

J932
30

To the Graduate Council:

I am submitting herewith a thesis written by Kurt Allen Easthouse entitled "The Paleoenvironmental Analysis of the Lower Silurian Rockwood Formation at Green Gap, Whiteoak Mountain, Southeastern Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Geology.

Steven G. Driese

Steven G. Driese, Major Professor

We have read this thesis
and recommend its acceptance:

Karla C. Misra

Nicholas B. Woodward

Accepted for the Council:

Cowminkel

Vice Provost
and Dean of The Graduate School

**THE PALEOENVIRONMENTAL ANALYSIS OF THE LOWER SILURIAN ROCKWOOD
FORMATION AT GREEN GAP, WHITEOAK MOUNTAIN,
SOUTHEASTERN TENNESSEE**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Kurt Allen Easthouse

March 1987

DEDICATION

This text is dedicated to my parents and my wife for their undying love and support.

ACKNOWLEDGEMENTS

Special thanks in given to Dr. Steven G. Driese for advice, assistance, guidance, and support. The author would also like to extend many thanks to his wife for her help in the typing and drafting of this thesis.

Recognition is extended to Dr. Misra and Dr. Woodward for their assistance in the preparation of this manuscript, and to Dr. Boucot for help with fossil identification. In addition, thanks is extended to Mark Fischer for aid in the field.

ABSTRACT

Deposition of the Lower Silurian Rockwood Formation occurred within a subtidal, shallow marine environment. The shallowest, most nearshore portion of the shelf was dominated by megarippled and rippled sand shoals deposited above fairweather wave-base, and subtidal, lower shoreface storm sands deposited below fairweather wave base. In this shallow, nearshore environment, conditions were favorable for the transportation and concentration of iron. Tidal currents and both fairweather-wave and storm-wave flows affected this environment. The effect of storms was to erode this nearshore environment, and transport sand and skeletal debris (some of which was replaced by iron) out into deeper portions of the shelf below fairweather wave-base.

Conditions below fairweather wave-base were for the most part quiet and placid with little agitation reaching this environment. Oxygen was typically in limited supply, which restricted the occupancy by soft-bodied infauna and calcified species. Occasionally storm flows entered this environment, depositing sharp-based sandstone and bioclastic limestone beds. The abundance of skeletal debris within the storm beds implies skeletal sand banks must have been present in the nearshore environment. These were intimately associated with the megarippled and rippled sand shoals. The storm beds deposited above storm wave-base exhibit features indicative of combined-flow currents such as form-discordant wave ripples, HCS, micro-HCS, and some graded bedding. Within this realm, both the action of the unidirectional flow transporting the material and storm waves impacting the sea

bottom influenced the resultant sedimentary structures. Once the storm flows reached below storm wave-base, the effects of oscillatory currents were greatly reduced. In this locality, beds were typically graded and contain horizontal laminations. The most probable transporting mechanism was by storm-surge-ebb currents that evolved into geostrophic flows.

Fairweather flows, such as tidal and alongshore flows, transported sand in the nearshore environment above fairweather wave-base. Effects of storm flows were probably intense in this environment, but reworking by fairweather tidal and wave processes have erased any trace. Below fairweather wave-base, during periods of non-storm conditions, deposition was dominated by mud.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION.....	1
Purpose.....	1
Geologic Setting.....	3
Stratigraphic Nomenclature and Age.....	4
Previous Work.....	6
Methods.....	10
II. FACIES DESCRIPTION.....	11
Introduction.....	11
Facies H.....	11
Facies MB.....	32
Facies AH.....	34
Facies QA.....	37
Facies FC.....	41
III. FACIES DISCUSSION.....	48
General Characteristics.....	48
Depositional Conditions of Facies H.....	48
Depositional Conditions of Facies MB.....	77
Depositional Conditions of Facies AH.....	79
Depositional Conditions of Facies QA.....	82
Depositional Conditions of Facies FC.....	83
Iron Mineralization in the Rockwood.....	86
Ichnology of the Rockwood Formation.....	95
General Paleocurrent Analysis.....	113
IV. PROXIMALITY TRENDS.....	117
Introduction.....	117
V. ORIGIN OF THE ROCKWOOD.....	133
Depositional Model.....	133
Relation of the Rockwood to Equivalent Strata.....	145
Modern Analogue(s).....	150
Relation to Similar Storm Sequences.....	152

CHAPTER	PAGE
VI. SUMMARY AND CONCLUSIONS.....	155
REFERENCES.....	159
APPENDIX.....	168
VITA.....	218

LIST OF FIGURES

FIGURE	PAGE
1. Location of Study Area and Silurian Strata in East Tennessee.....	2
2. Stratigraphic Nomenclature and Approximate Correlations for Upper Ordovician and Lower Silurian Strata in the Central Appalachian Basin.....	5
3. Age of the Lower Silurian Rocks of East Tennessee, with the Possible Extension of the Rockwood Through the Upper Llandoveryan.....	7
4. Correlation Between Cotter's Work on the Tuscarora and the Work of Driese et al., on the Lower Silurian of East Tennessee.....	9
5. Distribution of Facies within the Rockwood Formation at Whiteoak Mountain.....	12
6. Brief Description of Facies.....	13
7. Internal Structures within Gutter Casts of Sub-Facies Hm...	17
8. Typical Graded Bedding Sequence.....	19
9. Typical Fossil/Granule Lag Composed of Hematite, Glauconite and Limonite(?) Replaced Bioclasts and Quartz Sand.....	20
10. Lenticular Bioclastic Wackestone-Packestone Bed that Pinches-Out to the Right and Left of Hammer.....	21
11. Types and Sizes of Trace Fossils in Sub-Facies Hm.....	23
12. Typical Sedimentary Structures of Sub-Facies Hs.....	25
13. HCS Sequence with Rippled Upper Surface Lacking Internal Stratification.....	26
14. Amalgamation of Thin Sandstone Beds Exhibiting Horizontal and Low-Angle Cross-Laminations.....	27

FIGURE	PAGE
15. Bioturbation Concentrated at the Top of the Storm Bed.....	29
16. Types and Sizes of Trace Fossils in Sub-Facies Hs.....	30
17. Variation in Thickness of Layers Due to Pinch-and-Swell Nature of Beds.....	31
18. Types of Trace Fossils in Facies MB.....	35
19. Typical Lithology of Facies AH Composed of Quartz Grains, Hematite Replaced and Unreplaced Bioclasts, Hematite Cement, and Calcite Cement.....	36
20. Photo-Micrograph of Basal Deposit of Reworked Material, Composed of Quartz and Phosphate Granules, Lithic Fragments, Hematite Cement, and Dolomite Cement.....	38
21. Bioturbated Basal Sandstone Capped by a Thin Lag of Reworked Material.....	40
22. Conglomeratic Ironstone Bed Capping Facies FC.....	42
23. Amalgamation of Bedding within Facies FC.....	44
24. Types and Sizes of Trace Fossils in Facies FC.....	45
25. Interpretation of Facies.....	49
26. Typical Sedimentary Structures within Sub-Facies Hm.....	51
27. Upward Sequence of Structures Indicates Declining Flow.....	53
28. Micro-HCS Bed.....	55
29. Morphology of Ripple Crests.....	57
30. Symmetrical Gutter Cast in Cross-Section.....	59
31. Flute Cast at Base of Sandstone Bed.....	61
32. Hummock-Like Bed Enclosed in Mudstone.....	63

FIGURE	PAGE
33. Typical Sedimentary Structures within Sub-Facies Hs.....	65
34. Hummocky Sequences Formed by Accretion?.....	67
35. Abruptly Pinched-Out Layer Directly Below Hammer.....	70
36. Characteristic Assemblages of Strata which Change with Distance from the Source.....	72
37. Convolute Laminations within Storm(?) Emplaced Sandstone Bed.....	75
38. Amalgamated Hummocky Sequences of Dott and Bourgeois (1982).....	81
39. Sedimentary Structures and Inferred Depositional Conditions of Facies FC.....	84
40. Iron-Rich Lithologies Denoted by Fe.....	88
41. <u>Skolithos</u> Tube within Sandstone Layer.....	98
42. Horizontal Trace Fossils.....	101
43. <u>Gyrochorte</u> Trace Fossil.....	102
44. Marine Ichnofacies and Positions Relative to Shore.....	103
45. Trace Fossil Associations and their Environmental Signifi- cance.....	104
46. Different Levels of Oxygen Produced by Density Stratifica- tion and Dominant Characteristics of Each Zone.....	108
47. Maximum Burrow Diameters and Range of Diameters for the Rockwood Formation.....	110
48. Results of Paleocurrent Analysis.....	115
49. Proximity Concept of Aigner and Reineck (1982).....	118
50. Upward Transition from Distal to Proximal and Shoreface Tempestites.....	122

FIGURE	PAGE
51. Vertical Stacking of Distal and Proximal Tempestites.....	123
52. Determination of Distal, Proximal, and Shoreface Storm Deposits Based on Parameters Listed Above.....	124
53. The Application of the Proximality Parameters on the Rockwood Formation.....	126
54. Maximum Thickness of Storm Sands for the Rockwood Formation.....	131
55. Mean Thickness of Storm Sands for the Rockwood Formation.....	132
56. Early Silurian Paleogeography and Paleoclimatology.....	134
57. Application of Swift and Niedoroda's Coastal Set-Up Model to the Rockwood Shelf.....	137
58. Dynamic Zones of the Coastal Ocean.....	140
59. Hydrodynamic Model for the Rockwood Formation.....	144
60. Postulated Fairweather Conditions on the Rockwood Shelf.....	146
61. Processes Operating on Modern Storm Dominated Shelves.....	151

CHAPTER I

INTRODUCTION

Purpose

The aim of this study is to provide a paleoenvironmental interpretation of the Lower Silurian Rockwood Formation at Green Gap, Whiteoak Mountain, southeastern Tennessee (Fig. 1). It is a two hundred and sixty-four meter sequence of interbedded siltstone and shale with subordinate amounts of sandstone, limestone, and ferruginous beds. The study area represents the thickest and most complete exposure of the Rockwood Formation in east Tennessee and yields the most information concerning depositional conditions that existed on the Rockwood shelf. A focus of this study was to determine the hydrodynamic shelf processes that affected this setting, and to define paleoenvironments west of the Clinch belt. This study provides the first detailed sedimentologic examination of the Rockwood formation at Whiteoak Mountain, and proposes an environmental interpretation which will serve as a basis for comparison with equivalent strata. It contributes towards a more regional understanding of Lower Silurian depositional systems in east Tennessee, tying into the previous work of Schoner (1985) on the Clinch Sandstone, and the ongoing research of Fischer and Marks (Clinch Sandstone) and Driese (Rockwood). This study enhances the work conducted by Driese on the Rockwood through the application of the proximity concept of Aigner and Reineck (1982). In addition, special emphasis is placed upon the

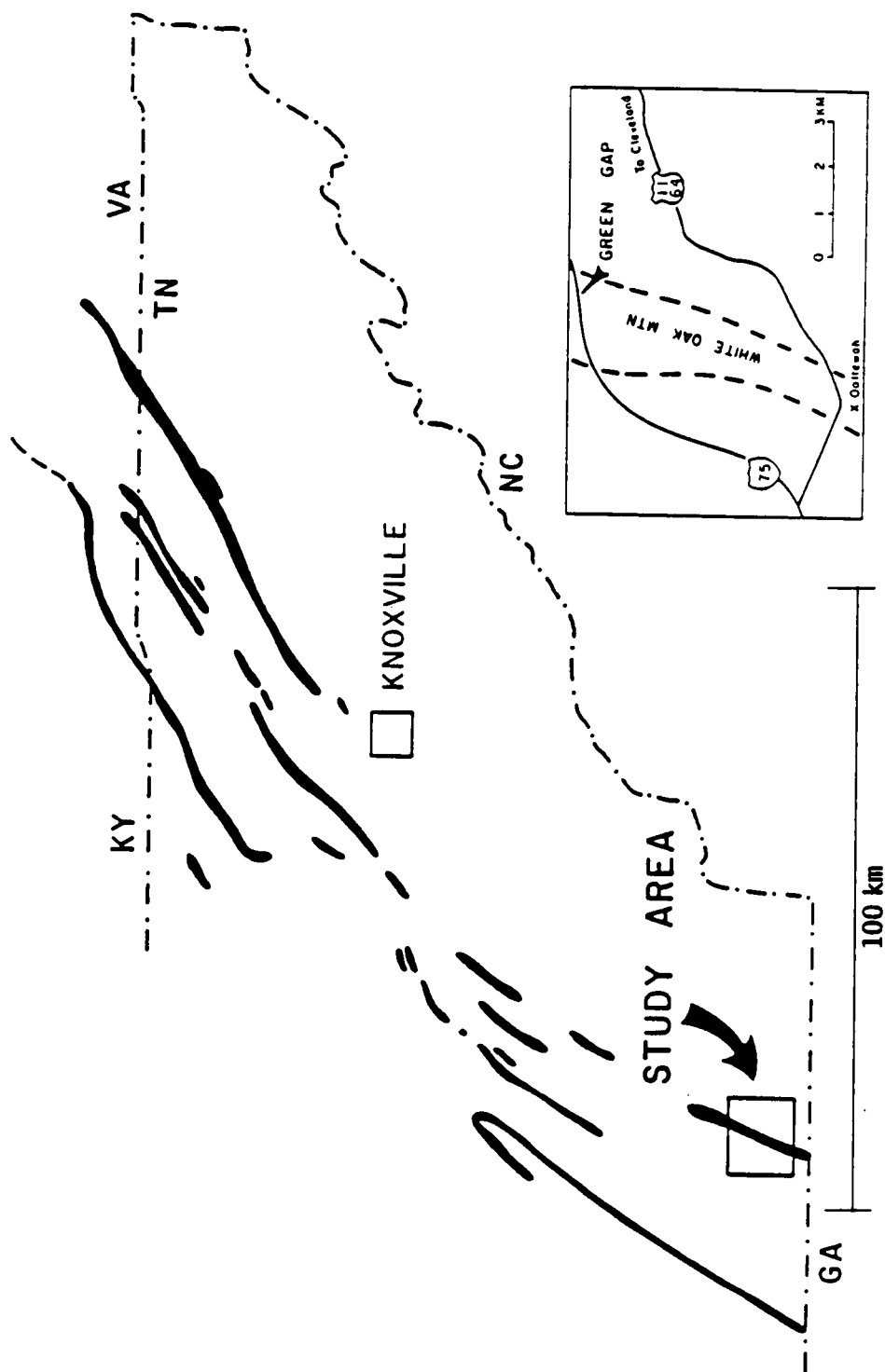


Figure 1. Location of Study Area and Silurian Strata in East Tennessee.
Silurian Outcrops Shaded in Black.

upon the analysis of trace fossils and iron sedimentation in terms of their environmental implications.

Geologic Setting

Silurian strata crop-out linearly from New York to Alabama within the Valley and Ridge province (Amsden, 1955). In the eastern Tennessee area, these Silurian rocks occur in northeast-trending belts that are separated from each other by thrust faults (Miller, 1976; Milici and Wedow, 1977) (Fig. 1). The Silurian rocks represent the culmination of a clastic wedge that formed as a result of degradation of uplands produced by the Middle Ordovician to Early Silurian Taconic Orogeny (Yeakel, 1962; Meckel, 1970). Thickness distribution of this clastic wedge indicates that the source of these sediments lay to the southeast and paleocurrent data (cross-beds) reveal predominant transport from the southeast to the northwest (Yeakel, 1962; Meckel, 1970).

There are three lithostratigraphic equivalent units that constitute the Lower Silurian (Llandoveryan) of the Valley and Ridge in east Tennessee (Chowns, 1972; Miller, 1976; Milici and Wedow, 1977). The eastern most unit is the Clinch Sandstone, which is a mature quartz arenite (Whisonant, 1977; Schoner, 1985 a, b). Passing westward, an alternating sequence of sandstone, siltstone and shale is encountered which comprises the Rockwood Formation (Milici and Wedow, 1977; Thompson, 1984; Driese, 1986 a, b; Driese et al., 1986 a, b). Further to the west lies the interbedded limestone and shale of the

Brassfield Formation (Chowns, 1972; Milici and Wedow, 1977). These units are conformably underlain by red beds of the Upper Ordovician Juniata and Sequatchie Formations (Miller, 1976; Milici and Wedow, 1977). Disconformably overlying the Lower Silurian rocks in most parts is the Chattanooga Shale (Devonian-Mississippian) (Chowns, 1972; Milici and Wedow, 1977).

Stratigraphic Nomenclature and Age

The Rockwood was originally named by Hayes in 1891 to take the place of an earlier nomenclature (the Dyestone group) assigned by Safford in 1869 (in Milici and Wedow, 1977). The Rockwood Formation derived nomenclature is from exposures in the town of Rockwood, Roane County, Tennessee where Hayes first studied it (Wedow, 1960). Hayes placed the Rockwood at the top of the Silurian, overlying the Chickamauga Limestone and Knox Dolomite, which he thought were Middle and Lower Silurian, respectively. In 1911, Ulrich (in Burchard, 1913) restricted the name Rockwood to the upper beds of Silurian clastic rocks and applied the name Sequatchie to the underlying red calcareous mudstone. The use of the name Rockwood today is limited to the Valley and Ridge belt in eastern Tennessee. Equivalent rocks include the Red Mountain Formation of Alabama and Georgia, the Clinch, Clinton, and Rose Hill Formations of northeastern Tennessee and southwestern Virginia, and the Brassfield Formation of central Kentucky (Fig. 2).

