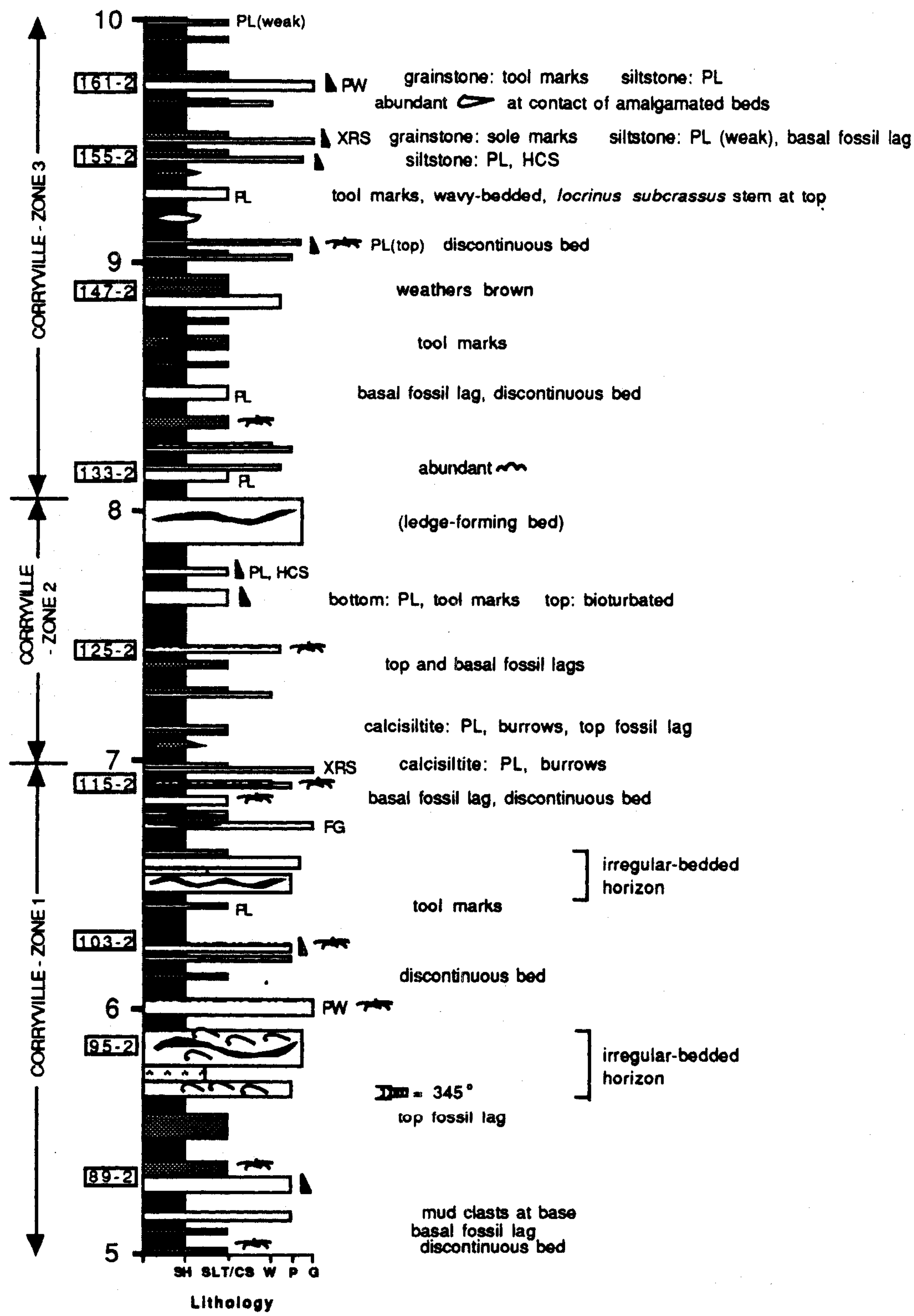

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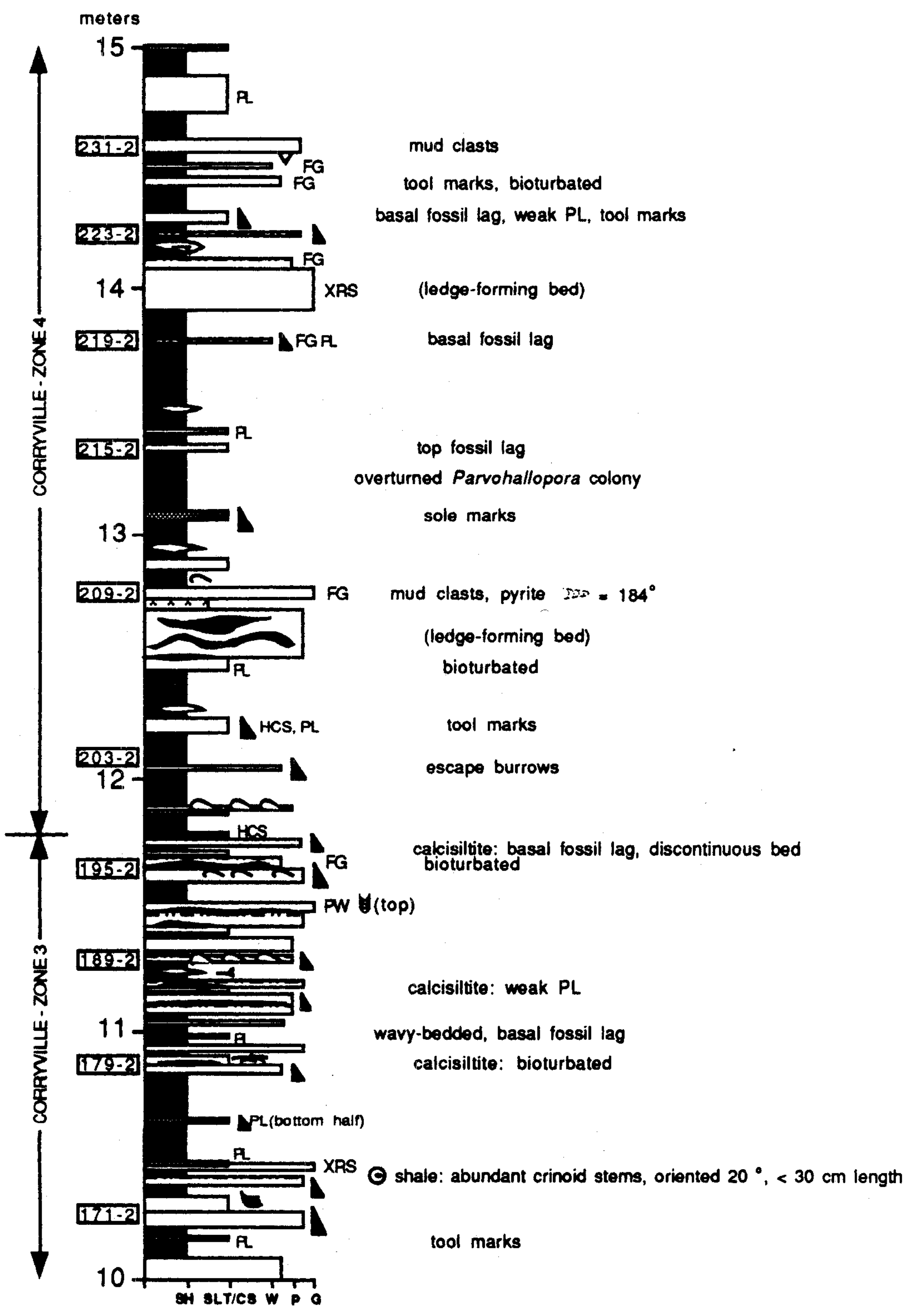

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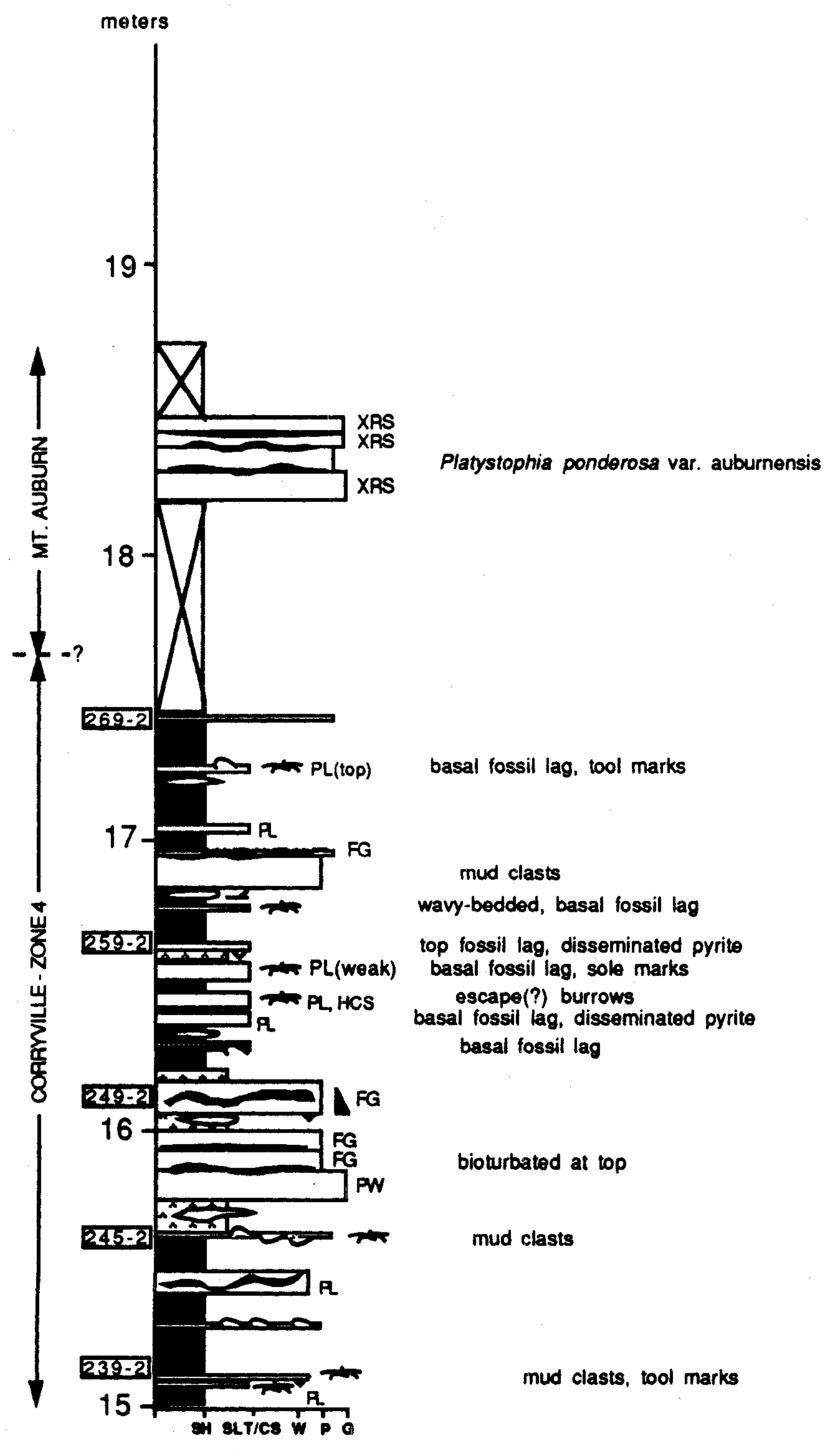
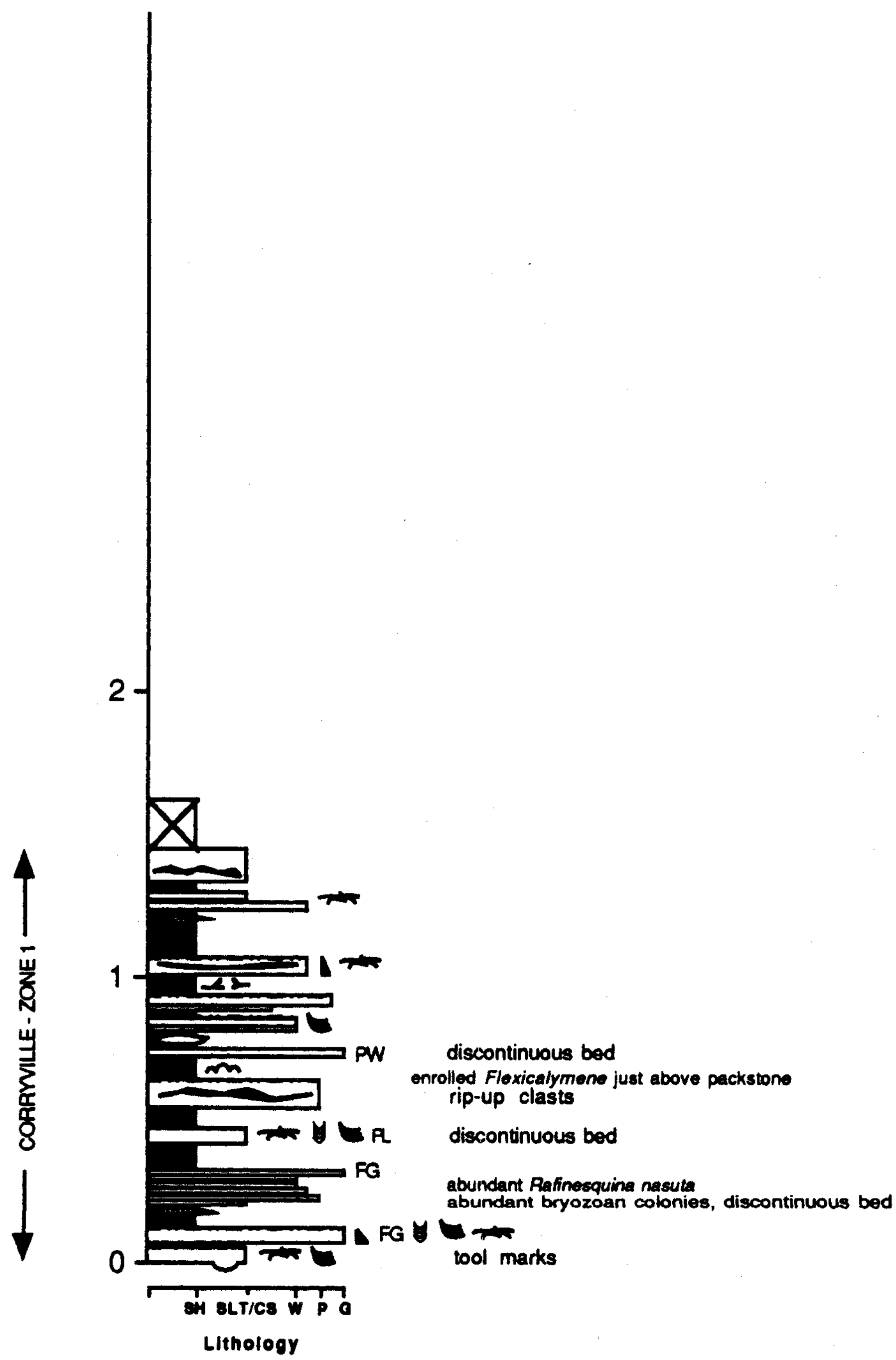
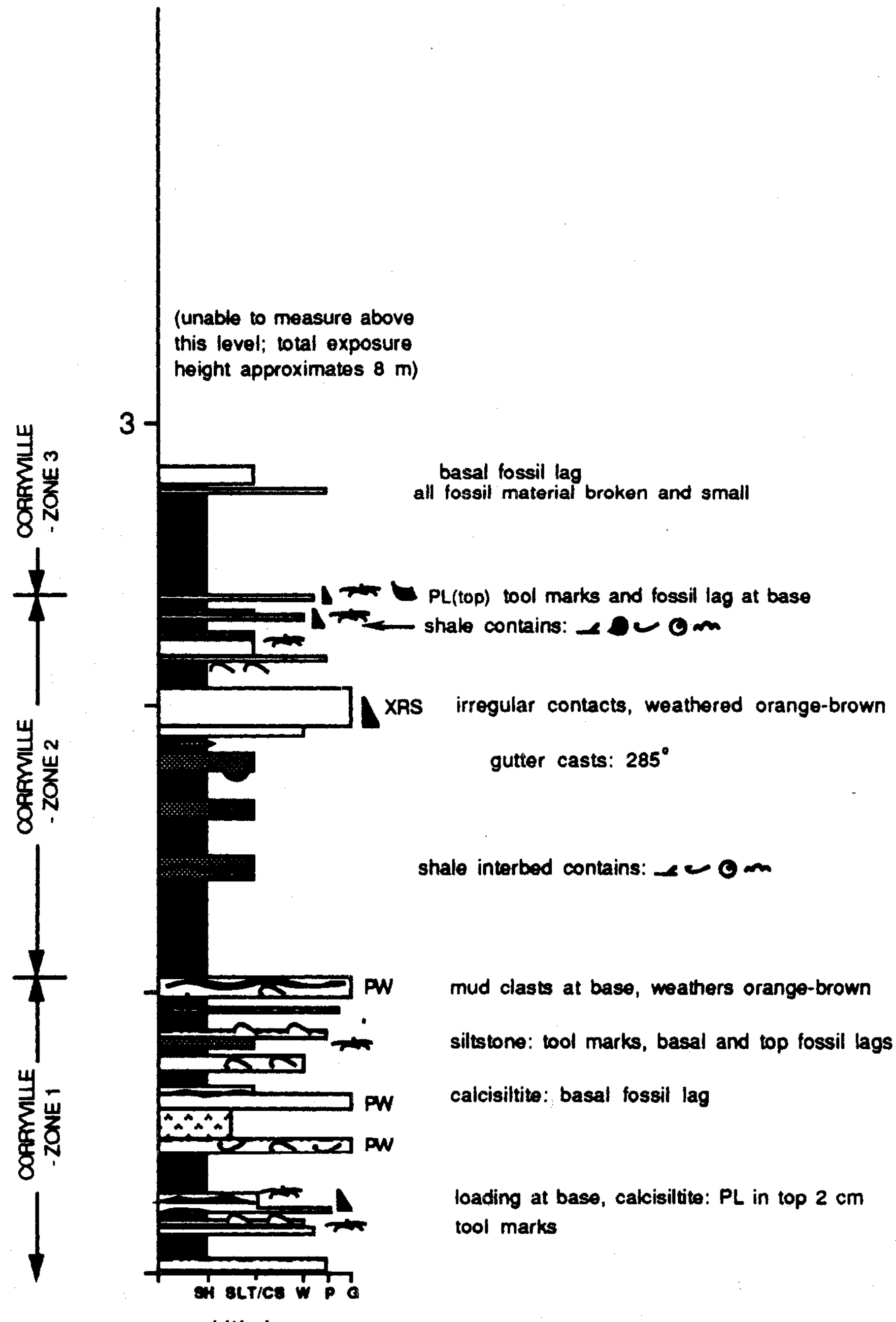