NW GEORGIA	E. TENNESSEE (Sequatchie Valley)	E. TENNESSEE (Westerly Belts)	E. TENNESSEE (Easterly Belts)	SW VIRGINIA
	CHATTANOOGA SH (DEV. - MISS)		WILDCAT VALLEY SS (LOWER DEVONIAN)	ROSE HILL FM (MIDDLE SILURIAN)
RED MTN FM LOWER and MIDDLE SILURIAN	BRASSFIELD FM (LOWER SILURIAN)	ROCKWOOD FM (LOWER SILURIAN)	SS CLINCH Poor Valley Ridge Mbr Hagan Shale Mbr	TUSCARORA/ CLINCH SS (LOWER SILURIAN)
	SEQUATCHIE FM (UPPER ORDOVICIAN)		JUNIATA FM (UPPER ORDOVICIAN)	

Figure 2. Stratigraphic Nomenclature and Approximate Correlations for Upper Ordovician and Lower Silurian Strata in the Central Appalachian Basin. (Modified from Driese, 1986a).

The age of the Rockwood is not well established, and the age has been determined by analysis of underlying and overlying units, and correlation with inferred time-equivalent strata. Berry and Boucot (1970) have placed the Rockwood along with the time equivalent Clinch and Brassfield within the Llandoveryian (Fig. 3). Samples of brachiopods were collected from the Rockwood at Whiteoak Mountain and sent to Dr. A. Boucot (Oregon State University) for age determination. The results were not conclusive, but it appears the Rockwood may extend farther into the Llandoveryian (C3-C5) than had previously been thought. Miller (1976) stated that the Rockwood is stratigraphically equivalent to the Clinch and Clinton Formations, which are Lower and "Middle" Silurian, respectively.

Previous Work

Aside from the recent work by Driese (1985; 1986 a, b; Driese et al., 1986 a, b; Driese et al., in preparation), previous detailed sedimentologic studies on the Rockwood Formation have been scarce. Most studies have concentrated on the equivalent Clinch and Red Mountain Formations. Sandin (1960) studied the Red Mountain Formation and interpreted it as being of shallow-marine (epi-continental sea) origin. Sheldon (1970) examined the Red Mountain Formation in Alabama and concluded that it represented lagoonal, barrier island, and neritic marine deposits. Associated with these deposits were iron-formations, which Sheldon thought were indicative of a lagoonal environment. Several workers have studied the contemporaneous Clinch

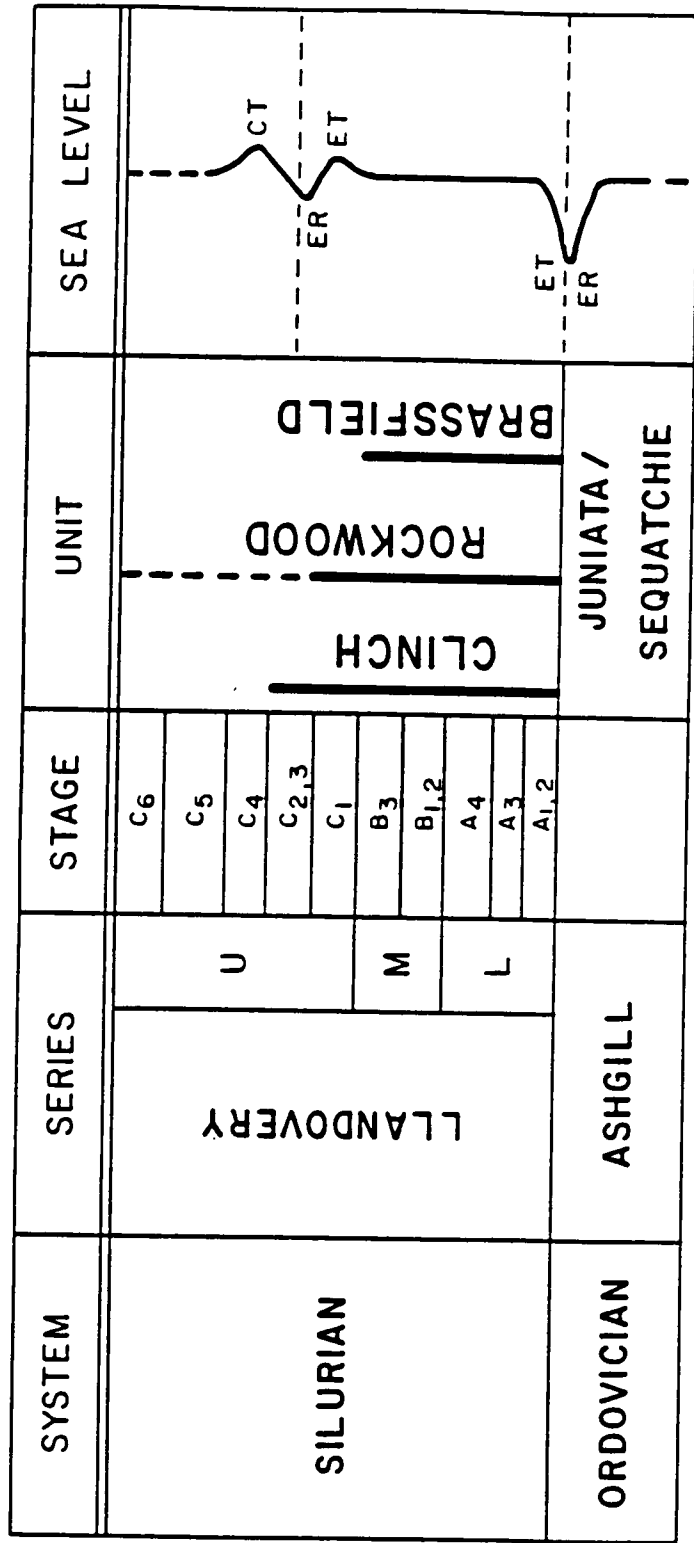


Figure 3. Age of the Lower Silurian Rocks of East Tennessee, with the Possible Extension of the Rockwood Through the Upper Llandoveryan (Modified from Driese et al., (in preparation)).

Sandstone, (Cundiff, 1951; Nicholson, 1978; Schoner, 1985 a, b; Fischer, in preparation) variously interpreted as a beach, barrier island, or subtidal sand ridge/shoal complex.

Thompson (1984) interpreted the Rockwood Formation in east Tennessee to represent a shallow, sublittoral shelf environment that developed along the eastern coastline of a large epi-continental sea. Driese et al, (Driese, 1985; 1986 a, b; Driese et al., 1986; Driese et al., in preparation) have interpreted the Rockwood to represent deposition in middle to outer shelf environments where storm-induced currents dominated. Features suggesting deposition above fairweather wave base, below fairweather wave base, and below storm wave base have been documented. Three Lower Silurian facies belts have been postulated in east Tennessee by Driese et al, which are as follows: megarippled sand banks/shoals (shoreface), hummocky stratified storm shelf, and a skeletal sand bank/storm shelf environment. This interpretation correlates with work by Cotter (1983) on the Lower Silurian of central Pennsylvania (Fig. 4). Siliciclastics are thought to have been supplied from the east/northeast and transported westward or southwestward into the basin by both fairweather and storm processes. Sands were moved from the nearshore environment out across the shelf by storm processes. Fairweather conditions on the shelf were dominated by terrigenous mud deposition. To the northwest of this basin lay carbonate-dominated sediments that may have been transported into the basin by storm flows (Driese et al., 1984; Schoner and Driese,

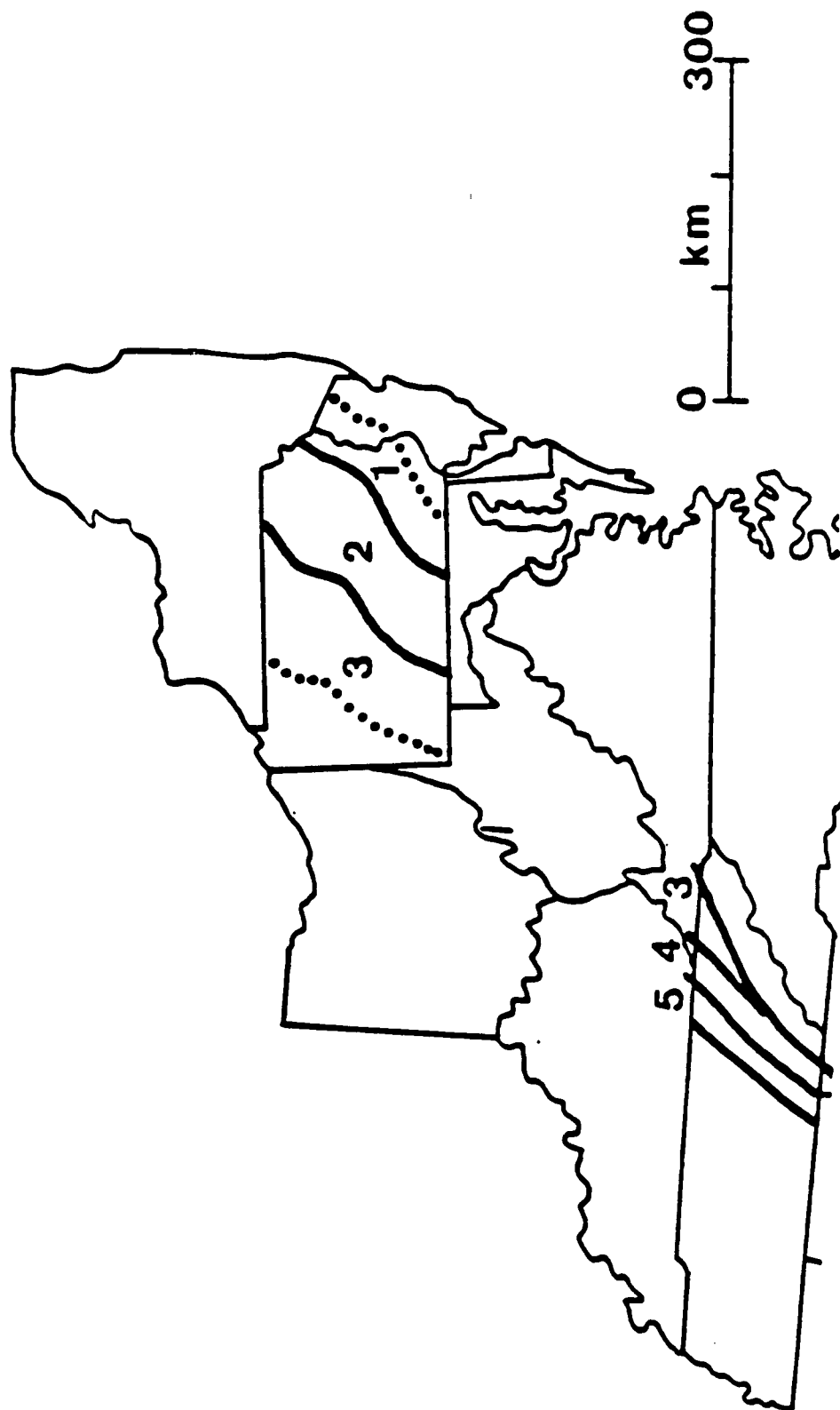


Figure 4. Correlation Between Cotter's (1983) Work on the Tuscarora (1 = Alluvial Fan Complexes; 2 = Coastal Alluvial Plain; 3 = Shelf Sand Wave Complexes) and the work of Driese et al., (in preparation) on the Lower Silurian of East Tennessee (3 = Mega-rippled Sand Banks; 4 = Hummocky Storm Shelf; 5 = Skeletal Sand Banks/Shelf).

1985; Driese, 1985; 1986 a, b; Driese et al., 1986 a, b; Driese et al., in preparation).

Methods

The study area is part of the Whiteoak Mountain syncline. Milici (1978) studied the structure and concluded that the east limb of the fold is steeply (west) dipping to overturned, with beds in its limb broken or folded. In contrast, the west limb lacks any major folding and/or faulting, and beds have low angles of (east) dip (3° - 15°). The concentration of this detailed sedimentologic study was on the less-deformed west limb, where a nearly complete stratigraphic section is exposed. The investigation was conducted using a process-oriented sedimentologic approach, which included the observation and interpretation of physical and biogenic sedimentary structures, lithology, paleocurrent data, and diagenetic features. The formation was measured with a Jacobs staff and described on a cm-by-cm scale, with special emphasis upon vertical and lateral variations in sedimentary features. The highly deformed beds of the east limb were also measured and described, and were used to supplement the detailed analysis of the west limb of the fold. Samples were collected where deemed necessary. Twenty-nine thin sections and forty polished slabs were made for further description.

CHAPTER II

FACIES DESCRIPTION

Introduction

The Rockwood Formation at Green Gap, Whiteoak Mountain, Tennessee consists of five principal lithofacies whose delineation was based on lithology, texture, biological features, mineral content, and physical sedimentary structures. These facies are an alternating (heterolithic) sandstone, siltstone, and shale Facies (H); a maroon-burrowed Facies (MB); a hematitic amalgamated hummocky? Facies (AH); a quartz arenite-high-angle cross-stratified Facies (QA); and a ferruginous-conglomeratic high-angle cross-stratified Facies (FC). The stratigraphic distribution and general characteristics of each facies are exhibited in Figures 5 and 6, respectively.

Facies H

The heterolithic sandstone, siltstone, and shale Facies (H) comprises the majority of the Rockwood section. This facies is divided into a mudstone-dominated sub-facies (Hm) and a sandstone dominated sub-facies (Hs). The delineation of these sub-facies is based primarily on the sandstone-to-shale ratio, which ranged from 1:1 to 1:30 for Hm (1:6 average), and 1:1 to 5:1 for Hs (2.3:1 average).

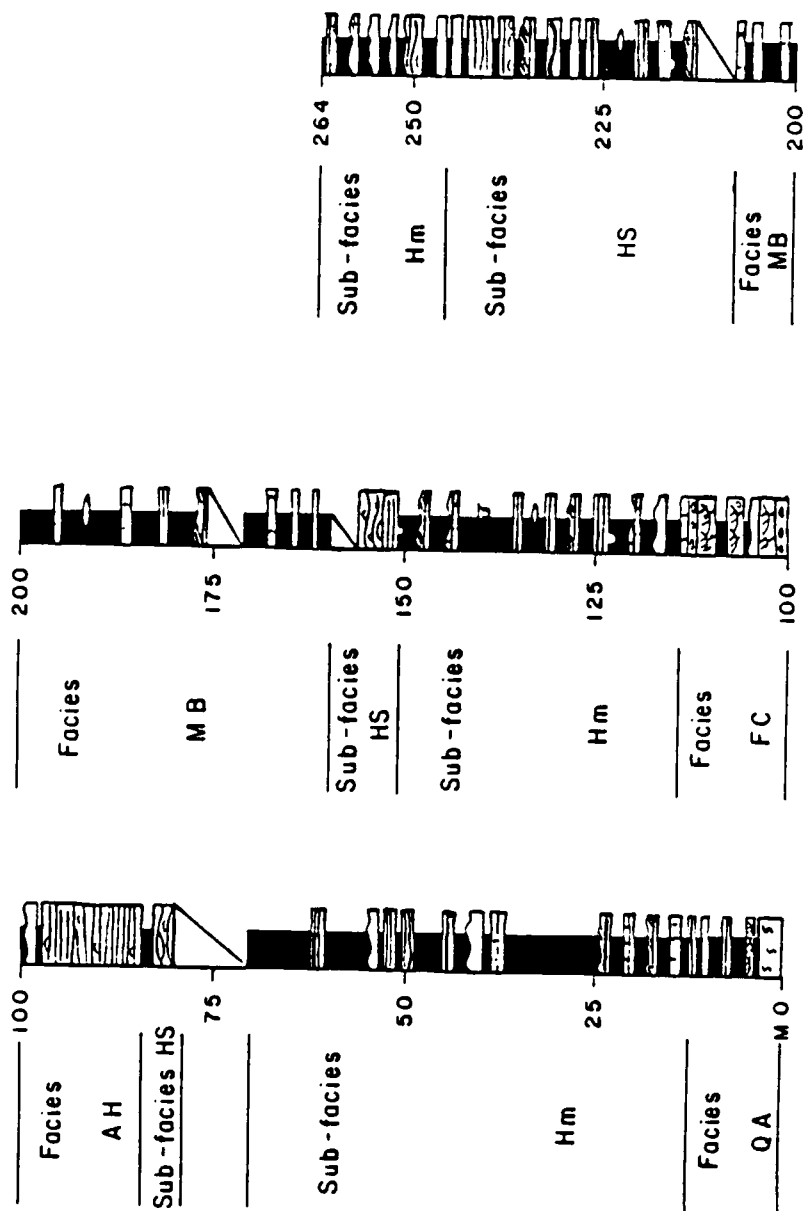


Figure 5. Distribution of Facies within the Rockwood Formation at Whiteoak Mountain.

<u>FACIES</u>	<u>LITHOLOGY</u>	<u>TYPICAL SEDIMENTARY STRUCTURES</u>
Heterolithic Mudstone Dominated Sub-facies (Hm)	-Calcareous-ferruginous quartz-arenite -Ferruginous trilobite echinoderm wackestone-packestone	-Horizontal laminations -Micro-HCS -Form-discordant wave-ripple cross-laminations (rare) -Wave-rippled upper surfaces (rare) -Gutter casts -Graded beds
Heterolithic Sandstone Dominated Sub-facies (Hs)	-Sandy limestone -Calcareous quartz-arenite -Ferruginous quartz-arenite -Fossiliferous quartz-arenite	-Horizontal laminations -HCS -Form discordant wave-ripple cross-laminations -Wave-rippled upper surfaces -Gutter casts (rare) -Graded beds (rare) -Thin amalgamated beds
Maroon-Burrowed (MB)	-Calcareous quartz-arenite	-Horizontal laminations -Low-angle cross-laminations (HCS?) -Wave rippled upper-surfaces (rare) -Gutter casts (rare)
Amalgamated Hummocky(?) (AH)	-Hematitic quartz-arenite	-Horizontal laminations -Low-angle cross-laminations (HCS?) -Graded beds -Thin-to-thick amalgamated beds
Quartz-Arenite (QA)	-Calcareous quartz-arenite	-Horizontal laminations -Ripple cross-laminations -Trough cross-stratification
Ferruginous-Conglomeratic (FC)	-Ferruginous trilobite-echinoderm wackestone-packestone -Sublitharenite -Ferruginous sublitharenite -Calcareous sublitharenite -Ferruginous litharenite	-Trough cross-stratification -Wave and current rippled upper surfaces -Amalgamation of bedding

Figure 6. Brief Description of Facies.

Sub-facies Hm - Strata assigned to the mudstone-dominated sub-facies occur in three groups: at the bottom, in the middle, and at the top of the Formation (Fig. 5). The strata within this facies are calcareous-ferruginous quartz-arenite and ferruginous trilobite-echinoderm wackestone-packstone. Sub-facies Hm constitutes 118.2m of the Formation and represents the most "distal" deposits of the section. The sandstone/shale ratio varies from 1:1 to 1:30, with an average of 1:6. Intercalated with the coarser grained-beds are mudstone beds, the principal lithology of this sub-facies. The mudstone is commonly light-to dark-gray, less commonly tan/brown to olive-green brown, rarely red/brown, and very rarely orange/brown to yellow. (See Appendix 1 for more complete descriptions.) The thinly laminated to very thinly bedded sequences are silty, in part, to rarely sandy. Internally the mudstone is massive to rarely horizontally laminated. The mudstone is commonly fissile with some intervals of blocky to hackly layers. The layers are continuous for the most part and commonly contain siltstone and very fine-grained sandstone lenses.

Bioturbation is absent to weak, with rare occurrences of moderate amounts of biogenic reworking. Many sequences contain no identifiable trace fossils, but biogenic reworking has probably occurred in the blocky/hackly intervals. Most of the identifiable trace fossils within the mudstone occurred at the soles of sandstone beds, and were dominated by Planolites and Paleophycus. Body fossils were rare in the mudstone. Found most commonly are crinoid columnals and brachio-

pods, though never in great abundance. Rare richly fossiliferous zones occur towards the top of the Formation, in which brachiopods, trilobites, crinoid columnals, belemnites, and gastropods were identified. Brachiopods were sampled from the middle to upper portions of the Rockwood section and sent to Dr. A. Boucot (Oregon State University) for identification. Results from Dr. Boucot's analyses indicate a Late Llandoveryan (late, Early Silurian) to Frasnian (early, Late Devonian) age based on some poorly preserved Atrypa reticularis. A Late Silurian age is speculated by Dr. Boucot based on a questionable Navispira. Other specimens identified are an unidentifiable strophomenacean brachiopod, an unidentifiable orthetacean brachiopod, and a dolerorthid. Unfortunately, abundant, well-preserved brachiopods were scarce in the Rockwood and not enough specimens were sent to Dr. Boucot to allow a more definite age determination.

Punctuating the mudrock are rare occurrences of sharp-based sandstone and bioclastic wackestone-packstone layers. Microscopic examination of the gray, maroon-gray, to rarely white to green-gray sandstone revealed a prevalence of calcareous-ferruginous quartz arenite lithologies. Dominant constituents included monocrystalline quartz grains and minor amounts of glauconite pellets, phyllosilicate minerals, and opaque minerals (for a more complete description, see Appendix 3). Dominant cementing agents included sparry calcite, and hematite, with minor amounts of chamosite, limonite, dolomite, silica, and clay.

Microscopic examination of the maroon-gray to yellow-orange bioclastic rocks reveal them to be predominantly trilobite-echinoderm wackestone-packstone. Dominant constituents include trilobites, echinoderms, molluscs, and bryozoans. Minor components include hematitic and limonitic superficial ooids, peloids, quartz grains, and sedimentary rock fragments. Many of the skeletal fragments are wholly or partially replaced by hematite, limonite, glauconite, and possibly chamosite(?). The dominant sedimentary structures are horizontal laminations, micro-hummocky cross-stratification (micro-HCS) and ripple cross-laminations. External ripple morphologies are generally symmetrical, with internal asymmetrical cross-laminations to rare symmetrical (chevron) cross-laminations. The beds occur either as continuous layers or as discontinuous lenses. The strata are thinly laminated to medium-bedded (1-100mm, 20-24mm average), with flat to uneven bases and flat to wave-rippled, burrowed, and hummock-like upper surfaces. Soles of beds commonly exhibit gutter casts, less commonly display tool marks, and load casts, and rarely show flute casts and groove casts. Gutter casts are abundant in sub-facies Hm, and are generally of three types. The first are isolated gutters (analogous to starved ripples) enclosed within mudstone. The second type are gutters associated with thin (1-2cm) sandstone beds. The third variety is associated with thicker beds (greater than 2cm). Internally the gutters are massive, horizontally laminated and, in some cases, low-angle cross-laminated (Fig. 7).



Figure 7. Internal Structures within Gutter Casts of Sub-Facies Hm.

Associated with the gutters are small tool marks and groove casts along the flanks of the erosive structures.

Graded beds are a common feature within the coarser grained layers, occurring almost exclusively within the sandstone (quartz arenite) beds. Almost all of the graded beds are flat-based, and contain the following sequence: Sharp, flat base (sole marks); millimeter thick fossil lag; horizontal laminations; wave-ripple or form-discordant wave-ripple cross-laminations (not always present); and weak to non-bioturbated mudstone (Fig. 8). Grain size changes from fine to granule-size grains and coarse skeletal debris at the base, to very fine sand and silt upwards, and eventually into clay-size particles. The fossil lags are composed of abraded brachiopods, crinoid columnals, gastropods, Tentaculites(?), and trilobite fragments. The lags are generally iron-rich, with most of the skeletal debris replaced by hematite, glauconite, and limonite(?) (Fig. 9). Cementing agents commonly include sparry-calcite, hematite, glauconite, dolomite(?), and silica. Above the fossil lags the sands are lacking in iron-replaced skeletal grains and iron cements.

The lateral continuity of beds vary, but in general the beds have a strong lenticular (pinch-and-swell) character. When traced laterally, some beds pinch-out altogether, leaving isolated lenses enclosed in mudstone. Almost all of the bioclastic wackestone-packstone beds are lenticular, and are easily spotted in the field by their hummock-like upper surfaces (Fig. 10).



Figure 8. Typical Graded Bedding Sequence.



Figure 9. Typical Fossil/Granule Lag Composed of Hematite, Glauconite, and Limonite(?) Replaced Bioclasts and Quartz Sand. Field of View from Left to Right is 2mm.



Figure 10. Lenticular Bioclastic Wackestone-Packestone Bed that Pinches Out to the Right and Left of the Hammer.

The abundance of bioturbation within the sandstone beds is non-existent to moderately-low. The trace fossils are commonly found at the tops and bases of beds, and rarely within beds. The morphology and dimensions of the trace fossils are highly variable and are exhibited in Figure 11.

Sub-facies Hs - Strata assigned to the sandstone-dominated sub-facies occur in three groups: in the upper, middle, and lower portions of the Rockwood Section, usually overlying sub-facies Hm (Fig. 5, p. 12). The strata within the facies are quartz arenite and sandy limestone. Intercalated with the coarser-grained beds are mudstone and silty mudstone, which are calcareous in part.

Microscopic examination of the gray-brown to orange-maroon quartz arenite beds revealed three varieties: calcareous quartz-arenite, ferruginous quartz-arenite, and fossiliferous quartz-arenite. The dominant constituents are monocrystalline quartz grains. Less abundant components include glauconite, phyllosilicate minerals, opaque minerals, and fossils (for a more detailed description, see Appendix 3). Typical cementing agents include hematite, sparry calcite, and silica.

Microscopic examination of the gray, well-sorted, sub-rounded to sub-angular, silty to medium-grained sandy limestone beds revealed an abundance of neomorphosed sparite. The only other major component is monocrystalline quartz. Minor components of these mixed deposits include opaque minerals, phyllosilicate minerals, and hematite cement.

<u>Morphology</u>	<u>Dimensions</u>	<u>Type</u>
Simple Straight Horizontal Tubes	1-3mm diameter by 5-10mm length	<u>Planolites</u>
	3mm diameter by 20-40mm length	<u>Planolites</u>
	0.5mm diameter by 3-5mm length	<u>Planolites</u>
	5-7mm diameter by 15-20mm length	<u>Paleophycus(?)</u>
Sinuuous Horizontal Tubes	10mm diameter by 50mm length	<u>Planolites(?)</u>
Branching Horizontal Tubes	2-5mm diameter by 20-50mm length	<u>Chondrites(?)</u>
Sub-vertical Tubes	5-7mm diameter by 15mm length	<u>Chondrites(?)</u>
Vertical Tubes	1-5mm diameter by 10-15mm length	<u>Skolithos</u>
	0.5mm diameter by 3-5mm length	Escape structure

Figure 11. Types and Sizes of Trace
Fossils in Sub-facies Hm.

Dominant sedimentary structures displayed by the coarser-grained beds include horizontal laminations, hummocky cross-laminations, form-discordant wave-ripple cross-laminations, and wave-ripple laminations (Fig. 12). The layers are thickly laminated to thickly bedded (5-600mm, 43.6mm average), with sharp bases that are commonly flat to rarely uneven. The upper surfaces of beds can be wavy (hummock-like), flat, burrowed, wave-rippled, and form-discordant wave-rippled. Several bedding sequences were observed in sub-facies Hs. The first bedding sequence is as follows: Sharp-based beds, commonly flat ($\pm$ sole marks, $\pm$ fossil lag) $\longrightarrow$ horizontal laminations $\longrightarrow$ hummocky cross-laminations $\longrightarrow$ ripple cross-laminations $\longrightarrow$ and non-bioturbated mudstone. In several instances the rippled upper surfaces are absent, or if present may not exhibit internal stratification (Fig. 13). The second sequence contains the following features: Sharp-based beds, commonly flat ($\pm$ sole marks, $\pm$ fossil lag) $\longrightarrow$ hummocky cross-laminations $\longrightarrow$ horizontal laminations $\longrightarrow$ ripple cross-laminations or rippled upper surfaces with no visible internal stratification. In some cases the ripples are absent all together. The last sequence consists of two or three thin, amalgamated sandstone beds. The base of the amalgamated sequence is commonly sharp ($\pm$ sole marks, $\pm$ fossil lags) followed by horizontal and/or low-angle cross-laminations (HCS?) (Fig. 14).

Graded beds are present, although not as abundant as in sub-facies Hm. The fining upward beds typically contain a fossil lag



Figure 12. Typical Sedimentary Structures of Sub-Facies Hs. Upper Photo Exhibits Amalgamation of Several HCS Beds. Lower Photo Displays Horizontal Laminations and Form-Discordant Wave-Ripple Cross-Laminations.



Figure 13. HCS Sequence with Rippled Upper Surface Lacking Internal Stratification.

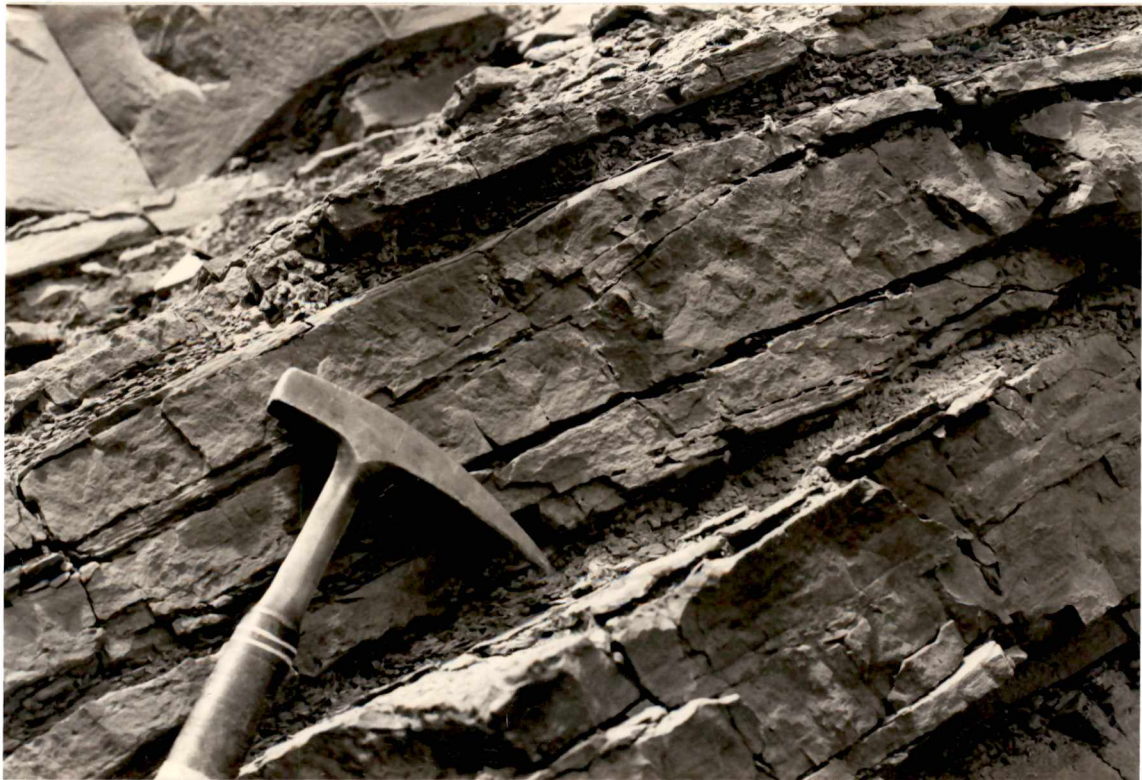


Figure 14. Amalgamation of Thin Sandstone Beds Exhibiting Horizontal and Low Angle Cross-Laminations (HCS?).

(mm-to-cm thick) at the base. The fossil lags are generally composed of brachiopods, crinoid columnals, crinoid stems, trilobite fragments, gastropods, and Tentaculites. Some of the skeletal material has been replaced by hematite and limonite, but not to the same degree as in sub-facies Hm.

The amount of biogenic reworking within the coarser-grained beds ranged from low to moderately high. The bioturbation was concentrated at the tops of beds, within the beds, and rarely at the soles of beds (Fig. 15). In some instances, entire layers are reworked, erasing any primary stratification. The amount of diversity is high, with several varieties of horizontal, inclined and vertical structures (Fig. 16).

Erosive features and load casts on the soles of beds were rare in this sub-facies. Gutter casts and tool marks were documented in a few instances, with the gutters commonly filled with horizontal to low-angle laminations. Rare load casts, on the scale of a few centimeters, were seen. Virtually all the coarser-grained beds were laterally continuous up to 10's of meters or more. Thicknesses of layers varied laterally due to the strong pinch-and-swell nature of these beds (Fig.17).

Intercalated with the coarser-grained beds were light to dark gray, olive-green, and rarely maroon-gray mudstone layers. The mudstone is silty in part, rarely sandy, and may grade into siltstone. The thinly laminated to very thinly bedded layers are internally featureless to horizontally laminated, to rarely low-angle cross-lami-

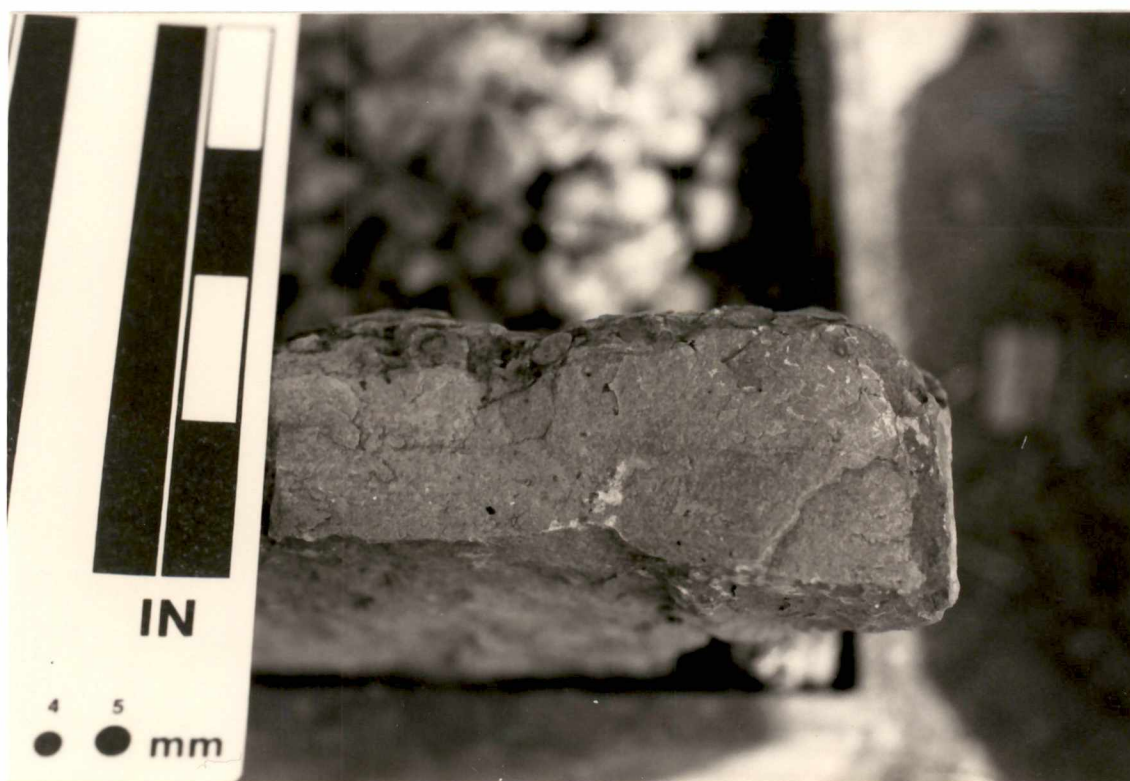


Figure 15. Bioturbation Concentrated at the Top of the Storm Bed.