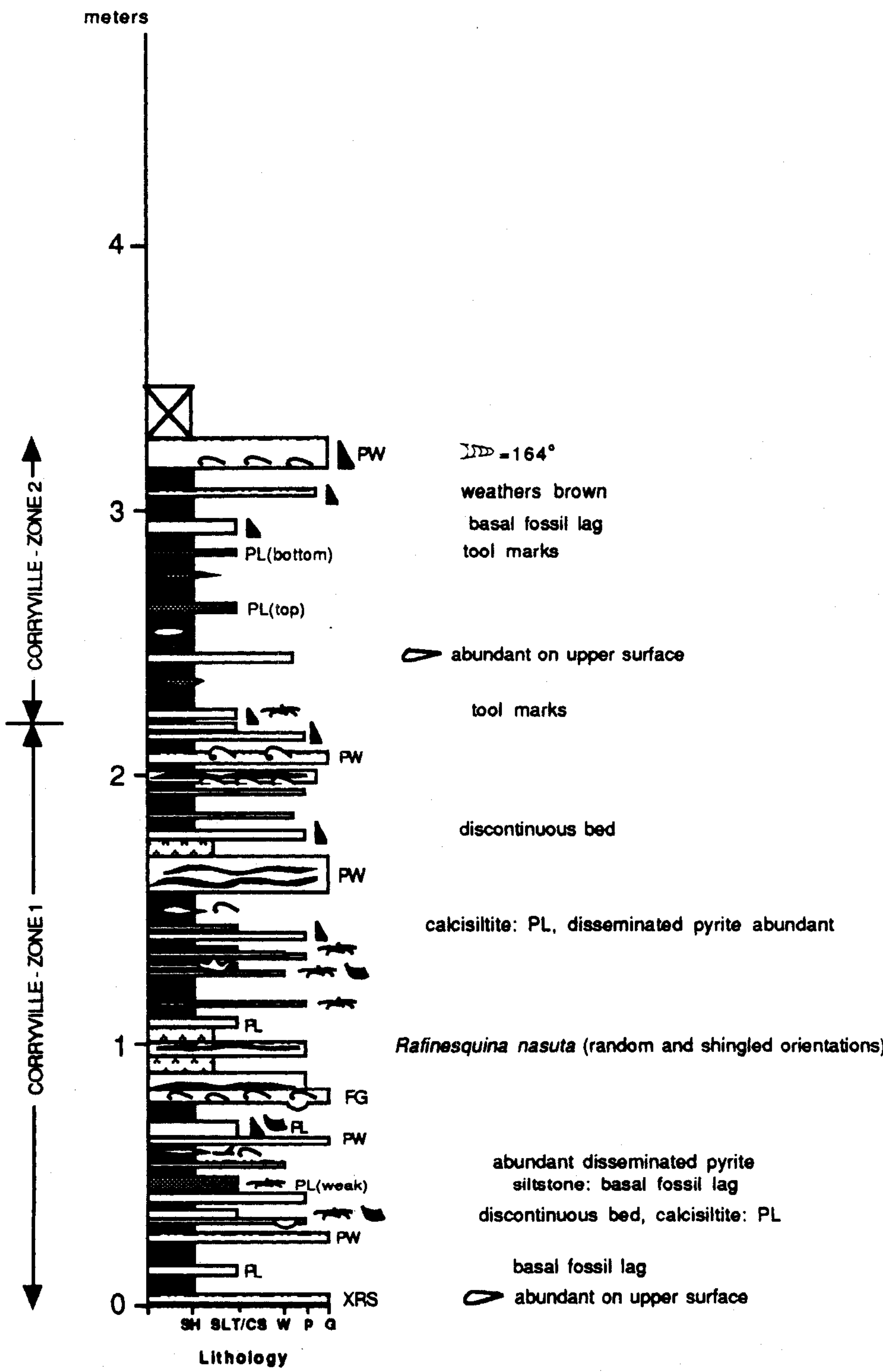
LOCATION: STONELICK CREEK, EXPOSURE #2A (PG 1 OF 1)



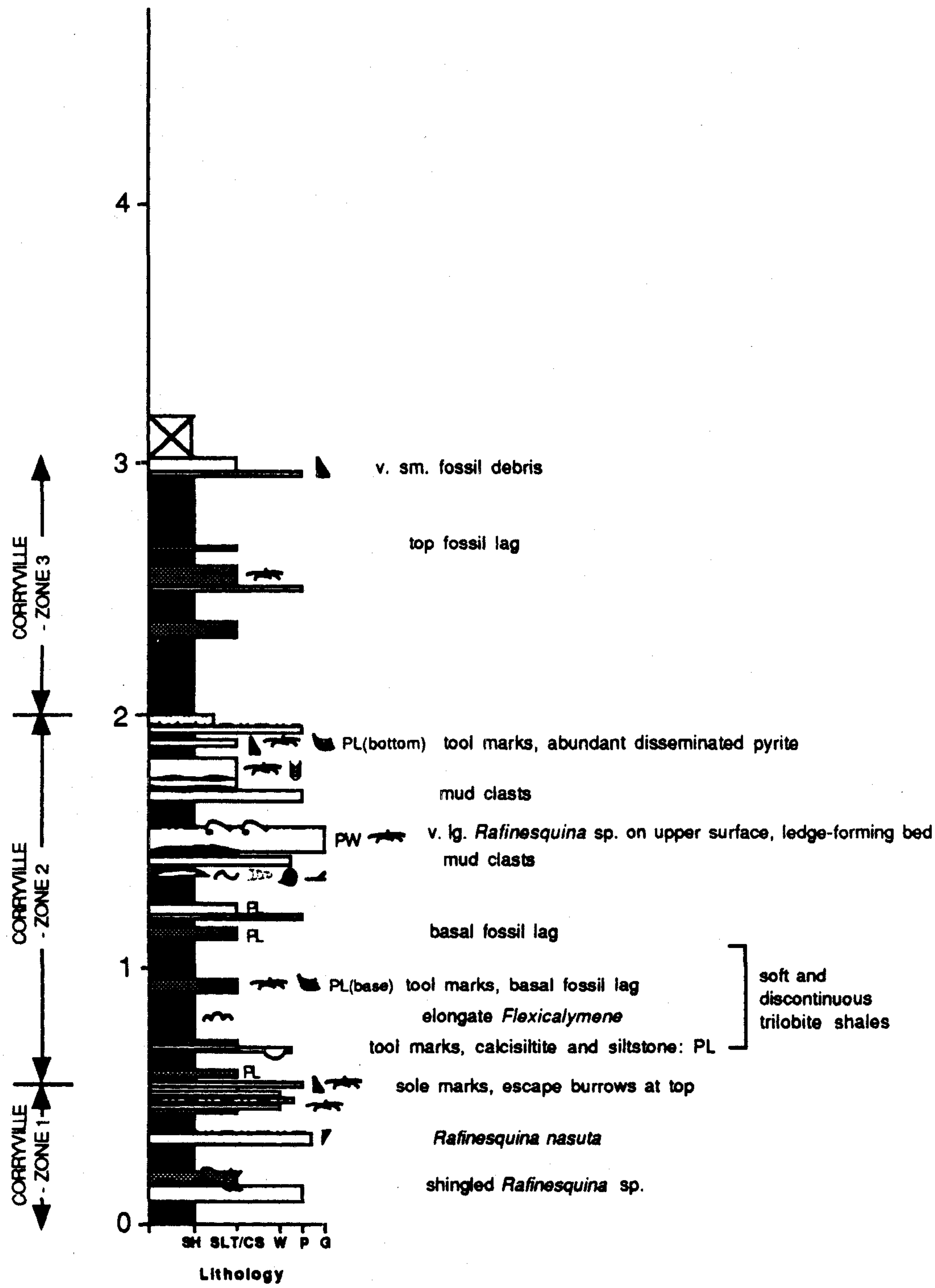
LOCATION: STONELICK CREEK, EXPOSURE #3 (PG 1 OF 1)