<u>MORPHOLOGY</u>	<u>DIMENSIONS</u>	<u>TYPE</u>
Horizontal Simple Straight Tubes	5-7mm diameter by 10-50mm length	<u>Paleophycus</u>
	10mm diameter by 40mm length	<u>Paleophycus(?)</u>
	0.25mm diameter by 3-5mm length	<u>Planolites(?)</u>
Horizontal Sinuous Tubes	5mm diameter by 50mm length	<u>Paleophycus</u>
U-Shaped to Irregular Winding Structures	1-2mm diameter by 8-10mm length	<u>Dictyodora(?)</u>
Sub-Vertical Tubes	0.5-1.0mm diameter by 5mm length	<u>Chondrites(?)</u>
Vertical Tubes	0.5-3.0mm diameter 5mm length	<u>Skolithos</u>
	0.5mm diameter by 3-5mm length	Unknown
Vertical Tubes that Flare at the Top	2mm diameter by 10mm length	<u>Monocraterion</u>

Figure 16. Types and Sizes of Trace Fossils in Sub-Facies Hs.



Figure 17. Variation in Thickness of Layers Due to Pinch-and-Swell Nature of the Beds.

nated. The mudrock ranged from very fissile to strongly blocky to hackly. The amount of bioturbation ranged from low to moderate. Most of the bioturbation was unidentifiable, except at the contact with soles of sandstone beds. At these proximities, Planolites, Paleophycus, and possibly Chondrites(?) were identified.

Facies MB

Strata assigned to the maroon-burrowed (MB) Facies occur in the upper part of the section (Fig. 5, p. 12). Maroon brown to gray quartz-arenite, intercalated with maroon-gray to maroon-purple mudstone occur within this facies. Sandstone-to-shale ratios were difficult to determine for this facies due to the extensive amount of cover. Where adequate exposure existed, the proportion of sandstone-to-shale ranged from 4:1 to 1:20, with a 1:8 average. Analysis of facies MB on the east limb of the fold where exposures are better revealed higher sandstone/shale ratios, ranging from 1:5 to 6:1, with a 1:2 average.

The maroon-gray to maroon-purple, to rarely light-green mudstone is silty to rarely sandy. The thin to thickly laminated mudstone is blocky to hackly, massive, very rarely horizontally laminated, and extensively bioturbated. The amount of bioturbation is moderately high and probably precludes fissility. It is sufficiently intense that individual structures could not be identified. A few intervals, where identification was possible, consisted of extremely abundant,

simple straight tubes (1-3mm diameter by 10-50mm length, Planolites?).

One of the more diagnostic features of this interval, besides the bioturbation and maroon color, was the abundance of brachiopods within the mudstone. Brachiopods were collected in this interval and sent to Dr. Boucot (Oregon State University) for identification and age determination. Results from Dr. Boucot's analysis indicate a possible middle Late Llandoveryan age (about C3-C5) based on specimens of Eocoelia and Atrypa reticularis.

Within intervals where the sandstone/shale ratio was fairly low (less than 1:5), siltstone and very fine-grained sandstone lenses occurred. The lenses ranged from 1-10mm in length, and from 2-5mm in thickness. Lenses are featureless to rarely horizontally laminated or low-angle cross-laminated.

Microscopic examination of the gray-brown to slightly maroon-gray calcareous siltstone and silty sandstone reveals an abundance of monocrystalline quartz. These rocks contain subordinate amounts of glauconite, phyllosilicates, opaque minerals, and peloids(?). The dominant cementing agent was sparry calcite with minor amounts of silica. (For a more detailed description, see Appendix 3.)

Sedimentary structures, although rare due to extensive bioturbation, are most commonly horizontal laminations and low-angle cross-laminations. The layers are thinly laminated to medium-bedded (1-160mm, 20-25mm average), with flat to uneven bases. The tops of beds are commonly burrowed; wave-rippled upper surfaces are very rare.

Hummocky cross-stratification and form-discordant wave-ripple cross-laminations were detected in one location at the top of the facies. The soles of beds were commonly reworked into the underlying mudstone and may explain the lack of obvious erosive or loading features. One bed containing gutter casts was detected at the top of the facies.

Biologic evidence includes molds of brachiopods at the base of beds and abundant trace fossils. The amount of bioturbation within the siltstone beds was moderately high. The amount of diversity is high, with several varieties of horizontal and vertical burrow structures (Fig. 18).

Facies AH

Strata assigned to the hematitic-amalgamated hummocky(?) (AH) Facies occur in the middle portion of the Rockwood section (Fig. 5, p. 12). The strata within this facies are hematitic quartz arenite. One of the most diagnostic features of this interval is the complete lack of shale, except in rare instances. Microscopically the maroon-gray, moderately sorted, angular to sub-rounded, silty to very fine-grained sandstone beds are dominated by monocrystalline quartz and skeletal debris. Dominant cementing agents include hematite, sparry calcite, and possibly dolomite (?) (Fig. 19).

Dominant sedimentary structures include horizontal laminations and low-angle laminations (HCS?). The layers are thin to thickly bedded (60-500mm, 100mm average), extremely well-indurated and contain hematite (limonite?)-replaced fossil debris and unaltered

<u>Morphology</u>	<u>Dimensions</u>	<u>Type</u>
Simple, Straight Horizontal Tubes	1-3mm diameter by 10mm length	<u>Planolites</u>
	5-8mm diameter by 20-50mm length	<u>Paleophycus</u>
	0.25-0.5mm diameter by 1-2mm length	Unknown
Horizontal Sinuous Tubes	1-3mm diameter by 10mm length	<u>Planolites</u>
Horizontal Branching Tubes	0.5-1.0mm diameter by 10mm length	<u>Chondrites</u>
Vertical Straight Tubes	0.25-0.5mm diameter by 1-2mm length	<u>Skolithos(?)</u>
Vertical U-shaped Tubes	1-3mm diameter by 5-10mm length	<u>Diplocraterion(?)</u>
Sub-vertical Tubes	0.25mm diameter by 5-10mm length	<u>Chondrites(?)</u>

Figure 18. Types of Trace Fossils in Facies MB.



Figure 19. Typical Lithology of Facies AH Composed of Quartz Grains, Hematite Replaced and Unreplaced Bioclasts, Hematite Cement, and Calcite Cement. Field of View from Left to Right is 2mm.

skeletal debris, which define laminations. Almost all of the sandstone beds are amalgamated, and lack any intervening shale. A few flat-based sandstone beds with flat upper surfaces contain discontinuous shale layers, and these are found at the bottom of the facies. The shale is gray to dark gray, silty, thin to moderately laminated, internally massive, and fissile. Bioturbation appears absent throughout this entire facies, except in a few rare instances where the shale is slightly blocky. Graded beds are common, exhibiting fining-upward trends.

Facies QA

Strata assigned to the quartz arenite, high-angle cross-stratified (QA) Facies are those at the base of the Rockwood Formation (Fig. 5, p. 12). In general, the strata are calcareous sandstone, siltstone, and shale. These rocks can be divided up into two main types of deposits: a basal sandstone bed, and a trough cross-laminated/ ripple cross-laminated sequence.

The base of the Rockwood Formation is characterized by a thick (1.35m), tan to orange-brown, silty to very fine-grained calcareous sandstone. Capping this basal deposit is a thin (2-4cm) lag of reworked material (Fig. 20). Microscopically the lag is composed of quartz grains, lithic fragments, ooids (chamosite and phosphate), phosphatic fossil fragments and grains, glauconite pellets, and hematite-replaced skeletal debris. The phosphate grains range from angular to well-rounded and are partially replaced by calcite. In



Figure 20. Photo-micrograph of Basal Deposit of Reworked Material, Composed of Quartz and Phosphate Granules, Lithic Fragments, Hematite Cement, and Dolomite Cement. Field of View from Left to Right is 2mm.

addition, the phosphatic fossil fragments (brachiopods) and ooids were also partially replaced by calcite. Cement types include sparry calcite, dolomite, hematite, and possibly siderite(?) (see Appendix 3 for detailed thin-section description). No primary sedimentary structures are preserved in this basal silty sandstone due to extensive biogenic reworking (Fig. 21).

Above the basal sandstone bed lies a 9.25m bioturbated interval that contains rare physical structures. The ones observed were horizontal laminations, trough cross-laminations, and ripple cross-laminations. Trough cross-laminations and horizontal laminations occur in the lower 4.25m of the interval, whereas ripple cross-laminations and horizontal laminations are present in the upper 5.0m of the sequence. Microscopically, these extremely calcareous silty sandstone beds are composed primarily of quartz, with minor amounts of phosphate grains, glauconite pellets, phyllosilicates, and other accessory minerals (see Appendix 3 for complete thin-section description).

The light gray to brown sandstone beds are thin-to medium-bedded (10-200mm, 35-40mm average), silty to medium-grained, and exhibit flat bases and burrowed tops. The extensive amount of bioturbation is dominated by horizontal, simple straight tubes (0.5-1.0mm diameter by 4-5mm length, Planolites?) with subordinate amounts of sub-vertical and vertical straight tubes (0.5-1.0mm diameter by 4-5mm length, Skolithos?).



Figure 21. Bioturbated Basal Sandstone Capped by a Thin Lag of Reworked Material.

The interbedded mudstone is very calcareous, gray to brown, silty, thin to medium-laminated, featureless, blocky, and moderately bioturbated. Siltstone lenses are present within intervals with low sandstone/shale ratios, and are commonly burrowed. Disseminated throughout the mudstone and above the basal lag zone are phosphate granules that are angular to well-rounded and phosphatic fossil fragments. The phosphatic material appears to have been biogenically reworked.

Facies FC

Strata assigned to the ferruginous-conglomeratic, high-angle cross-stratified (FC) Facies are those near the middle of the Rockwood Formation (Fig. 5, p. 12). The strata within this facies are sublitharenite, ferruginous sublitharenite, calcareous sublitharenite, ferruginous litharenite, and ferruginous trilobite-echinoderm wackestone-packstone lithologies. This 14.05m interval within the middle of the Rockwood represents a thickening-and coarsening-upwards sequence that culminates in a thick conglomeratic and bioclastic ironstone (Fig. 22). The dominant sedimentary structures of these green-gray, maroon, maroon-gray, maroon-orange layers are trough cross-laminations, form-discordant wave-rippled upper surfaces, and current(?) -rippled upper surfaces. The sandstone layers are thinly laminated to thickly bedded (2-500mm, 40-50mm average), and have flat to wavy bases.



Figure 22. Conglomeratic Ironstone Bed Capping Facies FC
(Looking Down at Bedding Surface).

The bedding patterns vary from wavy, lenticular, and flaser, to amalgamated. They are related to the sandstone/ shale ratio. The proportion of sandstone-to-shale varies in this facies from 10:1 to 1:1, with an average of 5:1. Lenticular bedding is characteristic of low ratios (1:8-1:10), wavy bedding is characteristic of moderately high ratios (2:1 to 10:1), and flaser bedding is characteristic of moderately high to high ratios (5:1 to 10:1). Amalgamated bedding is common in moderate to high proportions of sandstone to shale, and becomes increasingly dominant higher in the interval (Fig. 23).

One of the more striking features of these immature to sub-mature deposits are the abundant gray to maroon mud clasts. The size of these clasts varies from 1mm to 6mm in length. The mud clasts are more common in the coarser-grained layers, usually concentrated at the tops of beds and along foresets.

The amount of bioturbation seems to be a function of the amount of sand in the interval. In general, biogenic reworking is more common in the shale dominated sequences. In contrast, sandstone dominated intervals are typically devoid of burrows. Hence, the amount of bioturbation for the facies varies from very low to extensive. The amount of diversity is high, with several varieties of horizontal and vertical structures (Fig. 24).

Capping this interval is a 0.2m thick ironstone containing two distinct lithologies. The majority of the bed (0.15m) is composed of a calcareous litharenite, whereas the top 0.05m consists of a trilobite-echinoderm wackestone-packstone. In general, microscopic analy-



Figure 23. Amalgamation of Bedding within Facies FC.

<u>Morphology</u>	<u>Size</u>	<u>Type</u>
Simple, Straight Horizontal Tubes	1-3mm diameter by 10mm length	<u>Planolites</u>
Sinuuous to Branching Horizontal Tubes	15-20mm diameter by 50-60mm length	<u>Paleophycus(?)</u>
	1mm diameter by 10-50mm length	<u>Planolites</u>
Cone-Shaped Vertical Structures	20mm diameter by 40mm length	<u>Trichophycus(?)</u>
Straight to Slightly Sinuous Vertical Tubes	3-8mm diameter by 35-80mm length	<u>Skolithos</u>

Figure 24. Types and Sizes of Trace Fossils in Facies FC.

sis (see Appendix 3) showed these rocks to contain quartz (monocrystalline and polycrystalline), sedimentary rock fragments, hematite-replaced skeletal debris, phosphate grains, glauconite pellets, chamosite ooids, carbonate cement, and hematite cement. The iron content was high enough for them to be called ironstones. Many of the other beds within this facies also contained enough iron (in the form of hematite, chamosite, glauconite, limonite, and possibly siderite?) to be considered ironstones.

Absent to rare in this facies are clay drapes (rare), which are only present in the lower part of the sequence, reactivation surfaces (absent), herringbone cross-bedding (absent), and ripple cross-laminations (absent). Asymmetrical to symmetrical ripples are prominent external features, yet never exhibit visible ripple-laminations. In contrast, trough cross-laminations are prominent features, commonly defined by quartz granules and mud clasts.

Mudstone is common in the lower to middle portions of the sequence, and is completely absent in the upper 1.0m. The mudstone is dark gray to tan, to olive-green/gray, silty to rarely sandy, thin-to medium-laminated, featureless to rarely horizontally laminated, and fissile to blocky. Extensive amounts of bioturbation within the mudstone characterizes intervals with low sandstone/shale ratios (less than 1:1). Sequences with greater amounts of sandstone are characterized by non- to weakly bioturbated, fissile shale. All of the discontinuous shale lenses are non-bioturbated. Enclosed

within mudstone-dominated intervals are very fine- to medium-grained sandstone lenses which are commonly rippled.

CHAPTER III

FACIES DISCUSSION

General Characteristics

The strata comprising the Rockwood Formation at Whiteoak Mountain represent the interaction of several physical processes. The majority of the section was dominated by fairweather mud sedimentation that was punctuated by storm deposited siltstone, sandstone, and limestone beds. These were deposited below fairweather wave base but above storm wave base. Subordinate amounts of wave (fairweather and storm) and tidal deposits were present, indicating deposition above fairweather wave base. Figure 25 summarizes the depositional conditions postulated for each Rockwood facies. The iron sedimentation was associated with the major regressive phase of the Formation, when sea-level was at a minimum. Biologic activity was low throughout most of the section, which may be a function of oxygen deficient conditions. Analysis of the individual strata and paleocurrent data indicate that the storm flows were generally of a combined flow nature, probably representing geostrophic flows.

Depositional Conditions of Facies H

The strata assigned to Facies H represent an alternation between fairweather deposition (mudstone) and storm deposition (sandstone and bioclastic limestone). The facies was divided, based on percentage of sandstone, into a mudstone-dominated (Hm) sub-facies and a sand-

FACIESINTERPRETATION

Heterolithic (H)

Hm = Mudstone-dominated
Sub-faciesHs = Sandstone-dominated
Sub-faciesFairweather mudstone. Storm
deposited sandstone, silt-
stone, and limestone.

Maroon-Burrowed (MB)

Fairweather mudstone. Storm
deposited sandstone and silt-
stone.

Amalgamated Hummocky (AH)

Shoreface storm layers.

Ferruginous-Conglomeratic (FC)

Wave and tidal deposits.

Quartz-Arenite (QA)

Upper Ordovician/Lower Silurian
transgression.

Figure 25. Interpretation of Facies.

stone-dominated (Hs) sub-facies. Sedimentary structures were similar in both sub-facies, yet subtle differences were detected due to the proximal nature of Hs and the distal nature of Hm.

Sub-facies Hm - Analysis of the individual strata revealed a great amount of variability within the sandstone/limestone beds. Figure 26 displays the typical sedimentary structures seen within this sub-facies. The succeeding analysis will concentrate on analyzing the internal sedimentary structures and upper and lower bedding surface features in terms of causative depositional processes.

One of the more common features among the sequences in Figure 26 are the sharp, flat, erosive bases. Such erosive bases are indicative of high flow velocities (Hunter and Clifton, 1982), and the introduction of layers of coarse material into a quiet muddy environment implies that a strong flow deposited these layers (Hamblin and Walker, 1979). Aigner (1985) stated that these types of basal contacts are indicative of storm flows.