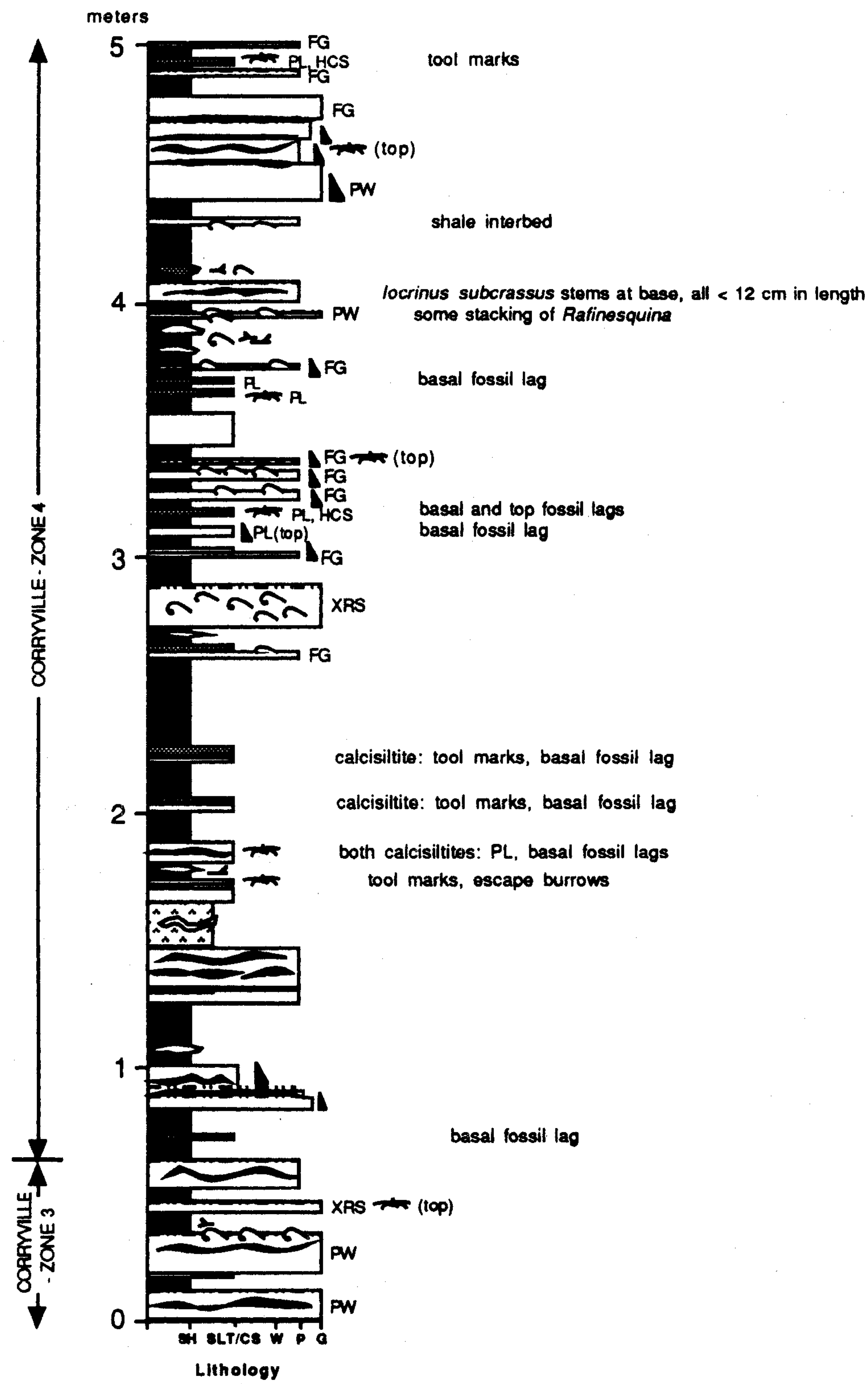
<u>LOCATION: STONELICK CREEK, EXPOSURE #4 (PG 1 OF 1)</u>



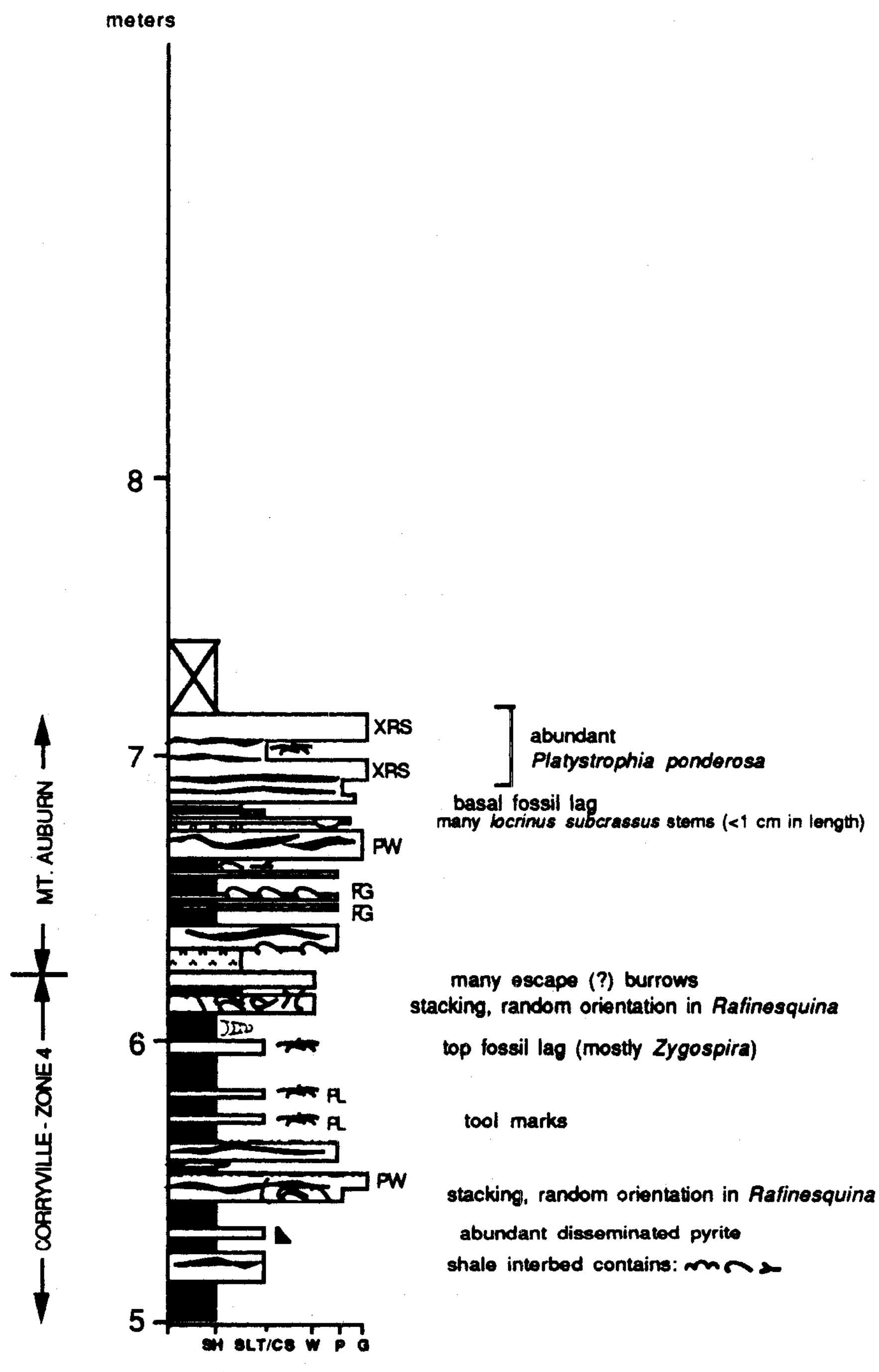
LOCATION: STONELICK CREEK, EXPOSURE #5 (PG 1 OF 1)



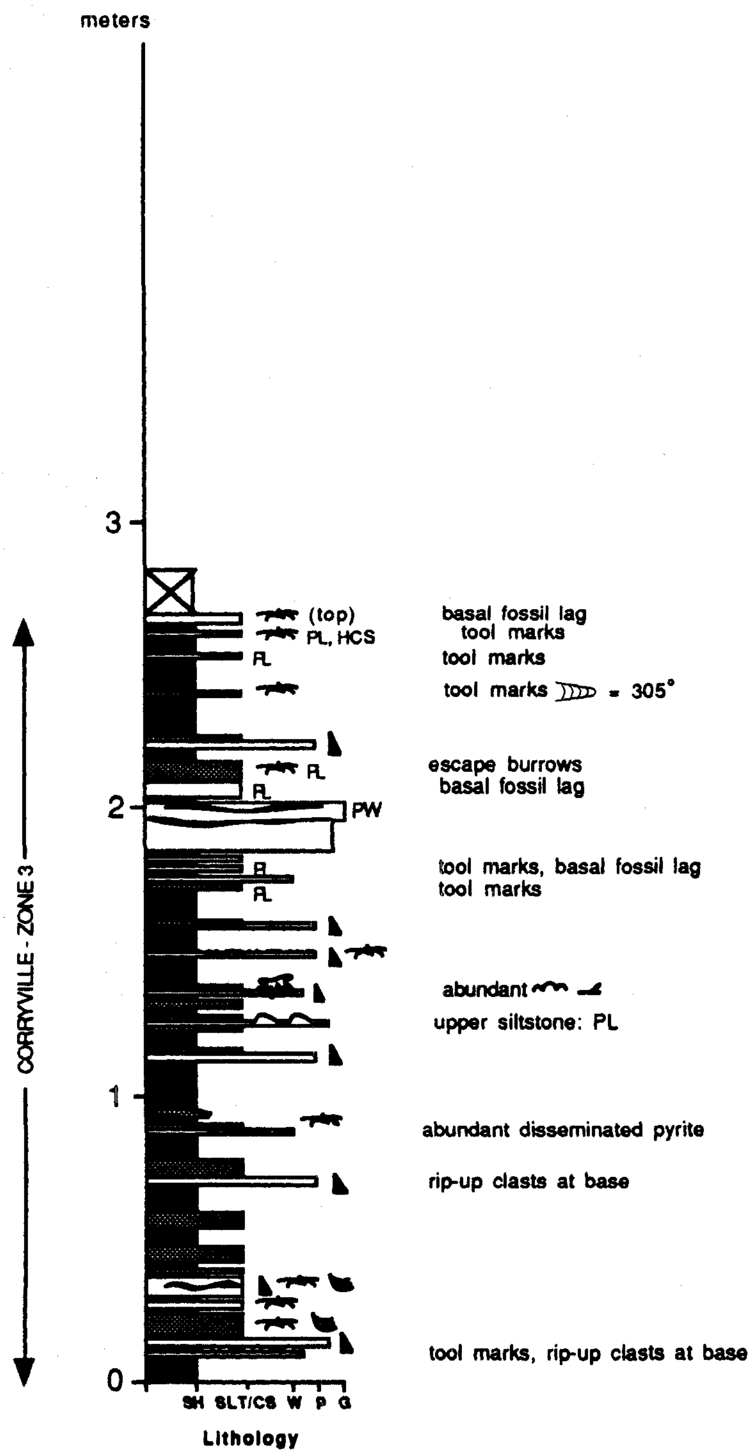
LOCATION: STONELICK CREEK, EXPOSURE #6 (PG 1 OF 2)



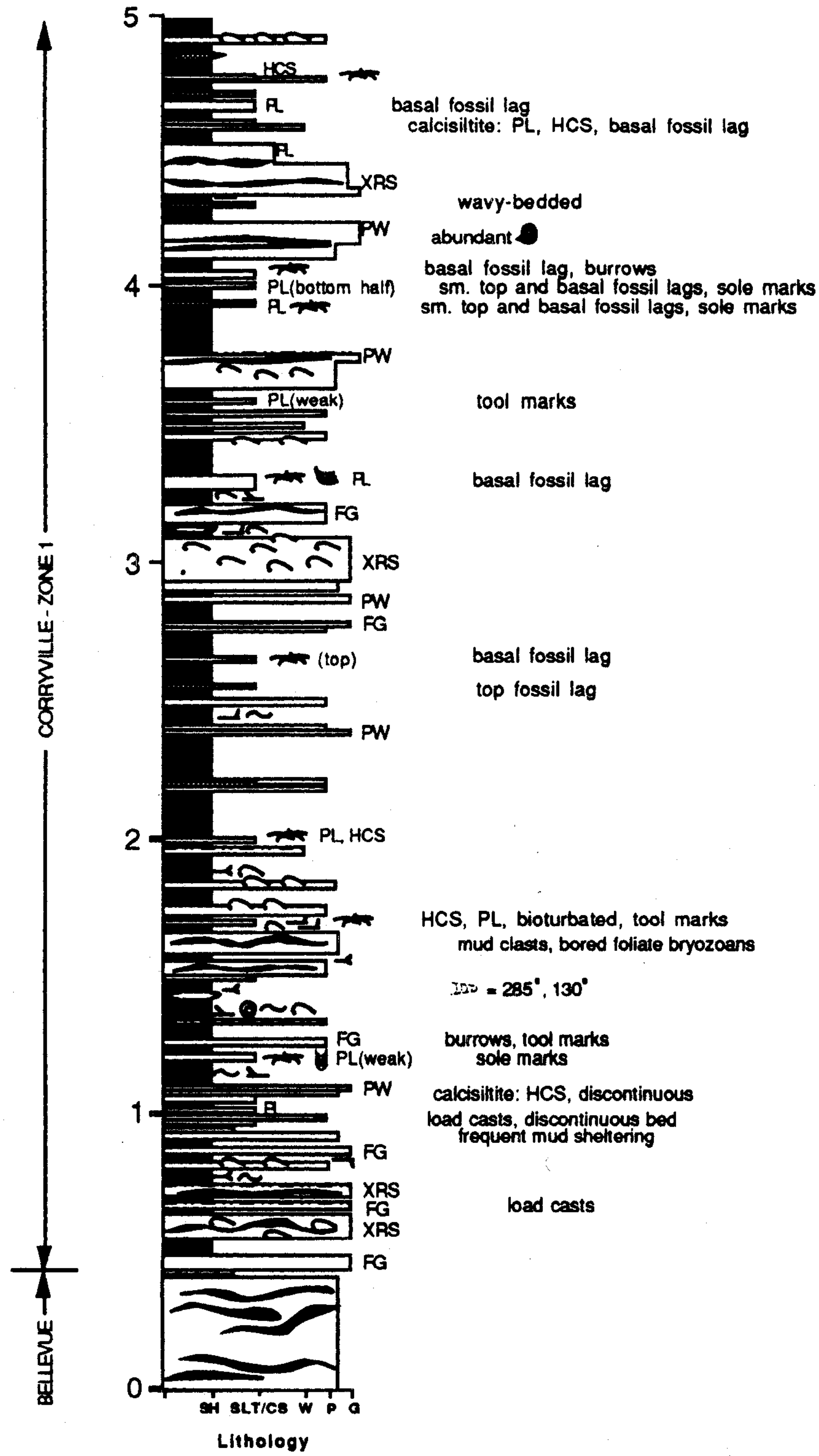
LOCATION: STONELICK CREEK, EXPOSURE #6 (PG 2 OF 2)