A common and characteristic feature of this sub-facies (Hm), are graded beds with fossil lags at the base (see sequences 1 and 5 in Fig. 26). The lags contain sub-rounded to well-rounded, granule-size quartz grains and abraded skeletal material of a mixed faunal association. Beds typically fine upwards into very fine sand and silt. Aigner (1985) discussed sharp-based beds with basal shell lags and attributed their formation to event deposition. Swift and Niedoroda (1985) concluded such layers are common in shelf settings. Several authors documented granule lag deposits within presumed storm-

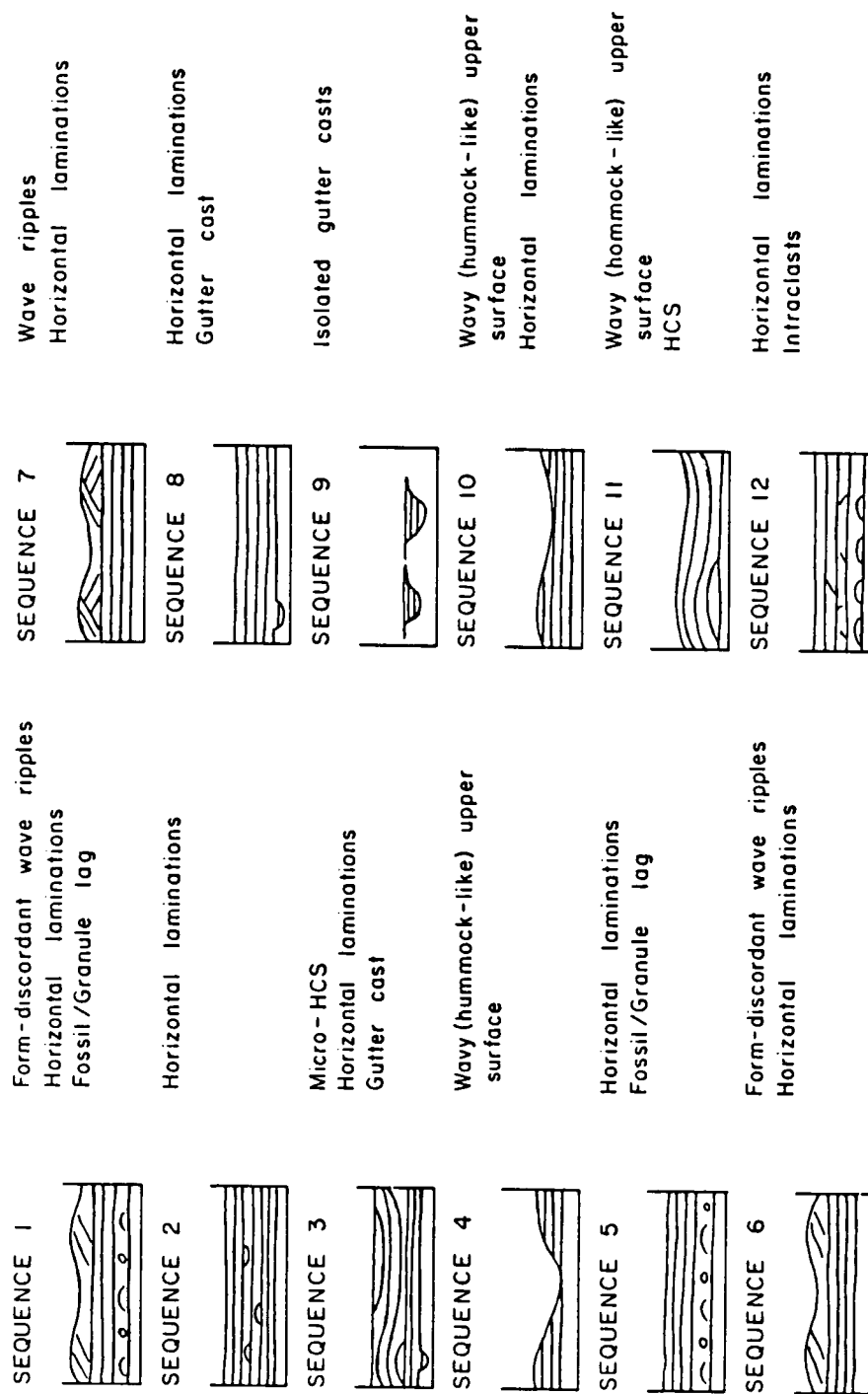
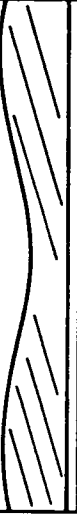
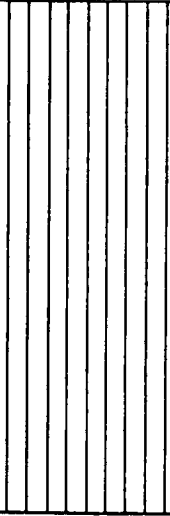


Figure 26. Typical Sedimentary Structures within Sub-facies Hm.

emplaced sandstone beds (Walker et al., 1983; Kumar and Sanders, 1976; Brenchley and Newall, 1982) and granule-plus-allochthonous shell lags, found in storm beds from a carbonate environment (Aigner and Reineck, 1982; Aigner, 1985; Kreisa, 1981).

Much can be learned about the nature of the depositing current of these graded beds from the vertical succession in grain size and sedimentary structures. The upward decline in grain size indicates deposition from a decaying (weakening) current. The upward sequence of structures (Fig. 27) also implies a declining flow. The significance of graded beds will be analyzed further when the depositional conditions of sub-facies Hs are discussed.

By far the most common sedimentary structure for the entire sub-facies were horizontal laminations. Several layers were composed entirely of horizontal laminations (see sequence 2, Fig. 26) or in conjunction with other structures such as micro-HCS (sequence 3), wave ripples (sequence 7), form-discordant wave ripples (sequence 6), gutter casts (sequence 8 and 9), hummock-like beds (sequence 10), and intraclast beds (sequence 12). Mount (1982) investigated the importance of horizontal laminations which were deposited by fairweather and storm processes. He lists several explanations for the parallel laminated sands: (1) as a product of plane-bed deposition under high-flow regime; (2) as a result of sedimentation of suspension clouds in current velocities below that necessary to generate ripples; and (3) as a plane-bed phase associated with sediment transport at very low current velocities. In the case of the Rockwood

TYPICAL GRADED BED	BEDFORMS	FLOW REGIME	SEDIMENTATION RATE
	PELITIC DIVISION	LAMINAR FLOW	VERY LOW
	FORM-DISSIMILAR WAVE RIPPLES	LOWER REGIME	MOD - LOW
	PLANAR LAMINATIONS	UPPER FLOW REGIME	HIGH
	FOSSIL/GRANULE LAG	RE-DEPOSITION	VERY HIGH
	PELITIC DIVISION	LAMINAR FLOW	VERY LOW

Declining Flow

Figure 27. Upward Sequence of Structures Indicates Declining Flow.

Formation, the association of the horizontal laminations with sharp, erosive bases that commonly contain gutter casts or fossil/granule lags implies that depositional currents must have been at high velocities. The unidirectional upper plane bed condition for 0.1mm sand requires a minimum shear velocity at the bed on the order of 100cm/sec (Dott and Bourgeois, 1982).

One of Dott and Bourgeois' (1982) variants to their idealized HCS sequence is micro-HCS. The difference between HCS and micro-HCS is a matter of scale. For the purposes of this paper, any HCS bed with a wavelength (distance from hummock to hummock) of less than 1m was classified as micro-HCS (Fig. 28) and any above 1m was classified as HCS. The difference between the two types may be a function of storm intensity, distance from sand source, or water depth. Typical wavelengths of micro-HCS beds ranged from 0.185m to 0.56m, with 0.21m average. Heights of hummocks ranged from 3-6cm, with a 4cm average. Micro-HCS was detected either composing entire layers (sequence 1, Fig. 26) or in combination with horizontal laminations (sequence 3). Micro-HCS beds always have a lenticular character and commonly pinch-out. The presence of hummocky stratification indicates that combined (oscillatory and unidirectional)-flow storm currents were probably responsible for storm-bed formation. It is speculated that the abundance of micro-HCS (and lack of HCS) is a function of the more distal nature of sub-facies Hm.

Both wave and form-discordant wave-rippled upper surfaces are rare within this sub-facies, which may be due to the decreasing



Figure 28. Micro-HCS Bed.

effects of oscillatory currents. When ripples are present, they are symmetrical in form and commonly do not exhibit any internal structures. When internal laminations are present, they commonly consist of asymmetrical cross-laminations and rarely symmetrical cross-laminations. Typical ripple spacings (wavelengths) range from 65mm to 115mm, and typical ripple heights from 3-15mm. The vertical form index (length/height) ranged from 7.33 to 25. The crests of the ripples are generally straight and tend to bifurcate. Ripple crests also exhibit an interference pattern, with crests of ripples virtually perpendicular to each other (Fig. 29).

Calculations have been performed on wave-formed ripples to estimate paleo-ocean condition (wave-length, wave-period, water-depth) (e.g., Komar, 1974; Harms, 1969). For these calculations to be valid, the vertical form index must be less than 7.5. If the value is greater than 7.5 (as it is for the majority of ripples observed in the Rockwood) this implies that a strong unidirectional component has influenced the wave ripples (Aigner, 1985). The predominance of unidirectional ripple cross-laminations also supports a unidirectional component modifying or interacting with oscillatory flows that produced the wave ripples.

The importance of these form-discordant wave ripples is that they suggest deposition by combined-flow currents. The asymmetrical cross-laminations indicate sediment transport under unidirectional flow, whereas the molding of the ripples into a symmetrical form implies oscillatory flow. Such combined-flows are common during



Figure 29. Morphology of Ripple Crests. Upper Photo Displays Straight Crested Ripples. Lower Photo Exhibits an Interference Pattern.

storms when storm waves interact with the sea floor and are superimposed on unidirectional currents (Aigner, 1985; Swift and Niedoroda, 1985).

One of the more subtle features of these storm beds were gray to dark-gray intraclasts (1-5mm in size), generally concentrated in the lower half of the beds. Typically these intraclasts were associated with beds containing fossil/granule lags. These basal lag zones show evidence of abrasion, and appear to be allochthonous. Such transported accumulations at the lowest part of sharp-based beds are evidence for storm deposition (Kelling and Mullin, 1975). A common feature of these storm beds are intraclasts of the substrate that have been rippled up during storm emplacement (Walker, 1985). Analysis of the intraclasts within the Rockwood storm beds indicate a lithologic similarity to the underlying mudstone strata. These beds are commonly graded, and fine upwards into very fine siliciclastic sand and silt. These beds are identical to the graded beds described earlier in this section aside from the presence of intraclasts.

One of the more characteristic features of sub-facies Hm were gutter casts, which were named by Whittaker in 1973 for a scour-and-fill structure. The gutter casts are thought to have formed by intense substrate scour produced by helicoidal fluid flow at the bed. When viewed in cross-section, they are generally asymmetrical to symmetrical in form (Fig. 30). The trends of gutters are typically straight to sinuous (meandering), and internally they are commonly massive, horizontally laminated, or low-angle cross-laminated.



Figure 30. Symmetrical Gutter Cast in Cross-Section.

It has been documented in the literature that gutter casts are associated with both carbonate and siliciclastic storm deposits (Walker, 1985). Cotter (1983) documented gutter casts in the "Middle" Silurian of central Pennsylvania, and concluded that they resulted from intense scouring of the substrate by storm-generated flows. Gutter casts within sub-facies Hm were commonly associated with wave ripples at the tops of beds. The trend of the ripple crests were on rare occasions perpendicular to the axis of the gutter, which would indicate that oscillatory flow-components may have been involved in the formation of the gutters (Aigner, 1985).

Other erosive features include flute casts, tool marks and groove casts. These features were extremely rare and were only detected in a few instances. The flute casts (Fig. 31) formed through local scouring by turbulent eddies associated with intense bottom currents, and are typical of turbidites, fluviatile sandstone and a few other sandstone sequences (Tucker, 1982). Groove casts are elongate ridges developed on the undersides of sandstone beds, and generally form through the infilling of grooves cut by objects dragged along by a current. Tool marks were difficult to identify and commonly occurred as small impressions on the undersides of the storm beds. Objects making the marks may have been mud clasts, or possibly skeletal material.

Sequence numbers 10 and 11 exhibit hummock-like wavy beds which contain micro-HCS or horizontal laminations. All of the skeletal wackestone-packstone beds exhibit this bedding nature, in addition to

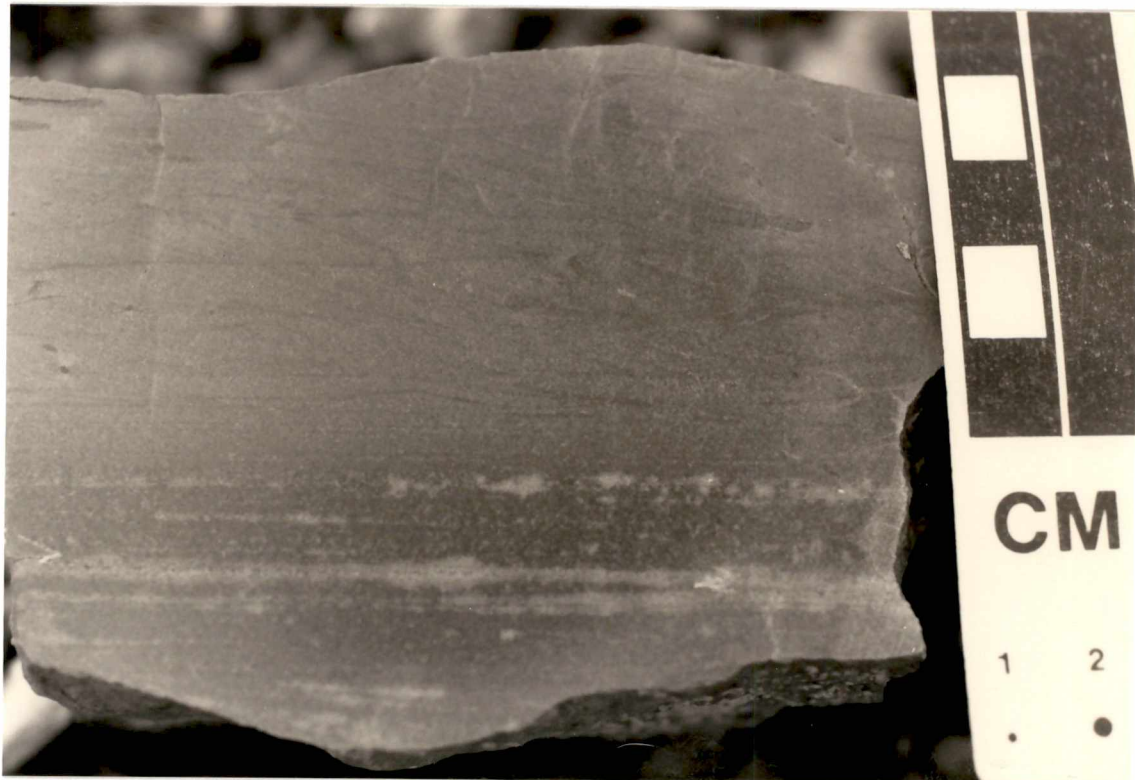


Figure 31. Flute Cast at Base of Sandstone Bed. Followed Upwards by Horizontal Laminations, Climbing Ripple Forms at Top of Bed, and Form-Discordant Wave-Ripple Profile.

many of the siliciclastic beds. The bases are generally flat, to rarely undulatory, and the upper surfaces tend to be broadly wavy. Several of the beds pinch-and-swell very strongly and even pinch-out altogether, resulting in the appearance of isolated hummocks enclosed in mudstone (Fig. 32). Similar hummock-like structures were described by Cotter (1983), who interpreted them to be the result of storm flows. Cotter explained the hummock-like surfaces in the following manner: As storm flows transport sediment and bioclasts to deeper water, flow intensity eventually begins to decrease, resulting in a sequence of bedforms. The initial aggrading sediment will have an undulatory surface of hummocks and swales. If the flow intensity and deposition of sediment were to end quickly, the result would be wavy, hummock-like beds analogous to sequence 10 and 11 (Fig. 26, p. 51).

The dominant lithology of sub-facies Hm was fissile to rarely blocky mudstone. The depositional environment of the mudstone was placid and quiet. Little or no agitation occurred within this environment, except the infrequent storm flows. A few body fossils were present and included crinoids and brachiopods, which may have been transported into this environment. Both body fossils and trace fossils were scarce, leading to speculation that oxygen may have been in limited supply. Many of the storm beds lacked erosive features which implies either the flows were not competent enough to scour, or the substrate was too cohesive. The time interval may have been great between storm flows (hundreds or thousands of years), thereby allowing ample time for the mud to dewater and solidify.



Figure 32. Hummock-Like Bed Enclosed in Mudstone.

Sub-Facies HS - The depositional conditions of sub-facies Hs are similar to Hm, but represent a more proximal, shallower water setting. The storm beds in sub-facies Hs commonly contain HCS, which is generally associated with horizontal laminations and rippled bedding. Amalgamation of storm beds is present, and typically involved two or three layers at the most. Other sedimentary structures include load casts, intraclastic beds, convolute laminations, and fossil/granule lags. Beds with hummock-like upper surfaces were also present, in addition to beds that abruptly pinch-out.

HCS is a very common sedimentologic feature of this sub-facies and is represented by the five different sequences shown in Figure 33 (sequences 1, 2, 3, 4, 14). The vertical succession of structures seen in sequences 1, 2, 3 and 4 resemble the idealized HCS-sequence of Dott and Bourgeois (1982). Two of the sequences begin with horizontal laminations (sequence 2 and 3), which was one of the variants of their model and was a division stressed by Walker et al, (1983) in their model.