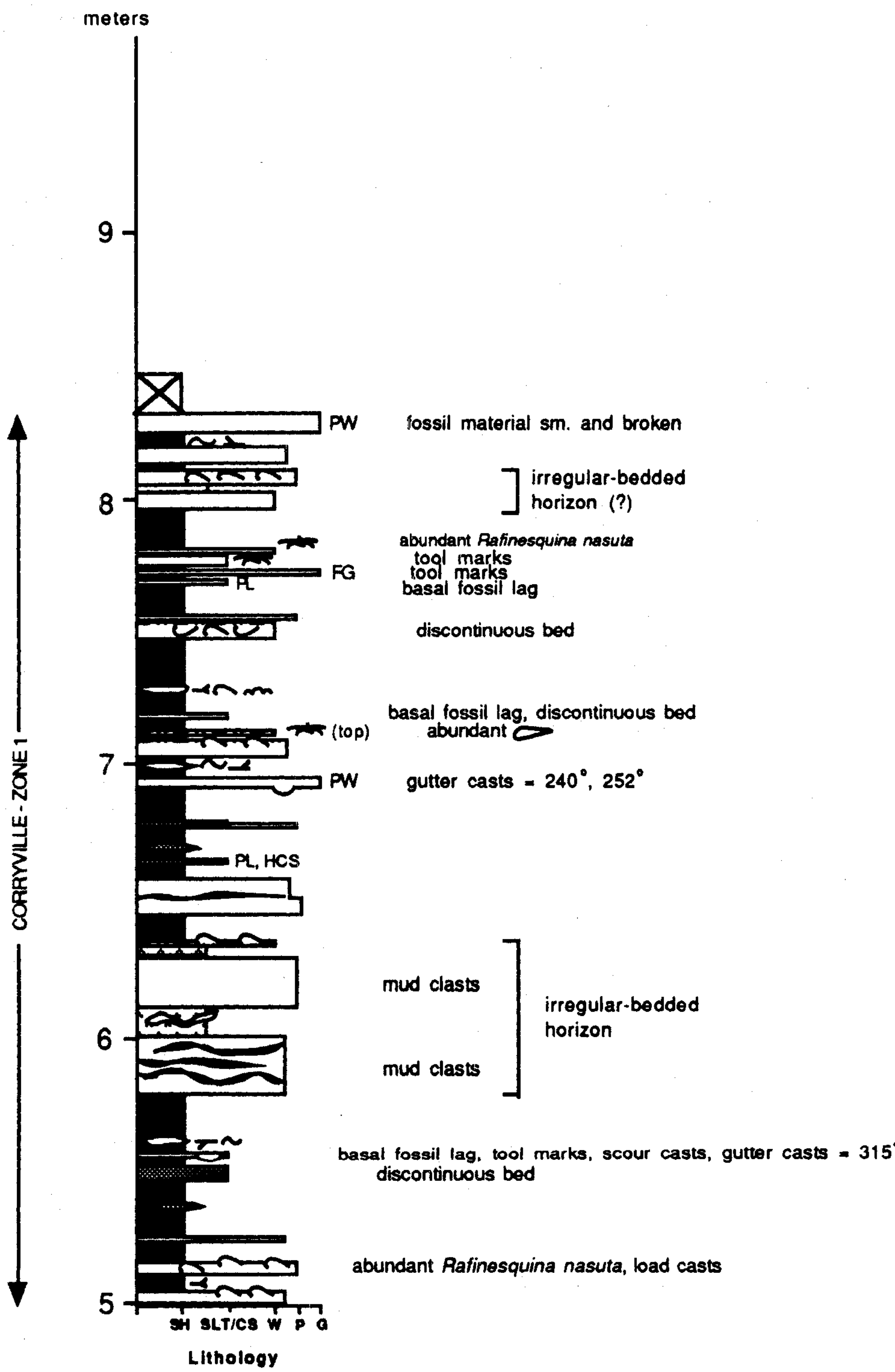
LOCATION: STONELICK CREEK, EXPOSURE #7 (PG 1 OF 1)



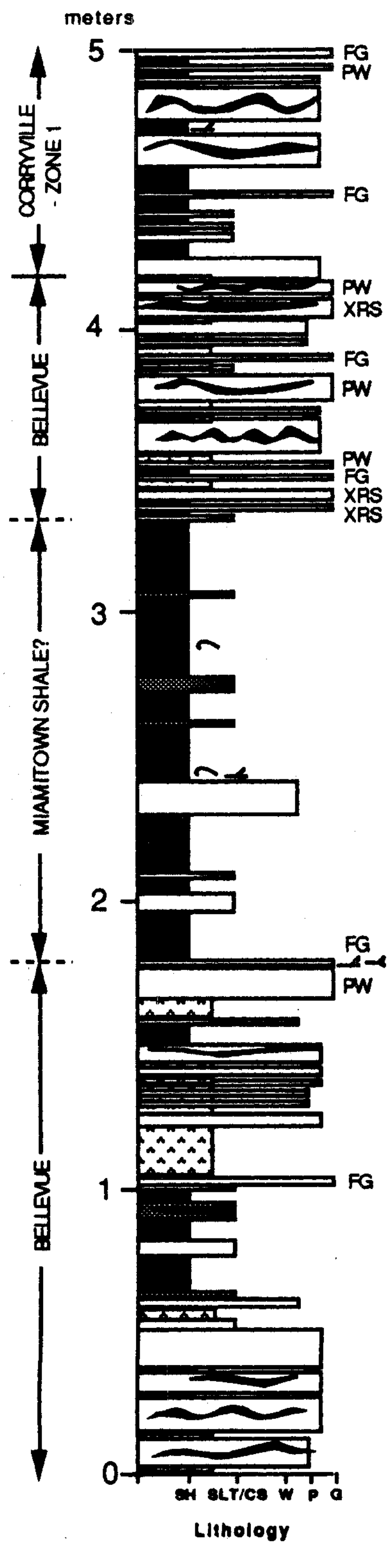
LOCATION: O'BANNON CREEK (PG 1 OF 2)

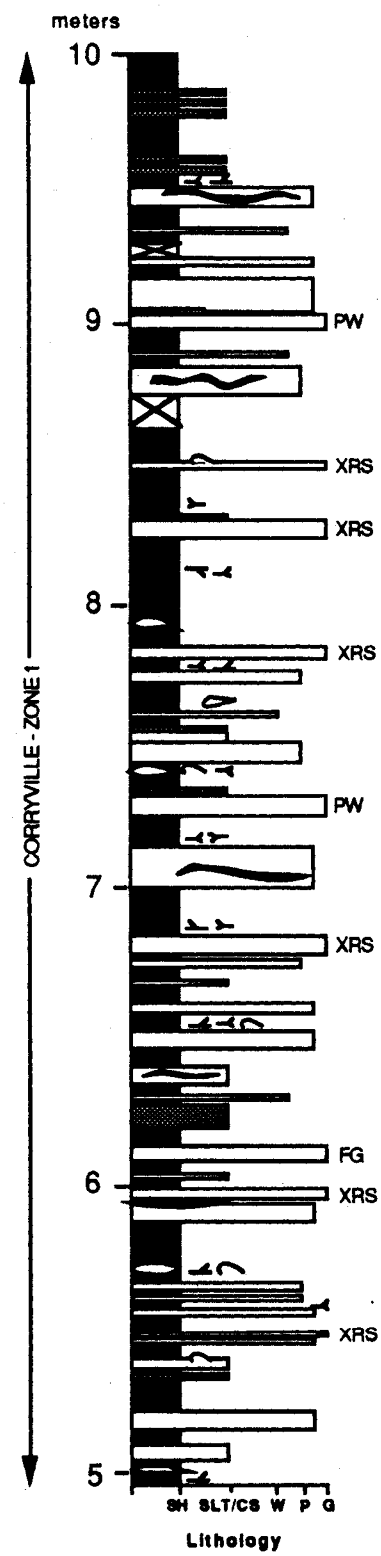


LOCATION: O'BANNON CREEK (PG 2 OF 2)

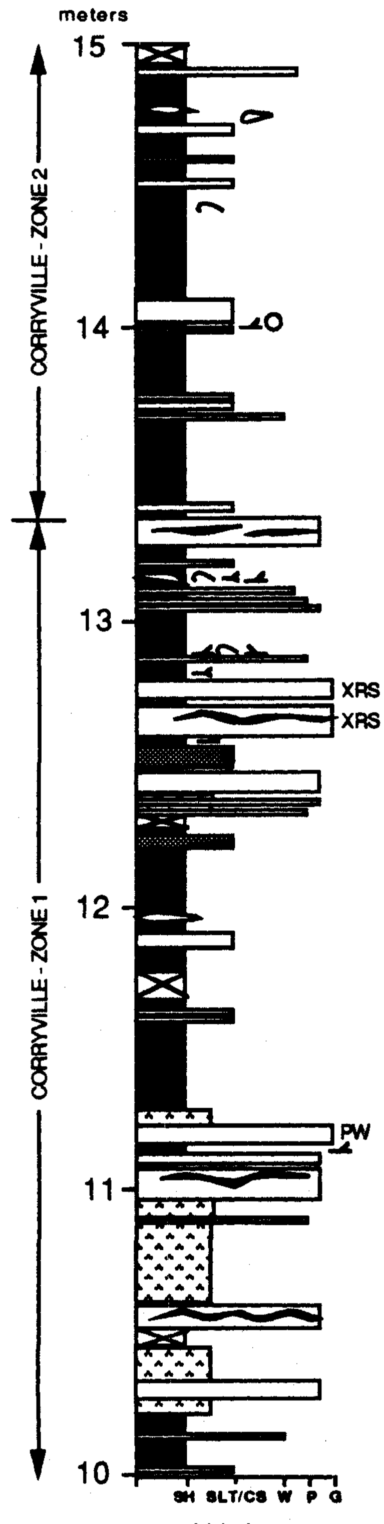


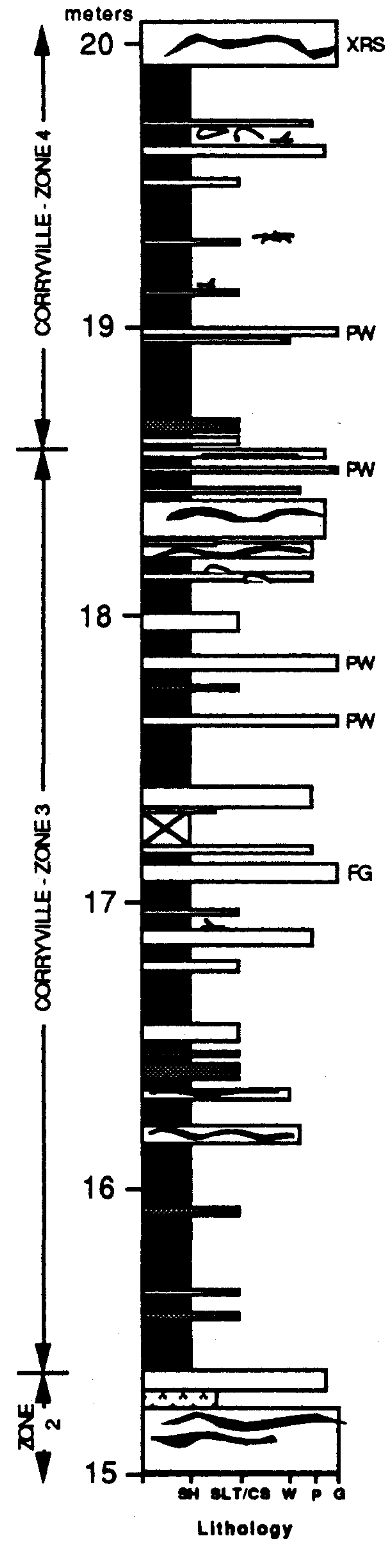
LOCATION: OGS CORE #868, CLINTON COUNTY (PG 1 OF 3)



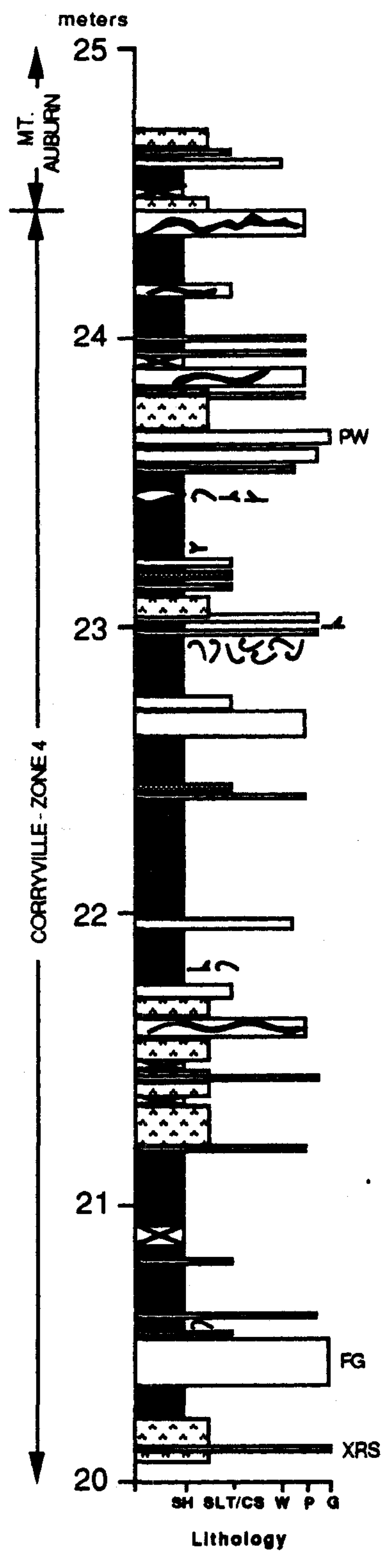


LOCATION: OGS CORE #868, CLINTON COUNTY (PG 2 OF 3)