The particular association of sedimentary structures within the models and sequences 1, 2, 3 and 4 (Fig. 33) reveal a vertical succession of structures indicating deposition from waning flow. The sharp-based soles of the beds indicate an abrupt change from mud to sand, more than likely the result of initiation of high velocity, competent current flow. According to Brenchley (1985), there appear to be two stages to the formation of a HCS-bed: An initial phase of transport and deposition; and a second phase where the sand is

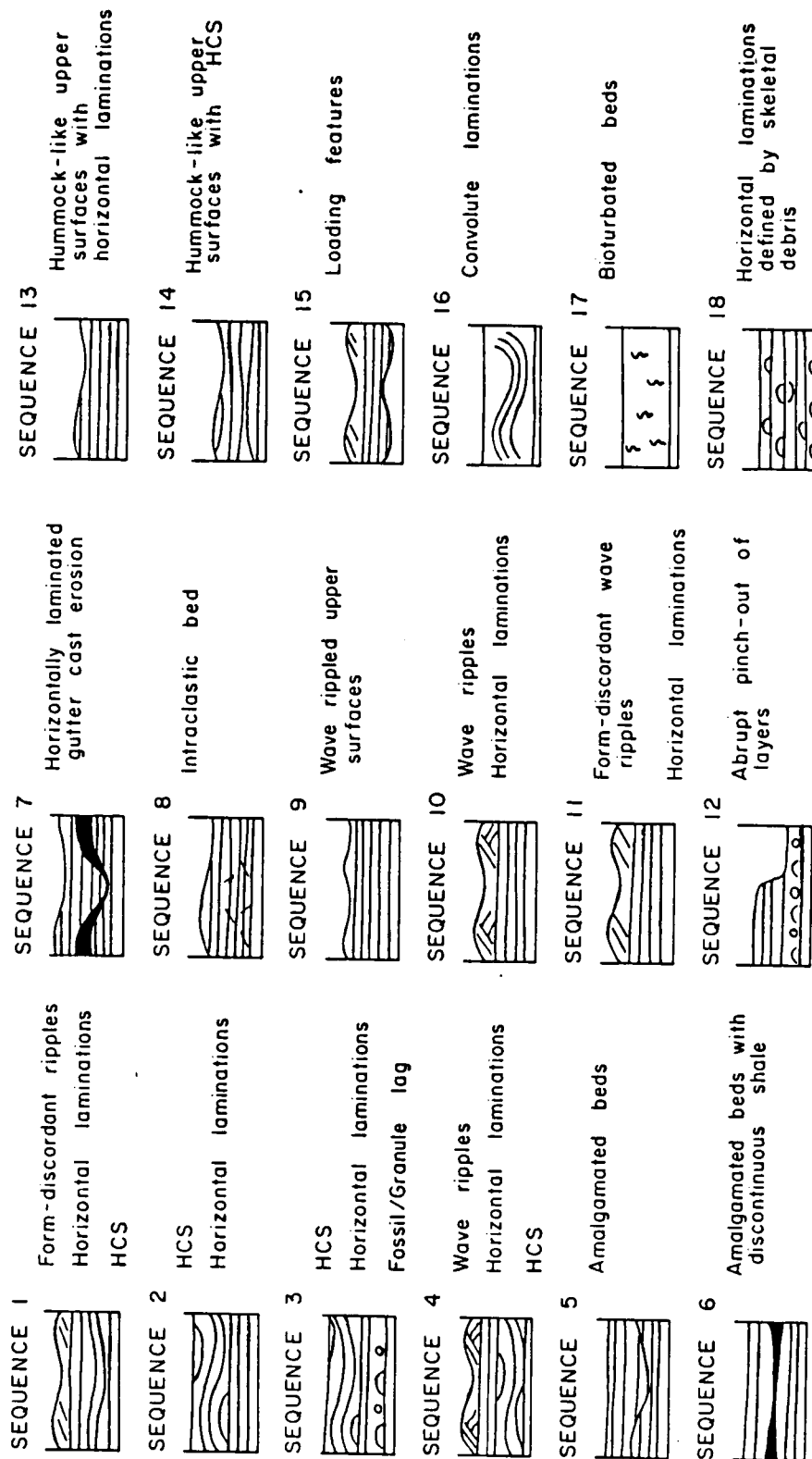


Figure 33. Typical Sedimentary Structures within Sub-facies Hs.

reworked by waves. Erosional structures and lag deposits are common features at the bases of beds. Succeeding the basal deposits are planar laminations (in Walker's model and sequences 2 and 3, Figure 33) which probably represent rapid deposition from suspension. The next overlying laminae are hummocky cross-stratified, with slopes of hummocks commonly less than 15° . The HCS division commonly commences with an erosion surface cutting into the underlying horizontal division. The erosional hummocky surface is typically draped with nearly concordant laminae. The laminae generally thicken from the domes into the troughs, resulting in the filling of depressions. The dip of the laminae decreases upwards until the hummocky morphology is completely lost.

However, according to Brenchley (1985), there are hummocks that appear to have been formed by accretion rather than erosion. The differentiating factor of these hummocks is the laminae thicken into crests and not into troughs. Many of the hummocky beds within sub-facies Hs may represent formation by accretion. Laminae thickening into crests were exhibited in Figure 34.

Above the HCS interval, typically there is a planar-laminated division that represents deposition on a flat surface formed when troughs between hummocks have been filled. This feature was not always seen in the Rockwood (sequence 2 and 3, Fig. 33), and may be the result of flow intensity and sediment aggradation abruptly ending, leaving broadly wavy surfaces. Rippled upper surfaces were not



Figure 34. Hummocky Sequences Formed by Accretion? (Laminae Thickens into Crests).

always present in the Rockwood sequences, and when they were they commonly were combined-flow ripples. Only rarely were upper surfaces gradational into overlying mudstone and siltstone due to bioturbation.

The complex nature of the HCS-sequence is indicated by features indicative of wave activity and unidirectional currents. The presence of HCS and lack of angle-of-response cross-bedding indicates deposition above storm wave-base, but below fairweather wave-base. The abundance of hummocky strata is interpreted by Swift and Niedoroda (1985) to represent storm-flow regimes where the wave-orbital current component is high relative to the mean-flow component. This is a change from sub-facies Hm, in which HCS was a minor constituent, indicating that the influence by wave-orbital currents was reduced. Further evidence for a decrease in effects by oscillatory currents in Hm is the rarity of wave ripples. In contrast, sub-facies Hs contains the highest percentage of wave ripples, indicating an increased importance of oscillatory currents.

Sequences 5, 6, and 7 (Fig. 33) represent minor (8-12cm thick) amalgamated intervals of varying types. In sequence 5, amalgamation and erosion was so intense that no intervening shale was preserved. In sequence 6, amalgamation and erosion were less intense, resulting in discontinuous shale layers. Sequence 7 represents intensive scour and erosion by gutter casts down through the shale and into the underlying sandstone bed. Internal structures were dominated by horizontal laminations. Amalgamated storm deposits have been described

by Aigner and Reineck (1982), who stated they indicate shallow-water conditions and/or closer proximity to shore. The amalgamation of storm deposits have been known to form in both proximal and distal facies (Brenchley, 1985). Amalgamation of beds in proximal facies is due to higher frequencies of storm events, whereas in more distal facies they result from lack of fairweather mud deposition. Due to the more proximal nature of Hs (compared to Hm), the amalgamation of bedding indicates shallower, more nearshore conditions where the frequency of storm events was probably higher.

Abruptly pinched-out layers were rare and quite striking in the field (Fig. 35). Beds of this nature (sequence 12, Fig. 33) were typically graded and contained extremely iron-rich fossil/ granule lags at the base. As these beds were followed laterally, they abruptly decrease in thickness within a matter of few centimeters. Similar features have been described by Cotter (1983), who terms these terminated-and-sculpted beds. Cotter identified the terminated/sculpted beds as of storm origin, and attributed the abrupt thickness changes to storm erosion. The bed was probably unconsolidated and partly eroded and sculpted before deposition of the overlying mudstone.

The amount of graded bedding in sub-facies Hs was not nearly as abundant as in sub-facies Hm. Intraclastic beds, which are generally associated with the graded beds containing fossil lags, also decreased in abundance. It has been documented that the amount of graded bedding should decrease in an onshore direction (Aigner and

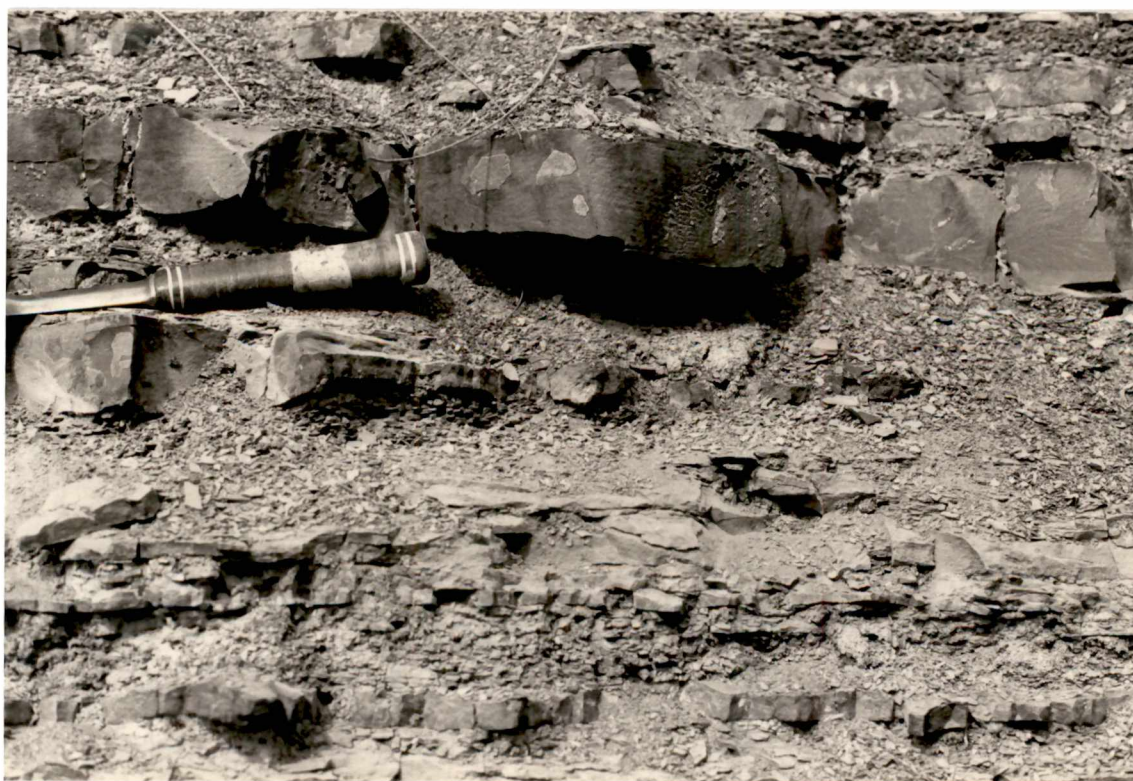


Figure 35. Abruptly Pinched-Out Layer Directly Below Hammer.

Reineck, 1982). This trend appears evident within sub-facies Hs and Hm, in which graded beds definitely increase in the more distal sub-facies Hm.

Graded shelf beds have been described by Swift and Niedoroda (1985) as consisting of very fine to fine sand that fines upward. They attributed these shelf beds to be the result of either tidal or storm flows. Analysis of the sedimentary structures within graded beds indicates the currents were of a combined flow origin. However, the absence of hummocky stratification suggests that the ratio of the wave-orbital current component to the mean-flow component was very low. The abundance of graded bedding and lack of HCS in a sequence indicates an approximate position on the marine shelf. Swift and Niedoroda have devised a model that shows characteristic assemblages of strata which change with distance from the source of the material. Figure 36 incorporates Swift and Niedoroda's (1985) model, and shows the distal position of graded beds relative to cross-beds and hummocky-beds. Such a diagram can be applied to the Rockwood Formation in which sub-facies Hm is characterized by abundant graded bedding and sparse hummocky bedding, implying a distal nature for it, whereas sub-facies Hs contains abundant hummocky beds and rare graded beds, indicating a more proximal position for this zone.

The soles of the storm beds were not exclusively flat, but in rare cases exhibited load casts. As can be seen from sequence number 15 (Fig. 33, p. 65), many load casts coincided with overlying wave ripples. The presence of load casts does not indicate any particular

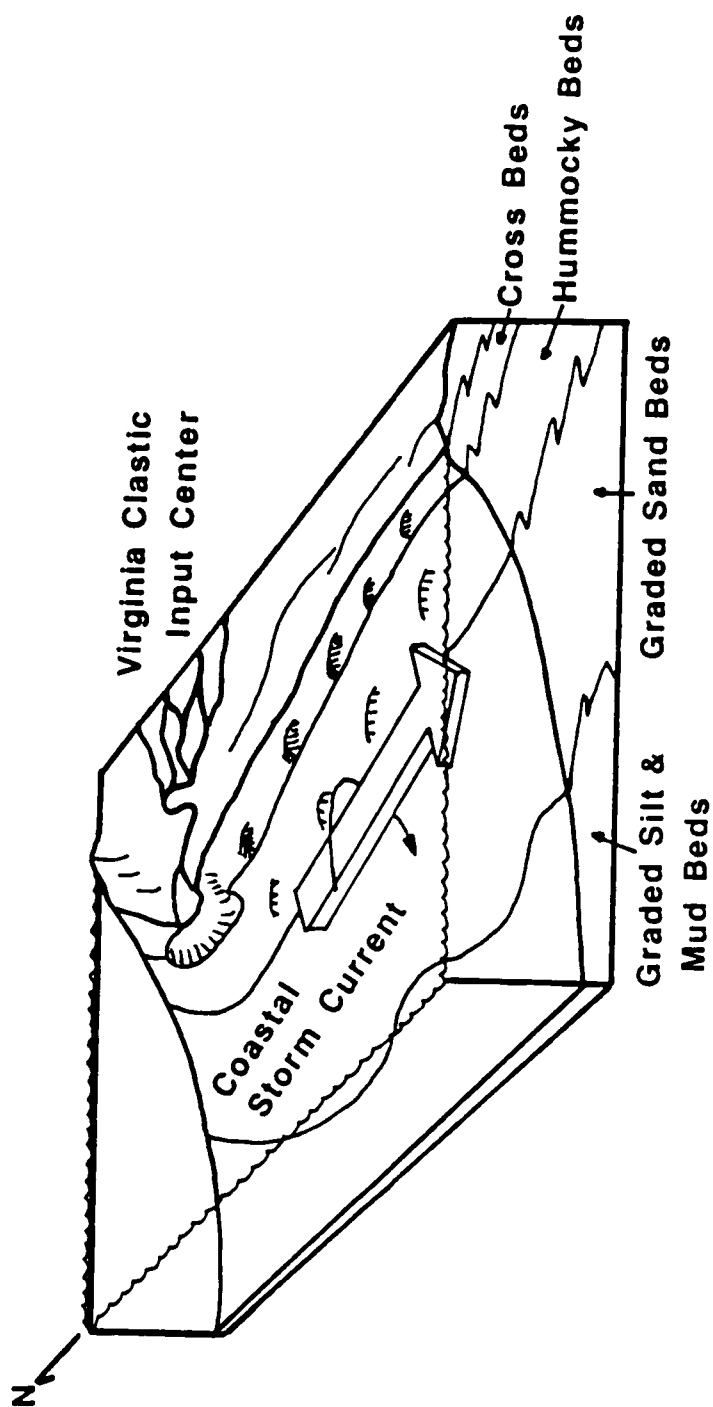


Figure 36. Characteristic Assemblages of Strata which Change with Distance from the Source.
(Driese et al., 1986b; in preparation).

environment. They seem to form when sand is deposited on a water-saturated hydro-plastic layer (Pettijohn et al., 1973). They are common features in turbidites, but do not occur on every bed. Whether or not they form appears to be a function of the condition of the underlying layer. If there is a significant time elapse between successive sand depositional events, the underlying mudstone will dewater and become cohesive enough to prevent the load casts from forming. This may explain the erratic distribution of sandstone layers with loading features in sub-facies Hs. Similarly the rarity of load casts in sub-facies Hm may be a function of the cohesiveness of the mud due to less frequent storm events or thinner nature of the sandstone beds (less of a load to cause deformation).

Horizontal laminations are extremely common in sub-facies Hs, and are present in most of the sequences in Figure 33, p. 65. A common feature of inner and middle shelf environments are wave-formed horizontal laminations. Such laminations result when wave-orbital flow encounters the bottom during storms (Tillman, 1985). They appear to be very similar to HCS, but are on a much larger scale. They are commonly thinly bedded and may be burrowed in part. A dominant feature of these layers, which was described by Tillman (1985) and is also present in many Rockwood sandstone beds, are thin layers of shell hash scattered throughout the bases of beds. Much of the skeletal debris in the Rockwood defines laminations, and is commonly composed of crinoids and brachiopods, and to a lesser extent gastropods, trilobites and molluscs. These horizontally laminated

beds with abundant skeletal debris are common in both sub-facies Hm and Hs, and appear to be additional evidence for storm deposition on the Rockwood shelf.

A very problematical structure was detected in some of the sandstone beds, which was difficult to explain. Figure 37 shows this structure, which may represent convolute laminations. The convolutions have affected the laminations within the bed, but not the bed itself. The structure seen in Figure 37 appears to be a set of folds, with synclines and anticlines. However, they are not folds in the normal sense of being due to compression, etc. The presence of convolute laminations indicates some kind of internal readjustment of material has occurred, in a quick or near-quick condition (Pettijohn et al., 1973). Convolute laminations are typically formed in sediments that have been rapidly deposited (Leeder, 1982). If the structure present in Figure 37 does represent convolute laminations, it indicates these sandstone beds were rapidly deposited and were highly fluidized.

Wave-rippled and form-discordant wave-rippled upper surfaces reached a maximum in sub-facies Hs. According to Brenchley (1985), the abundance of wave ripples indicates a proximal position relative to the sand source. Aigner and Reineck (1982) have documented that wave ripples reach an "optimum" in a zone they termed the transition facies, which in their study occurred in 7-15m of water depth. From this zone seaward wave ripples decrease in abundance due to the decreasing effects of oscillatory currents with increasing depth.



Figure 37. Convolute Laminations within Storm(?) Emplaced Sandstone Bed.

Landward of the transition zone, wave-ripple percentage decreases due to the increased erosion and amalgamation of storm layers.

Hummocky upper surfaces were present in Hs, as they were in Hm. The only difference between the two sub-facies was that the hummocky upper surfaces in Hs were capping thicker beds. Starved hummocks which were characteristic of Hm, were absent in Hs. This is probably due to a greater amount of sand, which is also a function of greater proximity to the source.

The last bedding sequence to be examined includes bioturbated beds that lack any primary structures. Faint laminations were detected in a few cases, and were commonly horizontal laminations. The thin bioturbated beds were always associated with storm sandstone beds. This association indicates the biogenic reworked beds may also be storm sandstones that have subsequently been reworked by fair-weather bioturbation activity.

The intervening mudstones were generally lacking in bioturbation, which was manifested by the fissile nature of the lithology. Byers (1974) studied shale fissility and concluded it is related to the parallel orientation of mineral grains in the rock fabric. Normal marine rocks should lack fissility due to bioturbation, whereas, lifeless marine mudrocks should exhibit good fissility due to lack of burrowing and preservation of particle alignment. Rare stratigraphic intervals did occur in which the mudstone was blocky and had lost all traces of fissility. This indicates that there were times when environmental parameters were conducive for metazoan life.

But in general, both trace fossils and body fossils were lacking from this normally quiet, placid (relatively oxygen depleted?) environment.

Depositional Conditions of Facies MB

Facies MB represents the most heavily burrowed interval in the entire Formation. Primary sedimentary structures and bedding surfaces were commonly obscured by biogenic activity. Even though information in the form of physical structures was lacking, the facies is interpreted to represent an alternation between fairweather deposition (mudstone) and storm deposition (silty-sandstone). Dominant sedimentary structures which were detected included horizontal laminations, low-angle cross-laminations (HCS?), and wave-rippled upper surfaces. Where undisturbed by biogenic activity, the soles of most beds were sharp and flat, lacking in any erosive features. The presence of sharp-based silty-sandstone beds indicates that a sudden change from mud deposition to silt and sand occurred and may be attributed to high velocity and highly competent currents. However, the lack of scour features implies that the currents which deposited the coarser grained beds were not strong enough to scour the muddy bottom and/or the muds were cohesive enough to resist any erosion. The tops of beds were commonly burrowed, to rarely flat or wave-rippled. No ripple cross-lamination was detected in any of the beds. The presence of wave formed features indicates that at least some of the time oscillatory currents affected the sea bed. Analysis of

facies MB on the east limb of the fold revealed slightly more primary structures and less bioturbation. Wave-rippled upper surfaces, horizontal laminations, HCS, and amalgamation of layers were common features. This additional information supports the inference that the silty-sandstone beds are of a storm origin.

One of the more distinctive features of this facies, in addition to the abundance of burrowing, was the abundance of brachiopods. Compared to the rest of the Rockwood Formation, which for the most part lacks skeletonized taxa, this facies represents a substantial change from earlier environments which characterized the Rockwood Shelf. Both the abundance and diversity of traces was also high. Such a profusion of life indicates a stable low-energy environment. Most of the burrows are horizontal, inferring low-energy and less abrupt shifts in temperature, salinity, and oxygen (Frey and Pember-ton, 1984). The amount of oxygen was probably high in this environment, which can be inferred from the abundance of life and the maroon coloration (iron oxide?) within the sediments.

A similar facies was described by Chowns (1972) in the nearby Red Mountain Formation (Lower Silurian), at Ringgold, Georgia, approximately 15-20km southwest along-strike of the study area included in this thesis. The facies was termed the red shale facies by Chowns and was characterized by red shale interbedded with fine sandstone beds. Chowns interpreted the red color to be the result of an oxidizing environment which prevented reduction of iron coatings. The facies occurs in the upper part of the Ringgold section, repre-

senting Upper Llandoveryan time (Chowns, 1972). Facies MB at White-oak Mountain also occurs in the upper part of the stratigraphic section, and age dates on Eocoelia brachiopods indicated middle Late Llandoveryan. In addition, Eocoelia brachiopods were also documented by Chowns in the red shale facies.

Depositional Conditions of Facies AH

The amalgamated hummocky(?) (AH) Facies represents shoreface storm layers. Beds are typically thin to thickly bedded and exhibit the following characteristic sequence. The bases of beds are erosional and typically contain a concentration of skeletal debris, that is succeeded upward by parallel laminations to low-angle cross-laminations (HCS?). Wave ripples, bioturbation, and intervening shale are extremely scarce, which may be due to the erosive nature and amalgamation of units. Similar sequences were described by Aigner and Reineck (1982) and Kumar and Sanders (1976), who termed them "shoreface storm deposits." Such sequences are typically sandwiched between tidal deposits and open shelf facies. This same position is represented by Facies AH, with wave- (fairweather and storm) and tidally influenced deposits above (Facies FC), and more offshore, storm-dominated deposits below (sub-facies Hs).

Brenchley (1985) described characteristics of shoreface storm deposits that are similar to those contained in Facies AH. In Brenchley's descriptions, units are thickly bedded, amalgamated, planar-laminated, and may or may not contain HCS. The abundance of

sandstone and lack of shale in amalgamated facies AH probably resulted from repeated and continual reworking by waves and currents in a shoreface environment. It has been speculated that the geologic records of shoreface deposits is dominated by storms (Kumar and Sanders, 1976). Successive storms in the shoreface erode fairweather units and possibly the top parts of the preceding storm deposits. Such erosion may account for the lack of wave ripple laminae, bioturbation and shale in Facies AH.

One of the difficulties with the analysis of this facies was that the degree of amalgamation made identification of individual events troublesome. Similar amalgamated hummocky sequences were described by Dott and Bourgeois (1982). They were also typically devoid of mudstone, rippled surfaces, and burrowed intervals. In their model (Fig. 38) one hummocky zone succeeds another. They discussed the fact that in such sequences first-order and second-order truncation surfaces are not easily discernable, and it may be impossible to distinguish between individual major events. The one feature of Facies AH that aids in distinguishing between individual events was the concentration of skeletal debris. A problem with lags of shells or pebbles, however, is that they also may occur along second-order surfaces or even within individual laminae sets (Dott and Bourgeois, 1982). The significance of such amalgamated hummocky sequences are that they indicate shallower conditions, in which larger waves dominated and storm events more commonly affect the bottom.

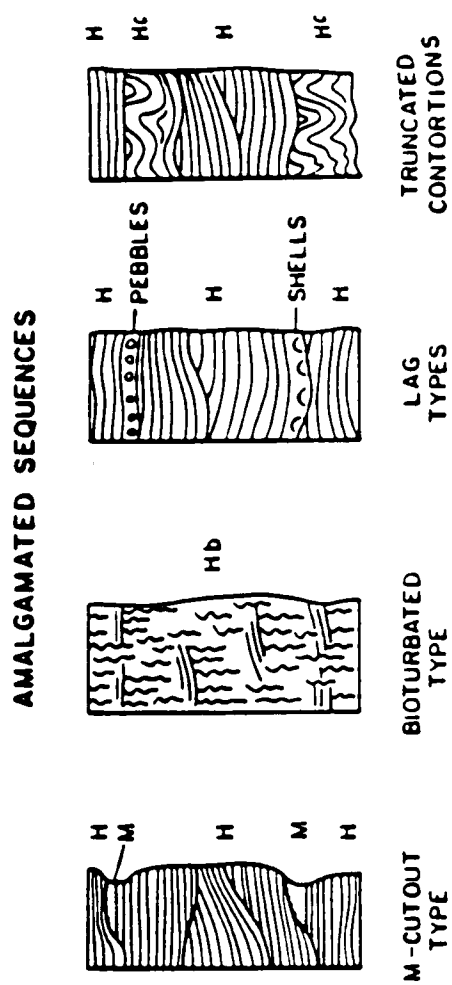


Figure 38. Amalgamated Hummocky Sequences of Dott and Bourgeois (1982).

Depositional Conditions of Facies QA

Facies QA represents the most enigmatic interval in the entire Formation. It occurs at the base of the Rockwood, conformably overlying the Upper Ordovician Sequatchie Formation, which represents a tidal flat to shallow subtidal environment (Milici and Wedow, 1977). The position of the basal Rockwood above the Sequatchie suggests that a marine origin is probable. Evidence indicating a marine origin is as follows: (1) open-marine megafossils; (2) Cruziana trace fossils; and (3) concentrations of glauconite, phosphate, and chamosite. Bio-turbation was extensive, erasing most primary structures. This hindered the collection of paleocurrent data, resulting in only a few measurements. The few primary structures that were detected were trough cross-stratification, horizontal laminations, and ripple cross-laminations.

The basal Rockwood at Whiteoak Mountain has been interpreted to be part of a transgressive phase, representing the action of advancing oceanic currents over the Upper Ordovician Sequatchie (Milici and Wedow, 1977). In contrast, Thompson (1984) interpreted the basal Rockwood to represent a short lived emergence in which coastal sands and tidal channels temporarily prograded out over the underlying Sequatchie. However, no evidence for emergence (such as mud cracks, etc.) or deep channeling was detected in Facies QA at Whiteoak Mountain. One of the characteristic features of the base of the Rockwood at Whiteoak Mountain and at other sections in east Tennessee, is the

presence of a bioturbated sandstone bed resting on a transgressive (?) lag of material. Exactly what this basal section represents is unknown, but the ubiquitous bioturbated sand associated with a thin lag zone seems significant. The position of the section at the beginning of Silurian time, when sea level was rising (McKerrow, 1979), and the thin lag of material implies the interval may record the Upper Ordovician/Lower Silurian transgression. Unfortunately the burrowing has erased the evidence necessary to determine what depositional processes dominated in this part of the section.

Depositional Conditions of Facies FC

Facies FC occurs in the middle of the Rockwood Formation and contains high-angle cross-strata, representing deposition above fair-weather wave-base. Facies FC represents a prograding, shoaling-upwards sequence that was dominated by wave and tidal processes. The most common sedimentary structures were trough-cross strata and wave/current ripples, resulting from the migration of three dimensional dunes (megaripples) and small-scale ripples, respectively. Figure 39 exhibits the dominant sedimentary structures, amount of sandstone and shale, and the general nature of Facies FC.

Facies FC represents a sub-tidal environment rather than a supra-tidal or intertidal setting. One of the factors arguing against a supra- or intertidal environment was the lack of mud cracks or any other emergent indicators. Additional evidence indicating offshore shallow-marine deposition (sub-tidal) include the following:

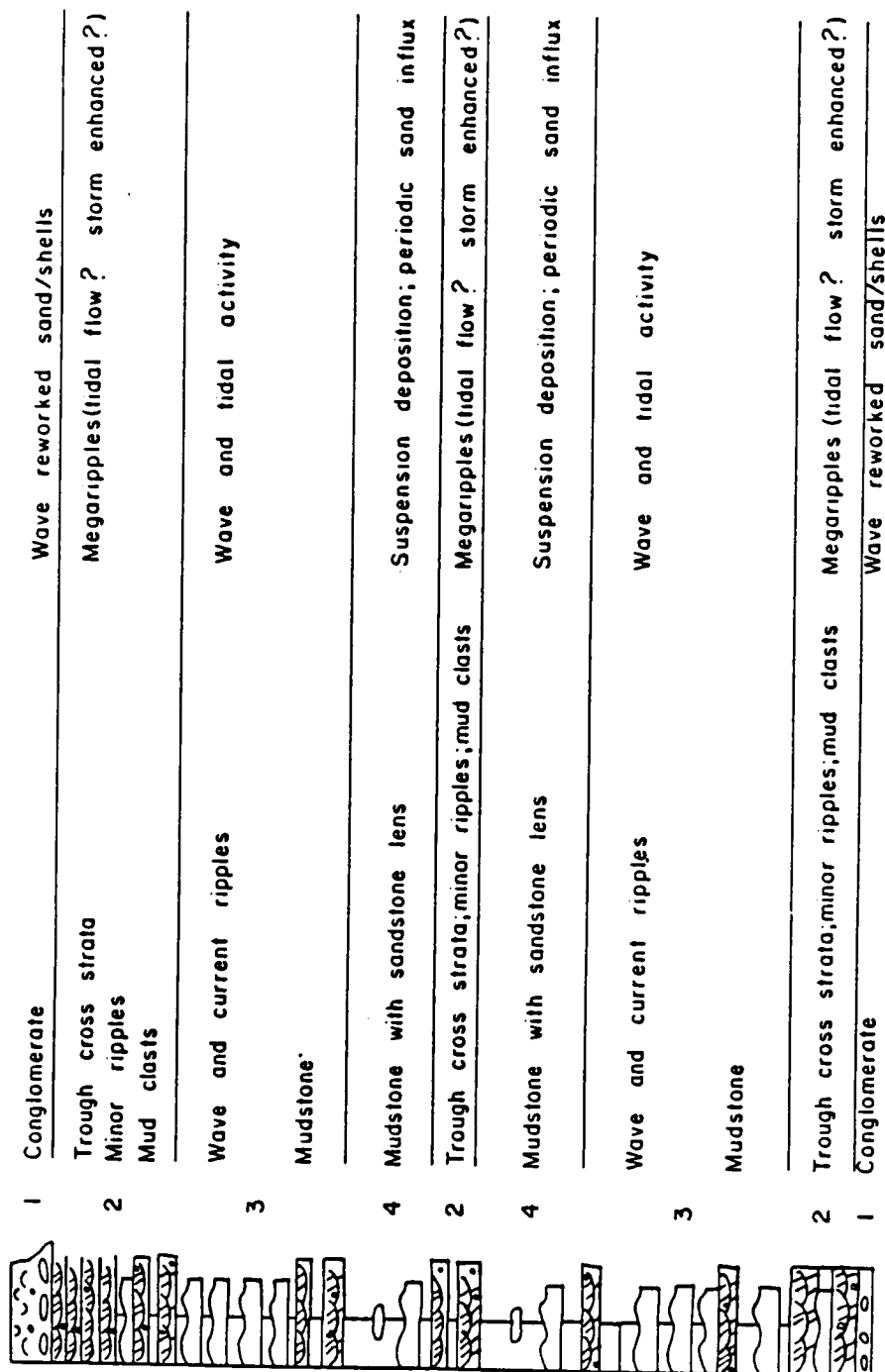


Figure 39. Sedimentary Structures and Inferred Depositional Conditions of Facies FC.

(1) The presence of open-marine body fossils; (2) Cruziana trace fossils; (3) Glauconite, phosphate, and chamosite accessory minerals; and (4) Absence of deep channels.

Evidence for tidal currents is relatively weak in this facies, although some features are not in conflict with a tidal interpretation. The paleocurrent data for this facies is sparse and exhibits a polymodal pattern. Such polymodal (multimodal) patterns are diagnostic of some tidal environments (Johnson, 1978) signifying fluctuations in direction or the rotary inclination of tidal currents, possibly with superimposed storm activity. The abundance of cross-bedding (indicating dunes) is a common feature in the modern environments of tidal seas (Johnson, 1978). Clay drapes were an additional factor indicating tidal currents, although they were not documented in great numbers. Typical tidal flow indicators lacking in this facies were herringbone cross-bedding, reactivation surfaces, and tidal bundles.

Evidence for wave activity (fairweather and storm) was represented by the abundant wave ripples and mud clasts, which tended to be concentrated at the tops of layers. Intervals in which wave ripples dominated indicated that the main sources of energy here was meteorologically induced by fairweather waves, and possibly storms. Subordinate amounts of current ripples were intercalated with the wave-formed features, possibly in response to tidal(?) currents. The presence of mud chips can be attributed to the action of storms (Cotter, 1983), that swept through this area and ripped up the muddy

bottom. The concentration of some of the mud clasts at the tops of beds appears to be the result of winnowing due to wave activity (Levell, 1980).

A summary of the characteristics of this facies is exhibited in Figure 39. As can be seen from the figure, the Facies was divided up into four sequences based upon sedimentary structures and inferred depositional conditions. Overall the Facies composes a coarsening-upward sequence that represents a gradual (and fluctuating) increase upwards in wave and current activity in response to a prograding sand body. Driese (1986 a, b) has described a similar progradational sequence in the Rockwood Formation from several strike belts in northeastern Tennessee. He interprets this sequence to represent a major regressive phase during which shoreface Clinch sands prograded across the muddy Rockwood shelf. Deposition within the prograding sands was dominated by tidal and wave processes. The analysis of Facies FC at Whiteoak Mountain thus appears to reinforce the previous interpretations of Driese (1986 a, b) on the Rockwood in northeastern Tennessee.

Iron Mineralization in the Rockwood

Most of the iron mineralization in the Rockwood was concentrated in Facies FC and AH, with a subordinate amount in sub-facies Hm. Within these facies, the iron principally occurred in three lithologies: the hematitic quartz arenite of Facies AH; the sublitharenite and litharenite of Facies FC; and the trilobite-echinoderm wacke-

stone-packstone of sub-facies Hm. The occurrence of these ferruginous beds are within the middle part of the Rockwood section (Fig. 40). The presence of iron minerals (iron-oxides, iron-silicates) is not uncommon in terrigenous sedimentary rocks, however, what is so unique about these ferruginous rocks is the amount of iron present, which is generally in excess of 15% of the total rock. Rocks that contain more than 15% iron are considered "ironstones" (James, 1966; Van Houten and Bhattacharyya, 1982). These rocks are thought to form either by direct deposition as ferruginous sediment or by chemical replacement of sediment.

Types of Iron Minerals - Hematite is the chief iron-bearing mineral in these sedimentary ironstones, and is abundant in all three ferruginous lithologies. Hematite was detected both coating fossil fragments as well as partially or wholly replacing skeletal grains. It also coated quartz grains, and occurred as matrix material. Glauconite was also very prominent in these rocks, occurring as pelletoidal material and partially replacing skeletal material. Less abundant iron-bearing minerals include chamosite, commonly in the form of ooids, limonite (generally replacing glauconite and hematite), and siderite cement.