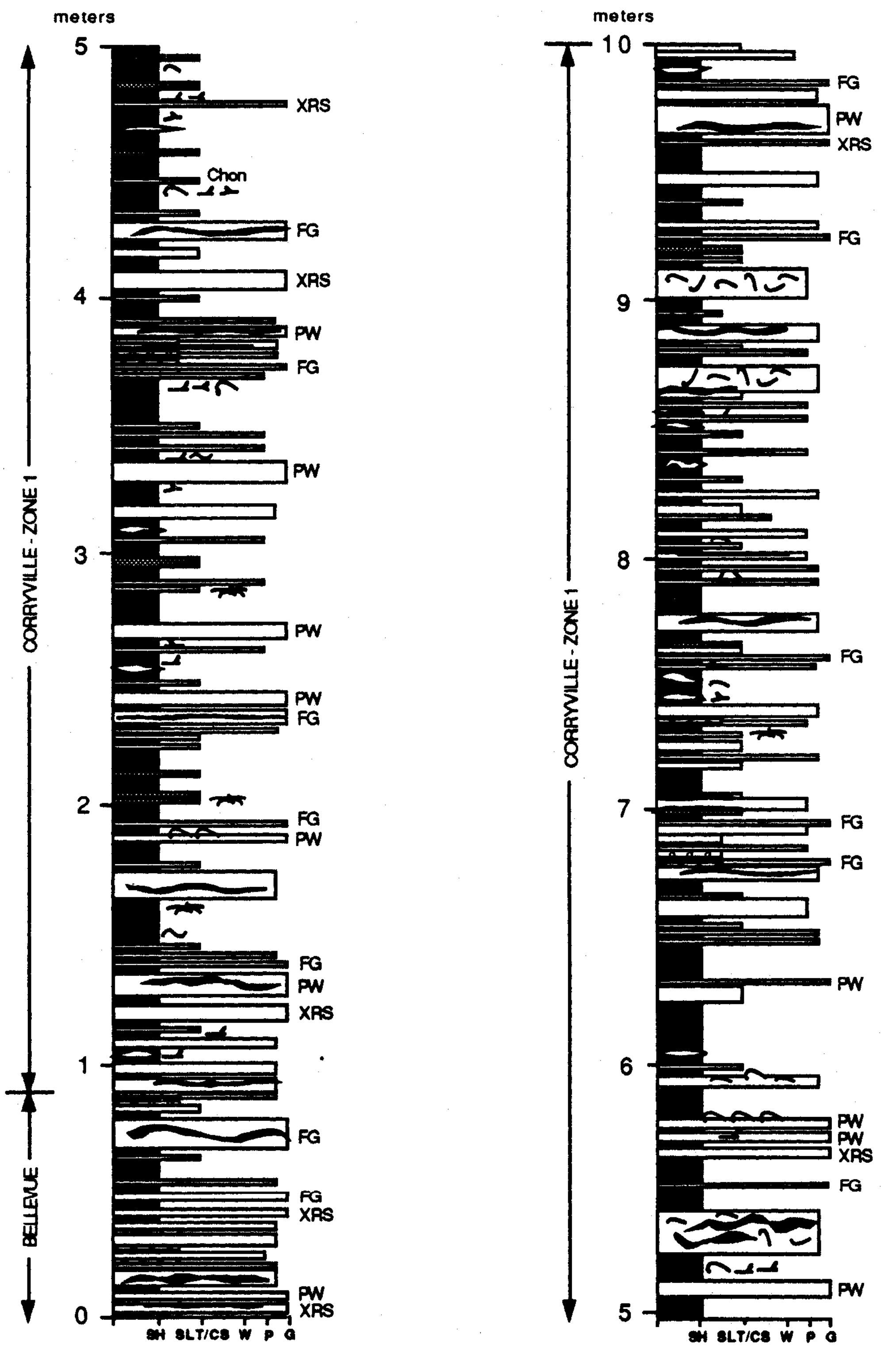




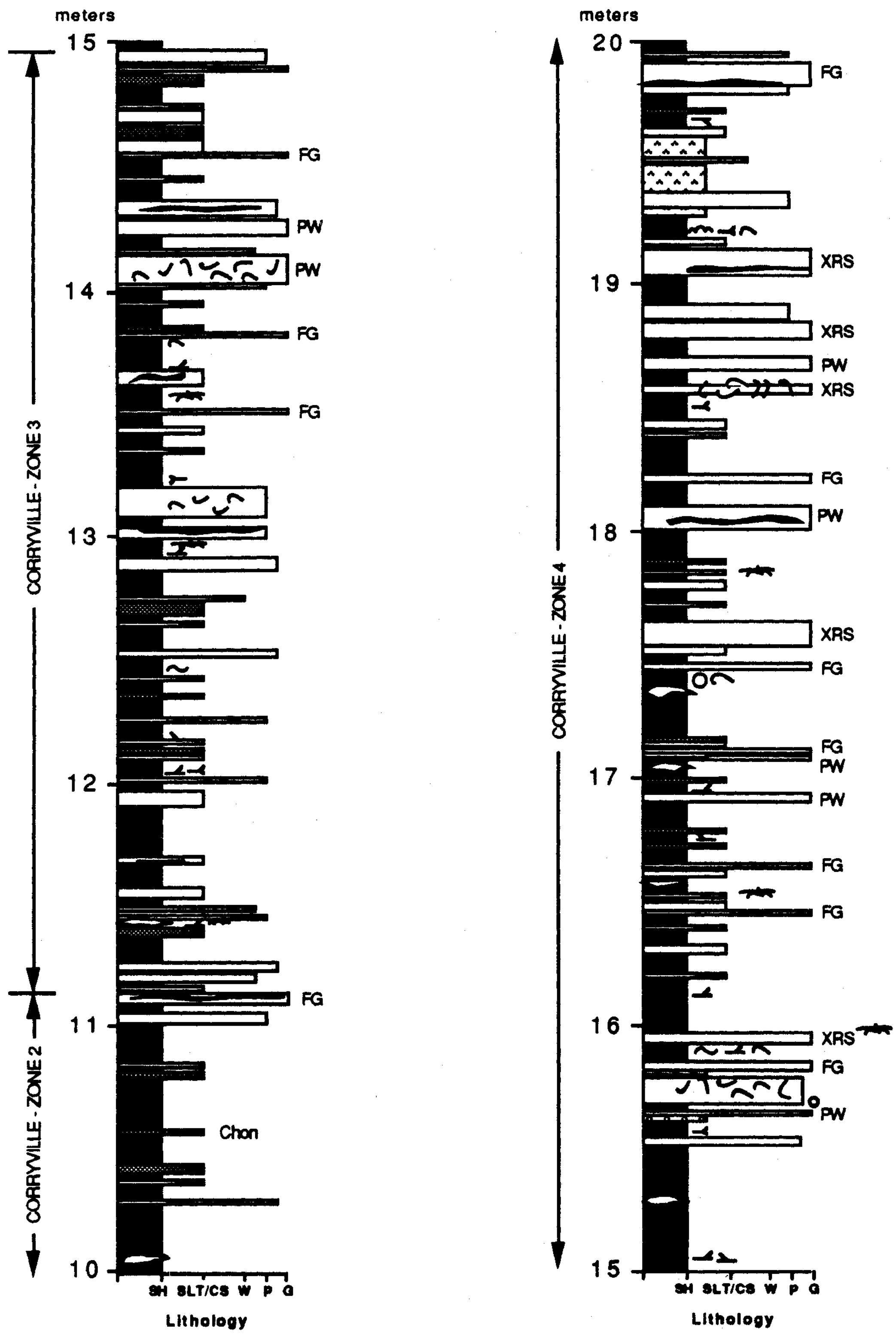
LOCATION: OGS CORE #868, CLINTON COUNTY (PG 3 OF 3)



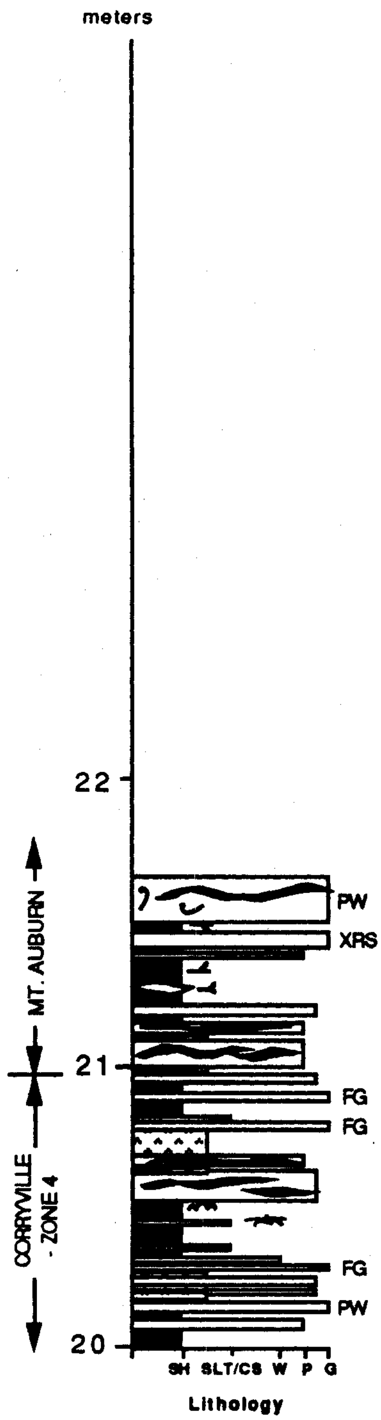
LOCATION: OGS CORE #2620, CLERMONT COUNTY (PG 1 OF 3)



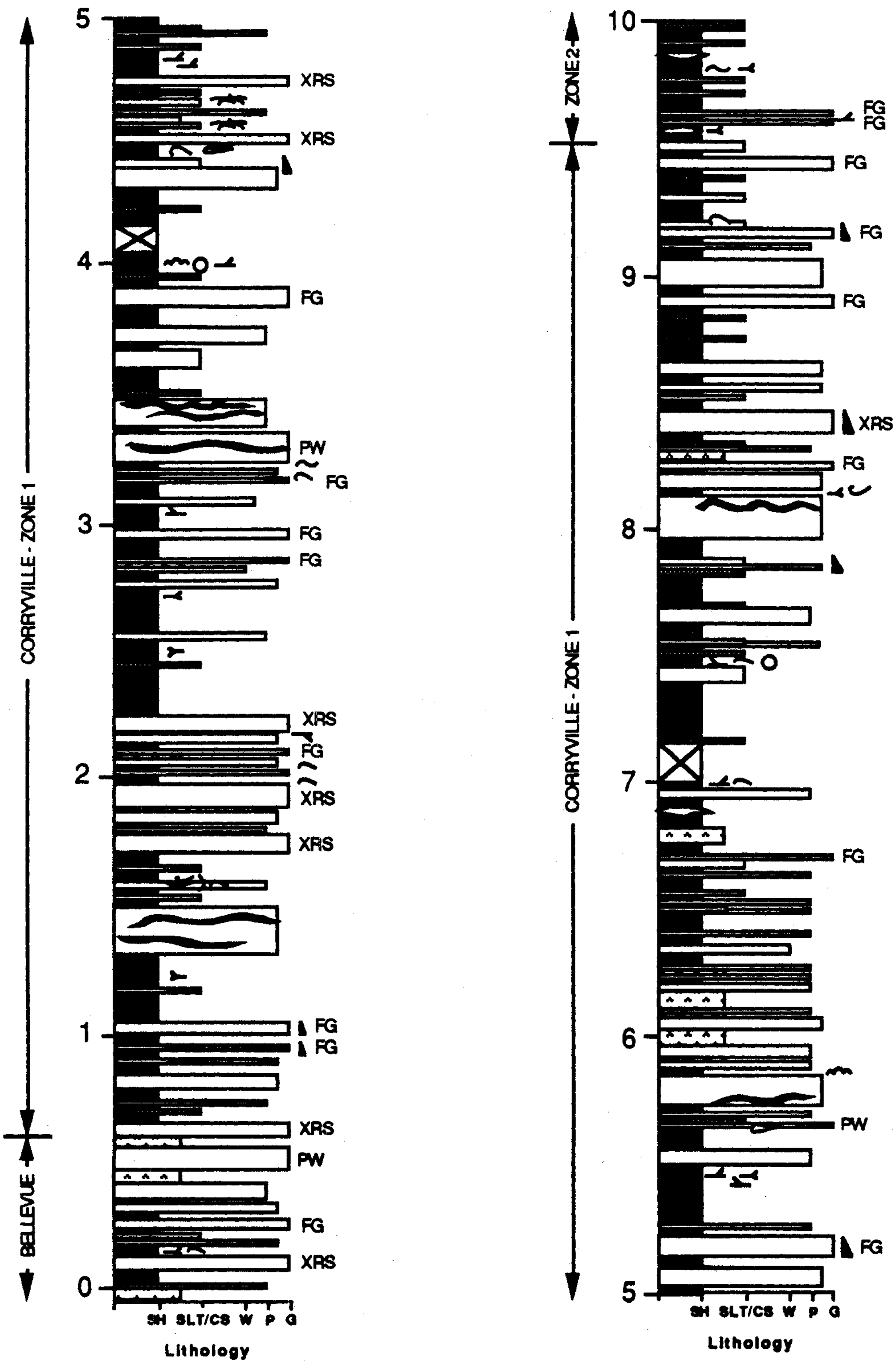
LOCATION: OGS CORE #2620, CLERMONT COUNTY (PG 2 OF 3)

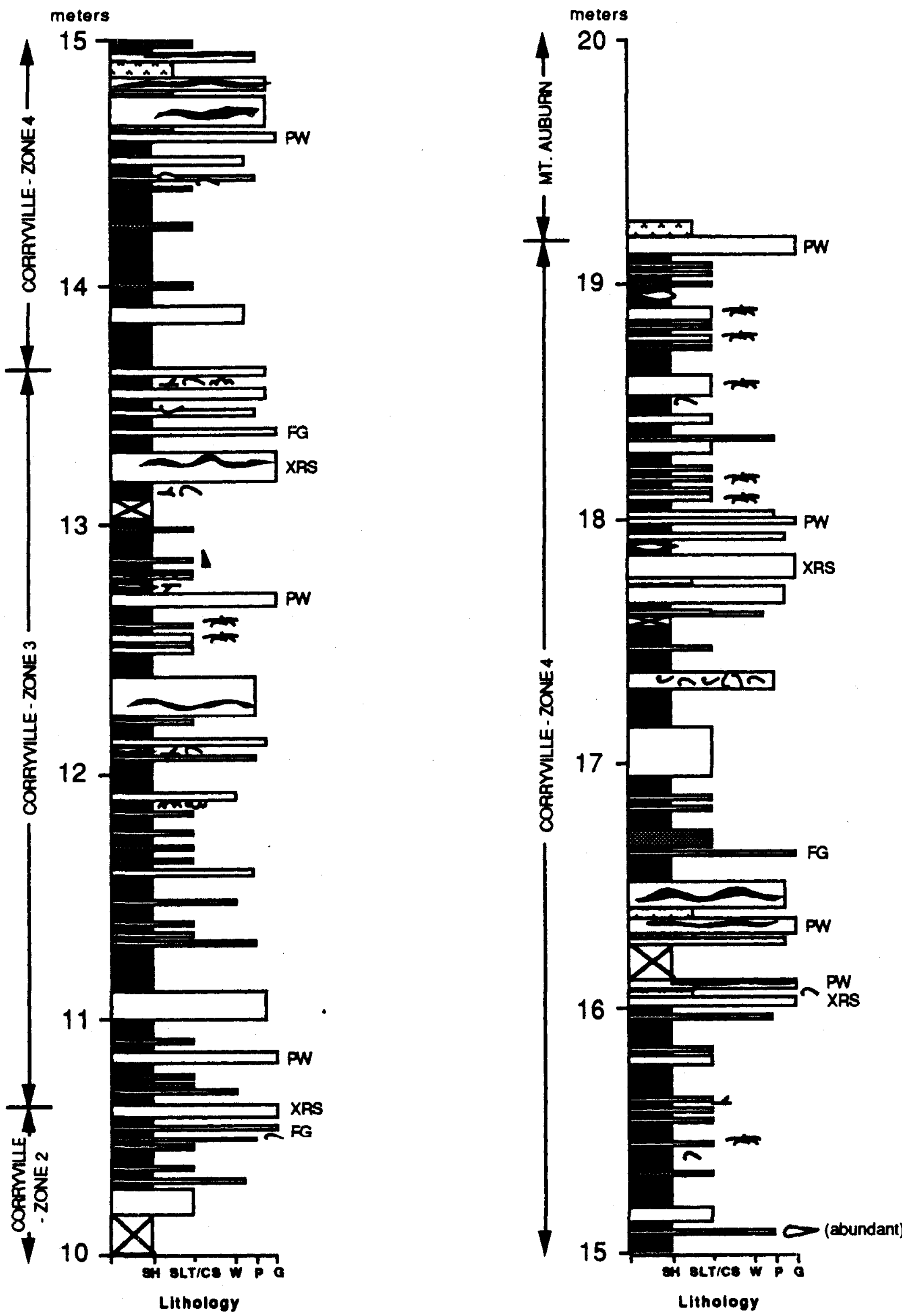


LOCATION: OGS CORE #2620, CLERMONT COUNTY (PG 3 OF 3)



LOCATION: OGS CORE #2623, BROWN COUNTY (PG 1 OF 2)



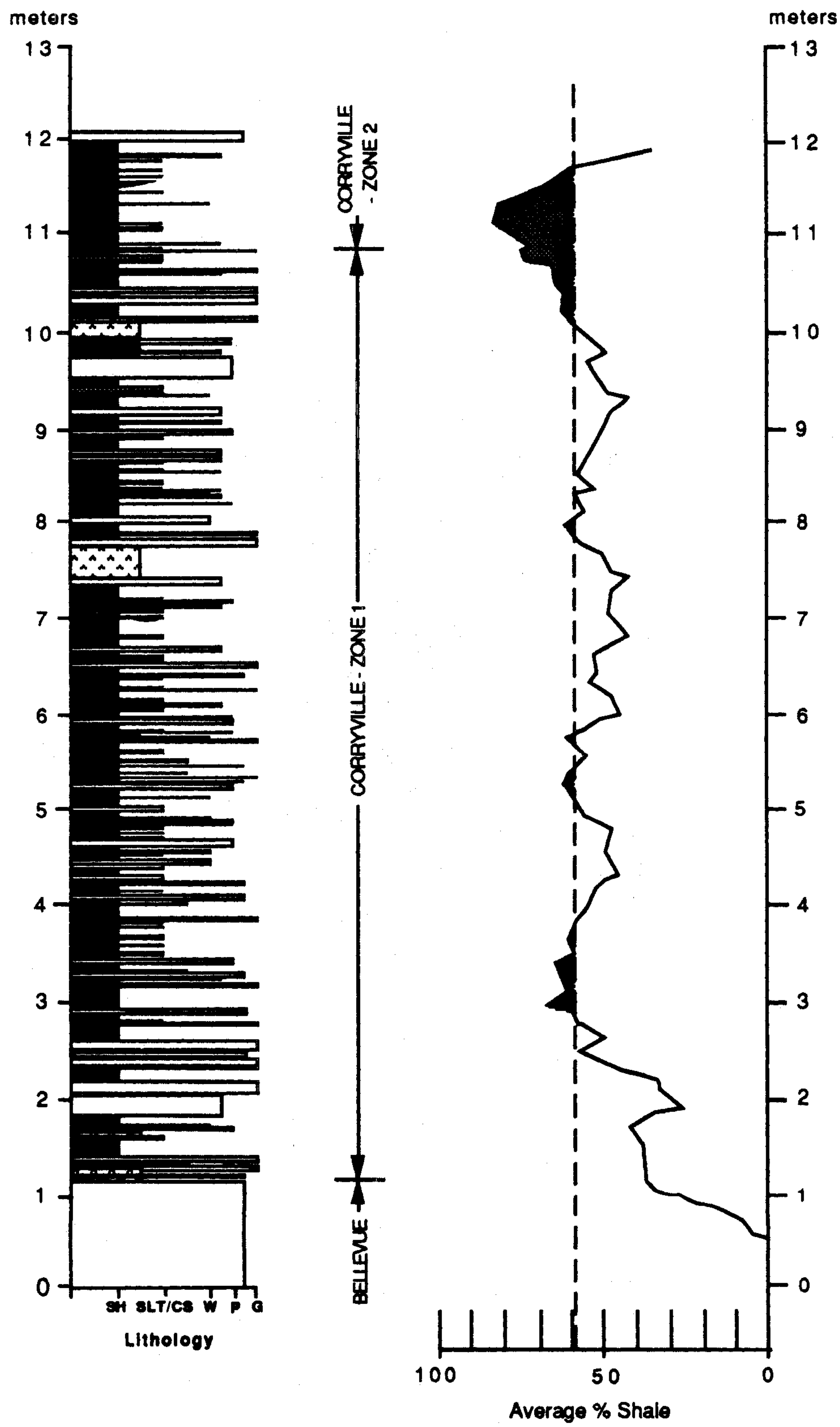

meters
15
14
13
12
11
10
CORRYVILLE - ZONE 4
CORRYVILLE - ZONE 3
CORRYVILLE - ZONE 2
PW
FG
XRS
PW
PW
XRS
FG
SH SLT/CS W P G
Lithology
meters
20
19
18
17
16
15
MT. AUBURN
CORRYVILLE - ZONE 4
PW
PW
XRS
FG
PW
PW
XRS
(abundant)
SH SLT/CS W P G
Lithology

Appendix 3

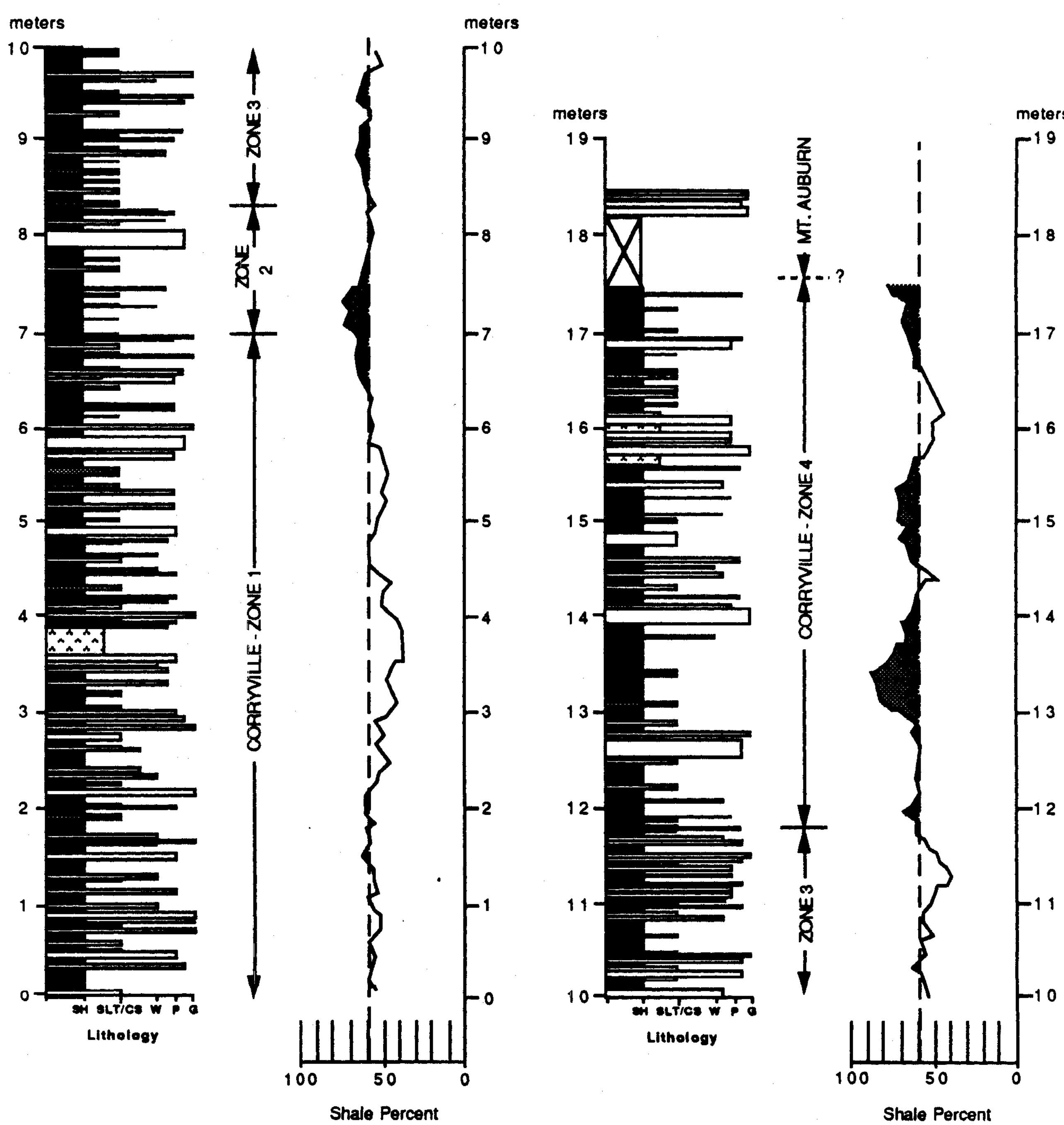
Shale Percent Logs

This appendix includes detailed shale logs for Stonelick Creek exposures 1 and 2, O'Bannon Creek, and all cores. Shaded log areas are those in which the mean shale percentage is higher than the average mean shale percentage for the individual section. Symbols are identical to those presented in the key of Appendix 2.

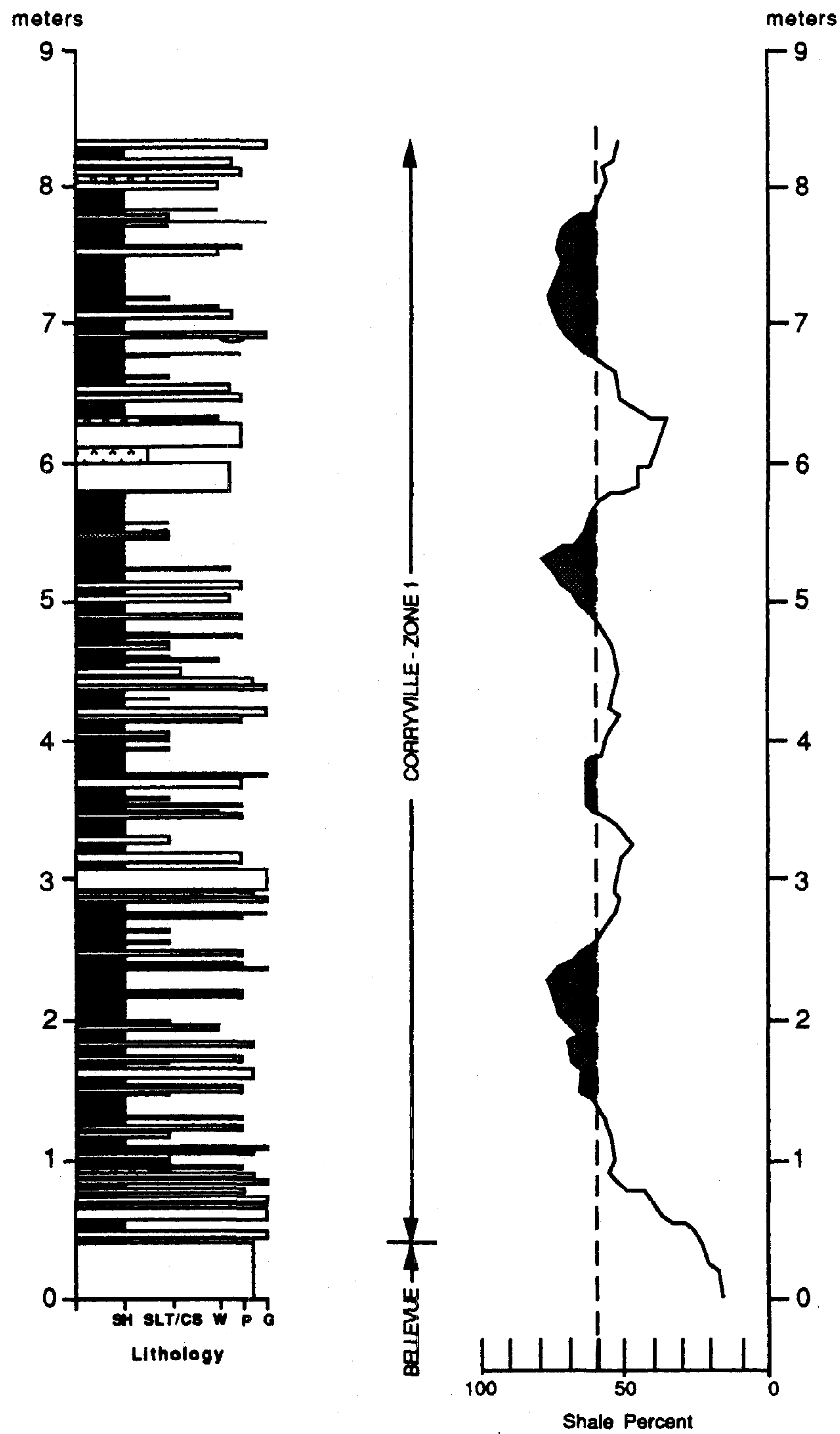
Location: Stonelick Creek, Exposure #1



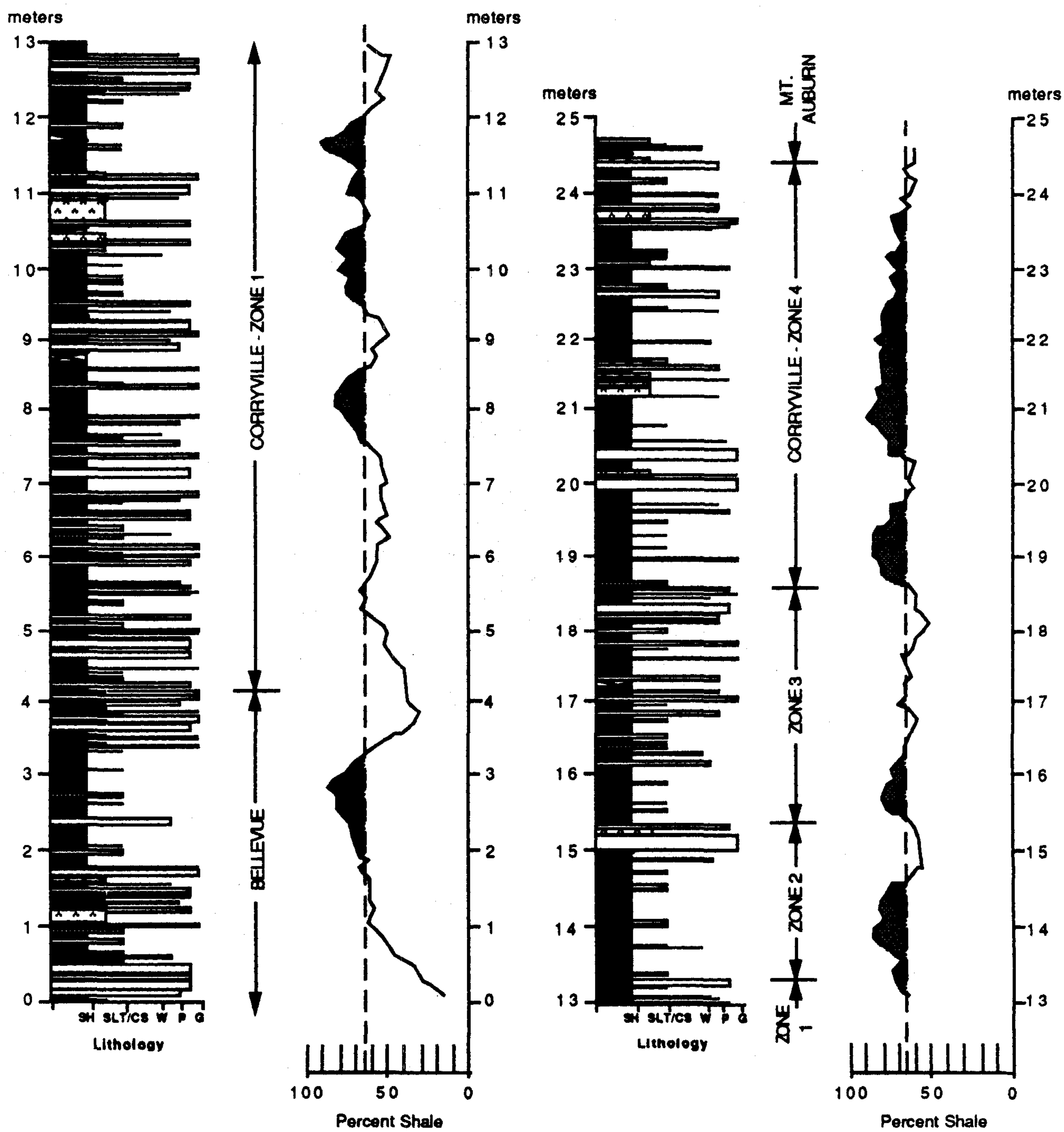
Location: Stonelick Creek, Exposure #2



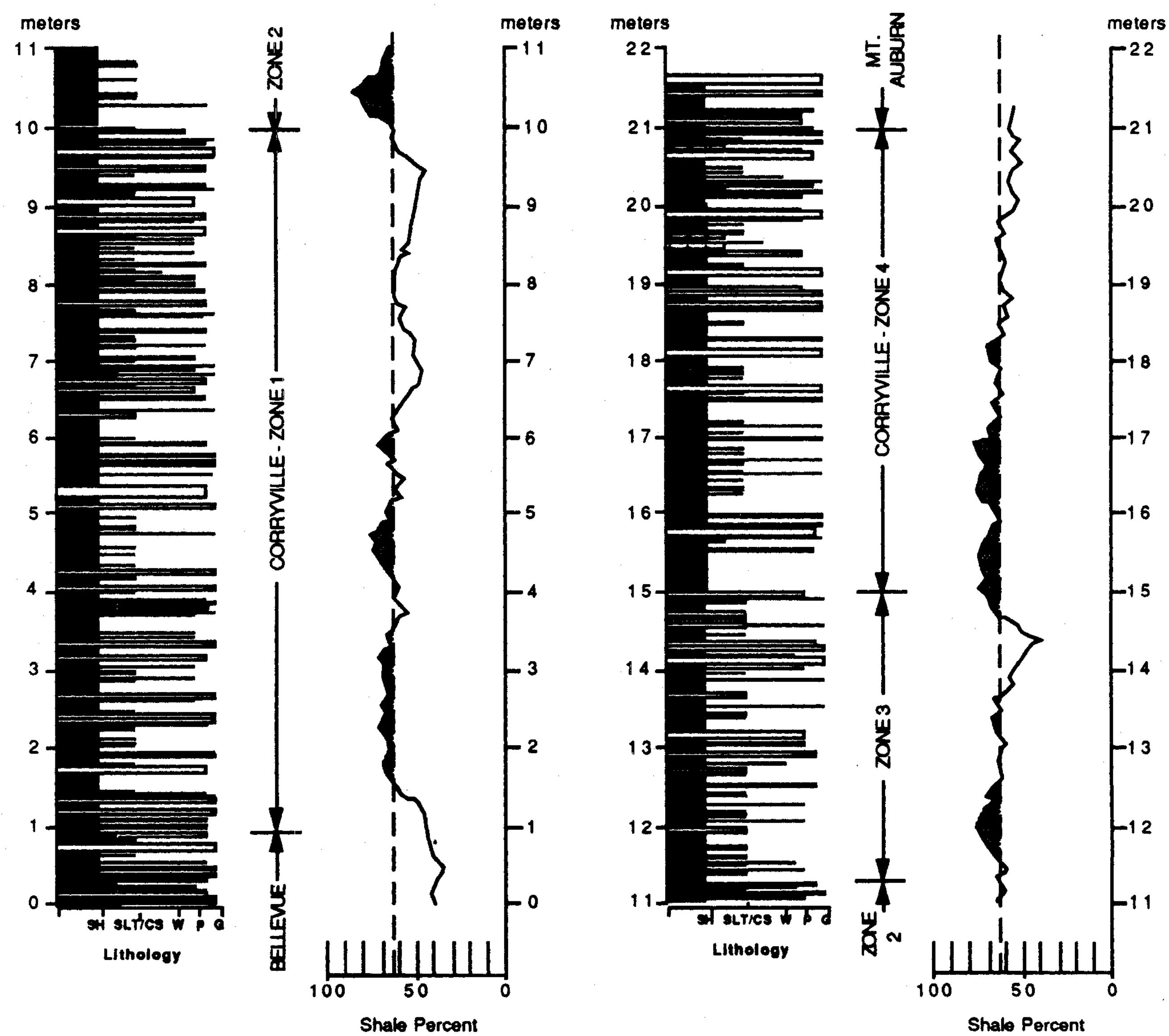
Location: O'Bannon Creek, Clermont County, Ohio



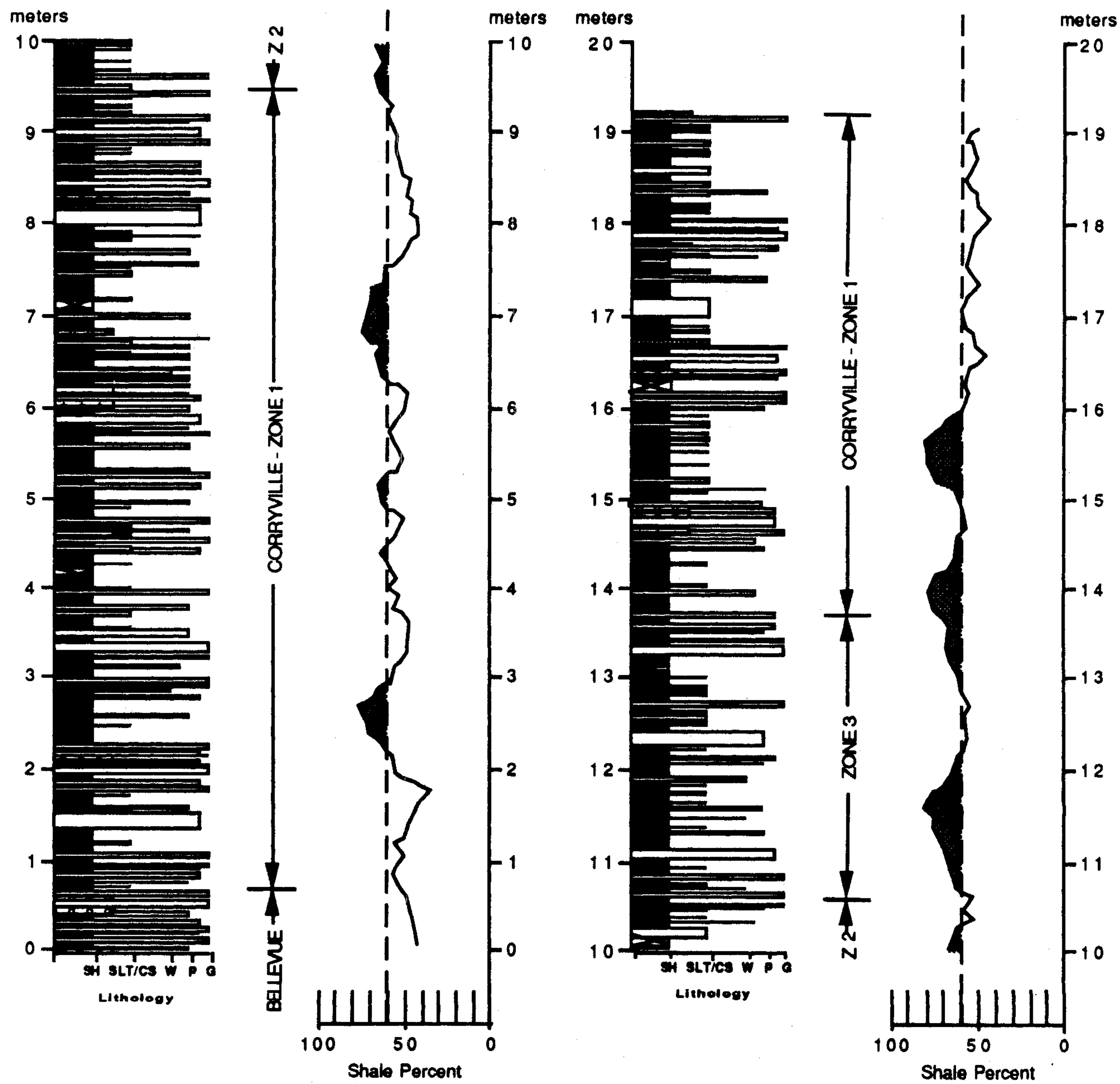
Location: OGS Core #868



Location: OGS Core #2620



Location: OGS Core # 2623



Appendix 4

Informal Faunal List

In the absence of a modern taxonomic description for the Corryville Member of the Grant Lake Formation, the following informal faunal list has been compiled. A previous faunal list was compiled by Dalvé (1948), but this accounting is outdated and in need of serious revision. In this compilation, all taxa were verified either from the plates and published references or from laboratory analysis of fossiliferous limestones and shale beds. Taxa were listed under their generic title when the species names could not be determined.

	Reference(s)
Coelenterata-Conularida:	
Conularia	Caster, 1942
Bryozoa:	
Amplexopora sp.	Hinterlong, 1981
Batostomella gracilis	Caster et al., 1955; Tobin, 1982
Chiloporella nicholsoni	Nickles, 1902; Braun, 1916; Caster et al., 1955; Gutstadt, 1958; Hinterlong, 1981; Tobin, 1982
Dekayia sp.	Nickles, 1902; Caster et al., 1955; Hinterlong, 1981; Tobin, 1982
Heterotrypa sp.	Nickles, 1902; Gutstadt, 1958; Hinterlong, 1981
Homotrypa sp.	Caster et al., 1955
Monticulipora sp.	Nickles, 1902; Caster et al., 1955; Hinterlong, 1981; Tobin, 1982
Parvohallopora ramosa	Caster et al., 1955; Gutstadt, 1958; Holland, 1990
Brachiopoda-Articulata:	
Hebertella occidentalis	Caster et al., 1955; Hinterlong, 1981
Onniella sp.	Tobin, 1982; Holland, 1990
Plectorthis sp.	Caster et al., 1955

	Reference(s)
Brachiopoda-Articulata (cont.):	
Platystrophia spp.. (*P. laticosta* and *P. ponderosa*)	Nickles, 1902; Braun, 1916; Caster et al., 1955; Gutstadt, 1958; Carpenter and Ory, 1961; Ford, 1967; Hinterlong, 1981; Tobin, 1982; Schumacher, 1984; Holland, 1990
Rafinesquina alternata	Nickles, 1902; Van Fossen, 1951; Hinterlong, 1981; Schumacher, 1984; Holland, 1990; Meyer, 1990
Rafinesquina nasuta	Nickles, 1902; Van Fossen, 1951; Caster et al., 1955; Carpenter and Ory, 1961; Holland, 1990
Zygospira modesta	Meyer et al., 1981; Hinterlong, 1981; Tobin, 1982; Schumacher, 1984; Holland, 1990
Brachiopoda-Inarticulata:	
Schizocrania filosa	Nickles, 1902; Caster et al., 1955
Trematis millipunctata	Nickles, 1902; Caster et al., 1955; Schumacher, 1984
Mollusca-Cephalopoda:	
Cameroceras sp.	Frey, 1987b
"*Endoceras*"	Dalvé, 1948
Oncoceras sp.	Frey, 1987b
Treptoceras	Dalvé, 1948
Mollusca-Gastropoda:	
Bellerophon sp.	Nickles, 1902
Cyclonema sp.	Nickles, 1902; Thompson, 1970; Tobin, 1982; Schumacher, 1984; Holland, 1990
Cyclora sp.	Tobin, 1982
Loxoplocus bowdeni	Caster et al., 1955; Tobin, 1982
Mollusca-Monoplacophora	
Cyrtolites sp.	Dalvé, 1948

	Reference(s)
Mollusca-Pelecypoda:	
Ambonychia sp. (includes *Byssonichia*)	Nickles, 1902; Braun, 1916; Pojeta, 1962; Tobin, 1982; Schumacher, 1984; Frey, 1987a; Holland, 1990
Anomalodonta sp.	Braun, 1916; Frey, 1987a
Caritodens demissa	Pojeta, 1971; Schumacher, 1984; Frey, 1987a; Holland, 1990
Cleidophorus sp.	Frey, 1987a
Corallidomus sp.	Frey, 1987a; Frey, 1987b
Ctenodonta sp.	Frey, 1987a
Cuneamya sp.	Frey, 1987a
Cycloconcha sp.	Frey, 1987a
Cymatonota sp.	Frey, 1987a
Deceptrix sp.	Frey, 1987a
Ischyrodonta sp.	Holland, 1990
Lyrodesma sp.	Frey, 1987a
Modiolopsis sp.	Nickles, 1902; Schumacher, 1984; Frey, 1987a
Orthodesma sp.	Frey, 1987a; Frey, 1987b
Pholadomorphas sp.	Frey, 1987a
Psiloconcha sp.	Frey, 1987a
Rhytima sp.	Frey, 1987a
Arthropoda-Aglaspida:	
Neostrabops martini	Caster and Macke, 1952; Hinterlong, 1981
Arthropoda-Ostracoda:	Dalvé, 1948; Tobin, 1982
Arthropoda-Trilobita:	
Acidaspis sp.	Hinterlong, 1981
Amphilichas halli	Dalvé, 1948
Ceraurus milleranus	Nickles, 1902; Caster et al., 1955
Flexicalymene meeki	Caster et al., 1955; Hinterlong, 1981; Tobin, 1982; Schumacher, 1984; Frey, 1987b; Holland, 1990
Isotelus sp.	Caster et al., 1955; Hinterlong, 1981; Schumacher, 1984; Frey, 1987b; Holland, 1990

	Reference(s)
Echinodermata-Asteroidea	
Promopalaeaster sp.	Schumacher, 1984
Echinodermata-Carpoidea:	
Enoploura popei	Caster, 1952; Hinterlong, 1981
Echinodermata-Crinoidea:	
Anomalocrinus sp.	Nickles, 1902
Cincinnaticrinus sp.	Dalvé, 1948; Holland, 1990
Ohiocrinus sp.	Nickles, 1902
Pycnocrinus dyeri (*Glyptocrinus dyeri*)	Nickles, 1902; Caster et al., 1955; Hinterlong, 1981; Meyer et al., 1981; Schumacher, 1984; Frey, 1987b
Iocrinus subcrassus	Hinterlong, 1981; Meyer et al., 1981; Schumacher, 1984; Frey, 1987b; Holland, 1990
"*Lichenocrinus*" sp.	Nickles, 1902; Caster et al., 1955
Echinodermata-Edrioasteroidea:	
Carneyella pilea	Caster et al., 1955; Bell, 1972; Meyer et al., 1981; Meyer, 1990
Isorophus cincinnatiensis	Caster et al., 1955; Bell, 1972; Meyer et al., 1981; Meyer, 1990
Streptaster vorticellatus	Bell, 1972; Meyer et al., 1981; Meyer, 1990
Protocordata-Graptolithina:	Schumacher, 1984; Bergström and Mitchell, 1986
Incerta Sedis:	
Cornulites corrugatus	Schumacher, 1984
Lepidocoleus sp. (a Machaeridian)	Dalvé, 1948; Schumacher, 1984
Conodonts	Bergström and Mitchell, 1986
Scolecodonts	Schumacher, 1984

Ichnofossils:	Reference(s)
Asteriacites stelliforme	Osgood, 1970; Meyer et al., 1981
Chondrites - Type B	Osgood, 1970; Hinterlong, 1981; Meyer et al., 1981; Tobin, 1982; Tobin, 1986
Conostichus sp.	Krumpolz, 1980 (Mt. Auburn); Tobin, 1980 (Mt. Auburn)
Diplocraterion biclavatum	Osgood, 1970; Hinterlong, 1981; Meyer et al., 1981; Tobin, 1982; Tobin, 1986
Fascifodina floweri	Osgood, 1970; Meyer et al., 1981
Lockeia siliquaria	Osgood, 1970; Meyer et al., 1981
Paleophycus - Type B	Osgood, 1970; Hinterlong, 1981; Meyer et al., 1981; Tobin, 1982; Tobin, 1986
Palaeoscia floweri (siphonophore?)	Caster, 1942; Osgood, 1970; Hinterlong, 1981
Phycodes flabellum	Osgood, 1970; Meyer et al., 1981
Rusophycus carleyi	Osgood, 1970; Meyer et al., 1981
Rusophycus pudicum	Osgood, 1970; Hinterlong, 1981; Meyer et al., 1981
Trichophycus venosum	Osgood, 1970; Bretsky, 1970b; Hinterlong, 1981; Meyer et al., 1981; Tobin, 1982; Tobin, 1986
"escape structures"	Tobin, 1982

Appendix 5

Raw Abundance Data

Sample	Ht. above base of Corryville (m)	Bryozoan	Trilobite	Crinoid	*Rafinesquina* sp.	*Zygospira*	*Platystrophia*	*Plectorthis*	*Raf. nasuta*	*Onniella*	*Ambonychia*	*Modiolopsis*	*Caritodens*	*Anomalodonta*	? pelecypod	*Cyclonema*	*Cyclora*	*Loxoplocus*	? gastropods	Cephalopods
5-1	0.38	32	4	11	25	55	6	0	0	0	2	0	0	0	2	0	0	3	0	1
11-1	0.78	10	10	2	15	26	1	2	0	1	4	1	0	0	2	0	0	0	0	0
19-1	1.41	11	11	2	131	82	13	0	10	0	1	0	4	1	0	2	0	0	0	0
3-2	2.13	23	10	2	12	104	0	1	0	0	0	0	0	0	2	6	0	0	0	0
9-2	2.52	12	6	2	52	53	0	1	0	0	3	1	2	0	0	1	0	0	0	0
17-2	2.93	34	3	1	11	46	0	0	0	0	2	0	2	0	0	0	0	0	1	0
27-2	3.52	4	8	0	33	51	0	1	48	0	3	0	0	0	1	0	0	0	0	0
37-2	4.15	15	16	1	3	27	0	3	0	0	4	0	0	0	0	0	0	0	1	0
47-2	4.43	35	5	2	7	66	0	9	0	0	6	2	1	0	0	4	0	0	0	0
57-2	5.37	33	9	5	2	68	19	4	0	0	3	0	1	0	0	4	0	0	0	1
65-2	6.03	40	15	1	12	22	1	6	0	0	7	0	1	3	2	1	0	0	1	0
75-2	6.43	34	14	1	3	44	0	33	0	0	5	0	1	0	5	0	0	0	0	2
89-2	7.16	16	16	8	27	85	0	6	0	0	13	4	1	0	25	0	0	0	0	0
95-2	7.70	11	16	0	67	4	0	4	2	0	0	0	0	0	0	2	0	0	0	3

Sample	Ht. above base of Corryville (m)	Bryozoan	Trilobite	Crinoid	*Rafinesquina* sp.	*Zygospira*	*Platystrophia*	*Plectorthis*	*Raf. nasuta*	*Onniella*	*Ambonychia*	*Modiolopsis*	*Caritodens*	*Anomalodonta*	? pelecypod	*Cyclonema*	*Cyclora*	*Loxoplocus*	? gastropods	Cephalopods
103-2	8.04	8	16	2	59	42	0	15	8	0	0	0	0	0	0	0	0	0	0	0
115-2	8.69	14	12	4	47	62	0	0	3	0	0	0	1	0	0	1	0	0	0	0
125-2	9.23	10	16	2	12	135	0	0	0	0	0	0	0	0	0	2	2	0	0	2
133-3	10.06	36	16	8	4	42	0	0	0	0	6	0	1	0	9	2	0	0	0	0
147-2	10.73	19	13	8	3	68	0	0	0	0	1	4	1	0	11	0	0	0	1	0
155-2	11.24	1	7	0	6	60	0	0	0	1	2	0	0	6	0	0	0	0	0	0
161-2	11.55	9	7	6	0	83	0	0	0	2	1	1	0	0	5	1	0	0	0	0
171-2	12.11	28	3	0	5	28	0	0	0	0	1	0	0	0	1	0	0	0	0	0
179-2	12.7	10	20	4	30	59	0	1	0	0	2	2	0	0	10	0	0	0	0	0
189-2	13.09	12	10	2	11	18	0	0	0	0	1	0	0	0	0	0	0	0	0	1
195-2	13.47	7	9	2	18	23	0	0	0	0	0	0	1	0	0	0	0	0	0	0
203-2	13.85	12	14	4	20	130	0	2	0	0	3	0	1	0	2	0	1	0	0	1
209-2	14.57	11	6	2	17	49	0	0	0	0	0	0	1	0	0	0	3	0	0	0
215-2	15.15	9	3	3	2	105	0	0	0	0	0	2	0	0	0	0	0	0	0	1

Sample	Ht. above base of Corryville (m)	Bryozoan	Trilobite	Crinoid	*Rafinesquina* sp.	*Zygospira*	*Platystrophia*	*Plectorthis*	*Raf. nasuta*	*Onniella*	*Ambonychia*	*Modiolopsis*	*Caritodens*	*Anomalodonta*	? pelecypod	*Cyclonema*	*Cyclora*	*Loxoplocus*	? gastropods	Cephalopods
219-2	15.57	2	4	0	16	5	0	0	0	0	0	0	1	0	2	0	0	0	0	0
223-2	16.01	19	12	2	9	15	0	9	0	0	1	0	2	0	6	0	2	0	0	1
231-2	16.4	22	8	0	32	64	0	0	0	0	0	0	0	0	1	0	0	0	2	0
239-2	16.89	9	1	10	33	2	0	0	0	0	0	0	0	0	1	1	1	0	0	0
245-2	17.42	6	0	2	20	6	0	0	0	0	0	0	0	0	0	0	1	0	0	0
249-2	17.96	22	2	0	5	25	0	0	0	0	0	0	0	0	0	0	3	0	0	0
259-2	18.46	6	5	3	19	34	0	0	0	2	2	0	0	0	1	0	0	0	0	0
269-2	19.24	14	4	8	7	6	0	0	0	0	1	0	1	0	2	0	0	0	0	0