Environmental Conditions - One of the problems in the study of iron-rich sediments is the lack of adequate modern analogues, although many do exist. Iron minerals are forming today in the following environments: (1) tidal flats; (2) bog lakes; (3) oceanic

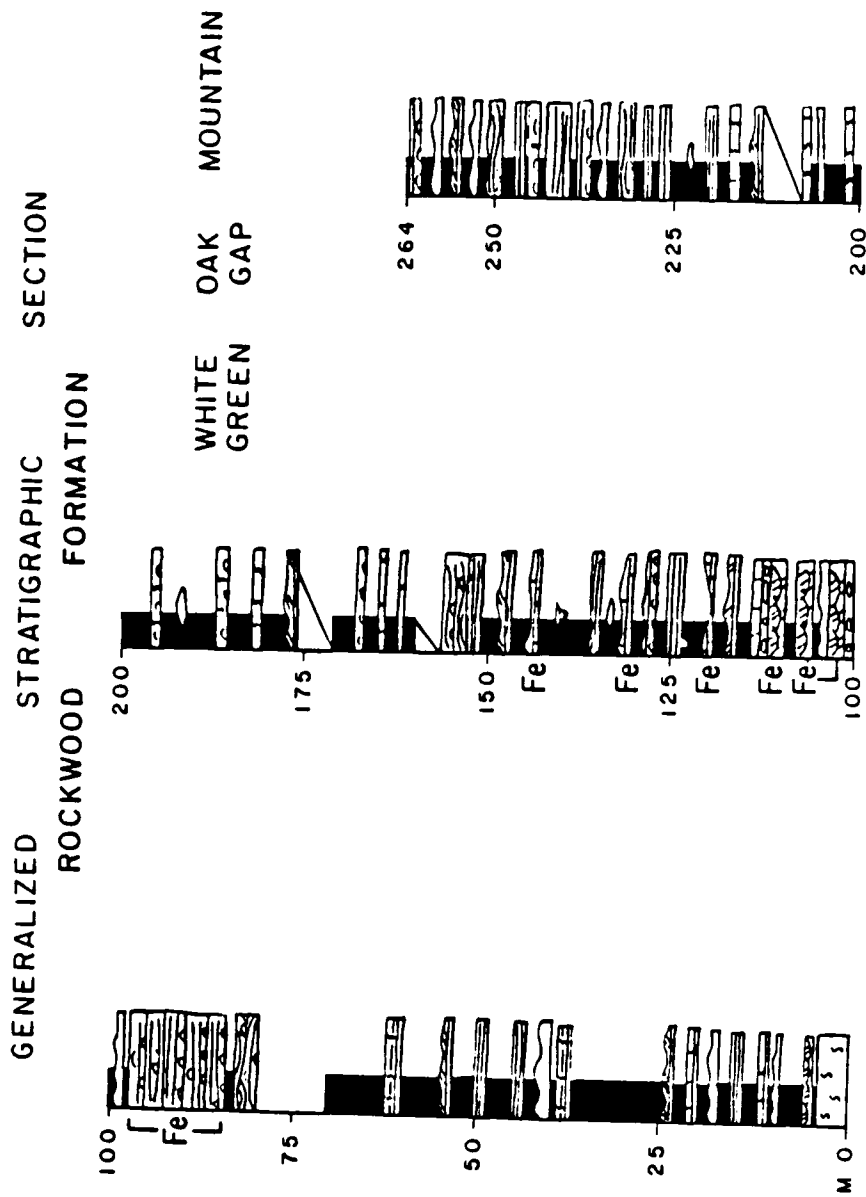


Figure 40. Iron-rich Lithologies Denoted by Fe.

shelves in tropical climates; and (4) deep basins with restricted circulation, such as Scandanavian fjords and the Black Sea (Blatt et al., 1973). The problem is that these settings do not sufficiently explain the types of deposits seen in the geologic record.

Extensive work has been conducted on Phanerozoic ironstones by Van Houten and Bhattacharyya (1982), who concluded that a specific set of environmental and tectonic conditions are necessary for the concentration and formation of iron-sediments. A mild maritime climate along with widespread transgressions of the continents, relatively subdued tectonic activity, deep weathering, and a high stand of sea-level are the criteria necessary for iron concentration. The combination of these factors results in the release of iron and clay. Of the above mentioned factors, the most critical ones are mild climate, subdued tectonic activity, and deep weathering.

The source of the iron and how it is brought to the depositional site have, for a long time, been major problems. The ideal conditions for the supply of iron to surface waters is in tropical, humid areas of low relief, where chemical weathering is intense (Blatt et al., 1973). Work has been conducted on the "Middle" Silurian Clinton group in the central Appalachian basin by Hunter (1970), who concluded the iron was derived from east of the basin, probably from the same land area that supplied the clastic material to the basin. The iron most likely originated from iron-bearing rocks in the source area. For the concentration of the iron, the amount of clastic input must be kept to a minimum so the iron-bearing

minerals will not be diluted by other sediments. The critical factors in preventing dilution are restricted circulation and a shallow body of marine water (Hunter, 1970).

Ironstone beds (specifically oolitic ironstone) are associated in the geologic record with transitional stages, either at the end of a regional regression or at the beginning of a renewed transgression (Van Houten and Bhattacharyya, 1982). Hallam and Bradshaw (1979) noted that oolitic ironstone sequences commonly mark the late stages of regional regressions, in which terrigenous input has lessened as the sea has shallowed. They related these regional changes in water depth to eustatic rises and falls of sea-level. Hunter (1970) stated that most ironstone beds in the geologic record are associated with major lithologic or faunal breaks. These horizons appear to represent times of shallowing due to decreased subsidence or actual uplift of the basin. Cotter's (1983) analysis of the "Middle" Silurian iron sedimentation in the northern Appalachian basin revealed a correlation between the concentration of iron minerals and periods of lowered sea-level. He interpreted this to be a time when the Taconic Highlands were reduced, and the sub-tropical latitude provided for intense weathering, at least seasonably. The result of such weathering was largely clay minerals (kaolinite?) and hydrated iron oxides. The "Middle" Silurian in Pennsylvania appears to have been a time where conditions were very conducive for iron sedimentation.

The Lower Silurian Rockwood Formation of southeastern Tennessee also was a time and place where environmental and tectonic factors

were favorable for iron concentration. Studies from the literature (e.g., Castano, 1950; Cotter, 1983) indicate that a specific set of conditions must be met before precipitation and concentration of iron can occur. A possible scenario has been worked out for the iron mineralization of the Rockwood, which largely draws upon the ideas of Castano, 1950; Cotter, 1983; Hunter, 1970; Bhattacharyya and Kakimoto, 1982; Van Houten and Bhattacharyya, 1982; and Hallam and Bradshaw, 1979. The iron ores of the Rockwood Formation were interpreted to have been deposited in shallow, well-aerated seas, where the water was clear and warm. The Taconic Highlands, which lay to the east of the proposed shoreline, were in their waning stages and clastic input was probably at a minimum. Eastern Tennessee's postulated subtropical latitude of 30 degrees south (Ziegler et al., 1977; 1979) would allow for periodic intense chemical weathering (much like what Cotter (1983) envisioned for the "Middle" Silurian of Pennsylvania), which would release clays and iron oxides that were probably transported to the shoreline by rivers or ground-water. The transport of iron in solution would require rivers and ground-water of low pH and low Eh (Hunter, 1970).

The rivers (and/or ground-water) would deliver the clays and iron oxides to the nearshore zone, which was probably dominated by megarippled and rippled sand shoals and skeletal shell banks. Once the rivers entered the sea, they would deposit their clastic load. If their entrance point was an area of open circulation, the iron would precipitate immediately and be diluted by the clastics. A pos-

sible solution to this dilemma (proposed by Castano, 1950) would be for the rivers to enter a lagoon or some other body of water where circulation is restricted. In this situation, the clastics would be dropped, however the iron would probably stay in solution and pass through this zone until reaching ocean water that is in equilibrium with calcium carbonate. Here the iron could precipitate and not be diluted by clastic input. In this situation the iron would be precipitated as iron-oxide and replace calcium carbonate as well as precipitate freely. This would result in the coating of sand grains and skeletal debris, as well as replacement of skeletal material. If agitation was sufficient, concentric rims could form around the grains. If the clay content was high enough, chamosite may form instead of hematite. In general though, concentrically coated, oolitic material was scarce in the Rockwood at Whiteoak Mountain, implying that agitation may not have been sufficient enough to allow for mechanical accretion of iron-oxide or clays. When concentrically coated material was present, it was typically in the form of hematite and rarely chamosite. The lack of chamosite-coated grains indicates the amounts of clay were low compared to the amount of iron-oxide.

The majority of the iron in the Rockwood is concentrated in the subtidal storm beds (Facies AH), cross-stratified beds (Facies FC, representing the megarippled and rippled sand shoals) and thin, lenticular storm beds of sub-facies Hm. The iron sedimentation is associated with the major regressive phase of the Formation, when

Clinch-like sands prograded out across the muddy shelf. This was a time of lowered sea level, when the slightly agitated megarippled and rippled sand shoals (and skeletal banks) expanded towards the basin center. The thin, lenticular storm beds were probably eroded from these sand shoals and skeletal banks by storms that swept through the area. The storm flows transported the ferruginous skeletal and clastic material basinward, and deposited them within the mudstone dominated sub-facies. These iron-rich storm beds (generally skeletal wackestone-packstone) occur rarely, and are associated with mudstone and sandstone/siltstone storm beds. The erratic nature of the ferruginous-skeletal storm beds may be a function of the rare occurrence and concentration of iron within the nearshore marginal shoal areas. Such a sporadic distribution of iron seems reasonable due to the delicate balance of factors necessary for iron concentration. Cotter (1983) discussed how rises in sea-level decrease the amount of agitation in the nearshore zones, resulting in the sedimentation of mud and lack of iron accumulation. Hunter (1970) attributed the decrease in iron-content in the uppermost Clinton to movements of the strand line and climatic factors. Gradual marine transgression of the source area that supplied both clastic and iron material to the basin could result in a decrease or complete cessation of iron concentration. A decrease in rainfall could also result in less transportation of the iron. The change in the amount of precipitation is probable if the source area (Taconic Mountains) was decreasing in relief, and this might have resulted in a decreasing ability of the uplands

to force air currents to rise, cool, and precipitate. In the case of the Rockwood, these hypotheses may apply. The regressive phase in the middle of the Rockwood, which ended with the deposition of the subtidal storm beds (Facies AH) and megarippled and rippled sand shoals (Facies FC) was followed by a transgression that may have affected the source area, and cut-off the concentration of iron. A decrease in rainfall is probable in the Rockwood, however, there is no conclusive evidence.

What is so unique about the iron-rich rocks within the Rockwood and other iron-bearing formations like the Clinton, is the lack (or rarity) of other iron-rich sedimentary rock in the Appalachian basin stratigraphic section. Hunter (1970) attributed this phenomenon to the tectonic setting of the depositional basin and source area. Iron-rich sediments are rare in terrigenous clastic rocks deposited during orogenies because the rapid erosion of the land area probably resulted in incomplete weathering of the source rocks, and the high rate of clastic sedimentation would dilute any iron that may have been present. The Rockwood, much like the Clinton, was deposited during a period in between the climax of the Taconic Orogeny and the extreme quiescence of the Early Devonian (Hunter, 1970). So it appears the Rockwood was a time of mild climate, subdued tectonic activity, and deep weathering. These factors and others (sea-level, reduced clastic input) were instrumental in the accumulation and concentration of the iron-minerals.

Ichnology of the Rockwood Formation

The preceding analysis of the ironstones disclosed much about the climatic and environmental conditions during the Lower Silurian in east Tennessee. Similarly, the following study of the trace fossils and paleoxygenation levels within the Rockwood unveils additional information about climatic and environmental parameters that dominated this shallow marine shelf setting. Most of the information concerning environmental conditions was based on the types and sizes of trace fossils present. Trace fossils have been classified based on behavioral characteristics and the major categories of benthic behavior are as follows (from Frey and Chowns, 1972).

- Resting traces - shallow depressions made by animals that temporarily settle or dig into the substrate.
- Crawling traces - trackways, trails and ephemeral intrastratal traces made by animals traveling from one point to another.
- Grazing traces - grooves, pits and furrows, made by mobile deposit-feeders at or very near the substrate surface.
- Feeding structures - ephemeral burrows (temporary burrows) or intrastratal feeding probes made by hemi-sessile deposit-feeders; burrows also provide shelter.

Dwelling structures- burrows or tubes providing permanent domiciles, mostly for hemi-sessile suspension feeders.

One of the important goals of the ichnological discussion is to distinguish between deposit-feeding and suspension-feeding burrows. Deposit-feeders prefer quiet-water environments in which currents are at a minimum and organic content is at a maximum. In contrast, suspension-feeders prefer more agitated conditions in which abundant food exists suspended in the water column. Being able to differentiate between the two burrow types will aid in the environmental interpretation of the Rockwood Formation. The trace fossils of the Rockwood were generally at the upper surfaces and soles of sandstone beds, and were less commonly detected within layers.

In general, horizontal burrows dominated throughout most of the Rockwood, with sub-ordinate amounts of vertical and sub-vertical structures. Most of the structures detected at the upper surfaces and soles of storm sandstone beds were simple, straight to slightly sinuous ridges and grooves (epichnia and hypichnia), and those found within sandstone beds were typically simple, straight cylindrical shafts (endichnia).

Simple Straight Vertical Burrows - Vertical burrows occurred rarely, except within some storm sandstone beds and within the sandstone sequences deposited above fairweather wave-base in Facies FC. Most of these vertical burrows probably represent dwelling structures of suspension feeders. They may also represent escape structures by

animals which preferred to exist at a certain depth in the substrate. However, structures reflecting upward displacement of the organism (deflected laminae) were only detected in a few cases. Much of the following determination of the genera present was based largely on the work conducted by Frey and Chowns (1972), who worked on the nearby Red Mountain Formation (Lower Silurian) at Ringgold, Georgia, which is along-strike (15-20km to the southwest) of the study area at Whiteoak Mountain.

Most of the vertical, simple straight shafts within the Rockwood had diameters of 1cm or less. Based upon the size and shape of the burrows, these structures were determined to be Skolithos. Figure 41 shows a typical Skolithos tube within one of the Rockwood sandstone sequences. They are interpreted as dwelling structures and are preserved as endichnia.

Extremely rare, small vertical tubes, 2mm in diameter that flared at the top were observed in sub-facies Hs and were interpreted to be Monocraterion, preserved as endichnia and representing dwelling or combination dwelling-feeding structures (Frey and Chowns, 1972). The genera Tigillites, which was detected at Ringgold by Frey and Chowns (1972), was not found at Whiteoak Mountain.

U-shaped Vertical Burrows - Vertical U-shaped structures were rare in the Rockwood and identification was difficult. A U-shaped structure with individual burrows 3mm in diameter and overall 10mm in length was observed in facies MB. This structure may represent Diplocraterion?, which is generally an elongate U-shaped structure, or Arenicol-



Figure 41. Skolithos Tube within Sandstone Layer.

ites?, which is more of a broad U-shaped structure. Another problematical burrow-type were cone-shaped burrows that occurred as exichnia. They are tentatively classified as Trichophycus, species B? (Frey and Chowns, p. 30, 1972), which are inferred to represent dwelling or combined feeding-dwelling structures.

Sub-vertical Burrows - Sub-vertical burrows were rare in the Rockwood, and appear to be dominated by Chondrites. These structures were made by mobile deposit-feeders and suspension-feeders, and occur either as dwelling or feeding structures (Frey and Chowns, 1972). Chondrites burrow systems (according to Frey and Chowns, 1972) occur in branched patterns and contain vertical, horizontal, and inclined components. The diameters of the Chondrites burrows at Whiteoak Mountain are generally small (0.5-3.0mm), which compares well with burrow diameters measured by Frey and Chowns (1972) at Ringgold (1-4mm). The Chondrites burrows at Whiteoak Mountain commonly occur as inclined structures within sandstone beds and as horizontal structures at the soles of beds.

Horizontal Burrows - The horizontal burrows within the Rockwood were generally straight to slightly sinuous to branching, and exhibited a wide range of burrow diameters (1-30mm). The horizontal traces have been classified into two genera, Paleophycus and Planolites, based on burrow size and whether or not the burrow exhibited collapse structures. Frey and Chowns (1972) described Paleophycus as straight to slightly curved, branched or unbranched and possibly collapsed.

Planolites burrows are straight to slightly sinuous, rarely branched, and lack collapse structures. Both Paleophycus and Planolites are extremely abundant throughout most of the Rockwood (Fig. 42), and constitute the most abundant trace fossils. They appear to represent dwelling or foraging structures made by mobile predaceous animals, and deposit- or suspension-feeders.

Trails and Trackways - The presence of trails and trackways generally can be interpreted to be the result of predaceous or mobile deposit-feeding animals. Trackways were not found within the Rockwood and only one type of trail was identified. The trail was classified as Gyrochorte, based on similarity in size and morphology to descriptions by Frey and Chowns (1972). The structure (Fig. 43) is straight to slightly sinuous, bilobate and 3-8mm wide.

Environmental Interpretation of Structures - The regional distribution of trace fossils in the rock record is a function of the environmental conditions acting upon those organisms (Seilacher, 1967). Figure 44 (in Walker, 1984, p. 192) depicts marine ichnofacies and their positions relative to shore. The Rockwood Formation is interpreted to represent a shallow-marine setting above storm wave-base and mostly below fairweather wave-base. According to Figure 44, the logical ichnofacies for this bathymetric setting would be Cruziana and possibly Skolithos and/or Zoophycus. Figure 45 lists the recurring trace-fossil associations and their environmental significance. It appears that the Scoyenia, Glossifungites, and Nereites

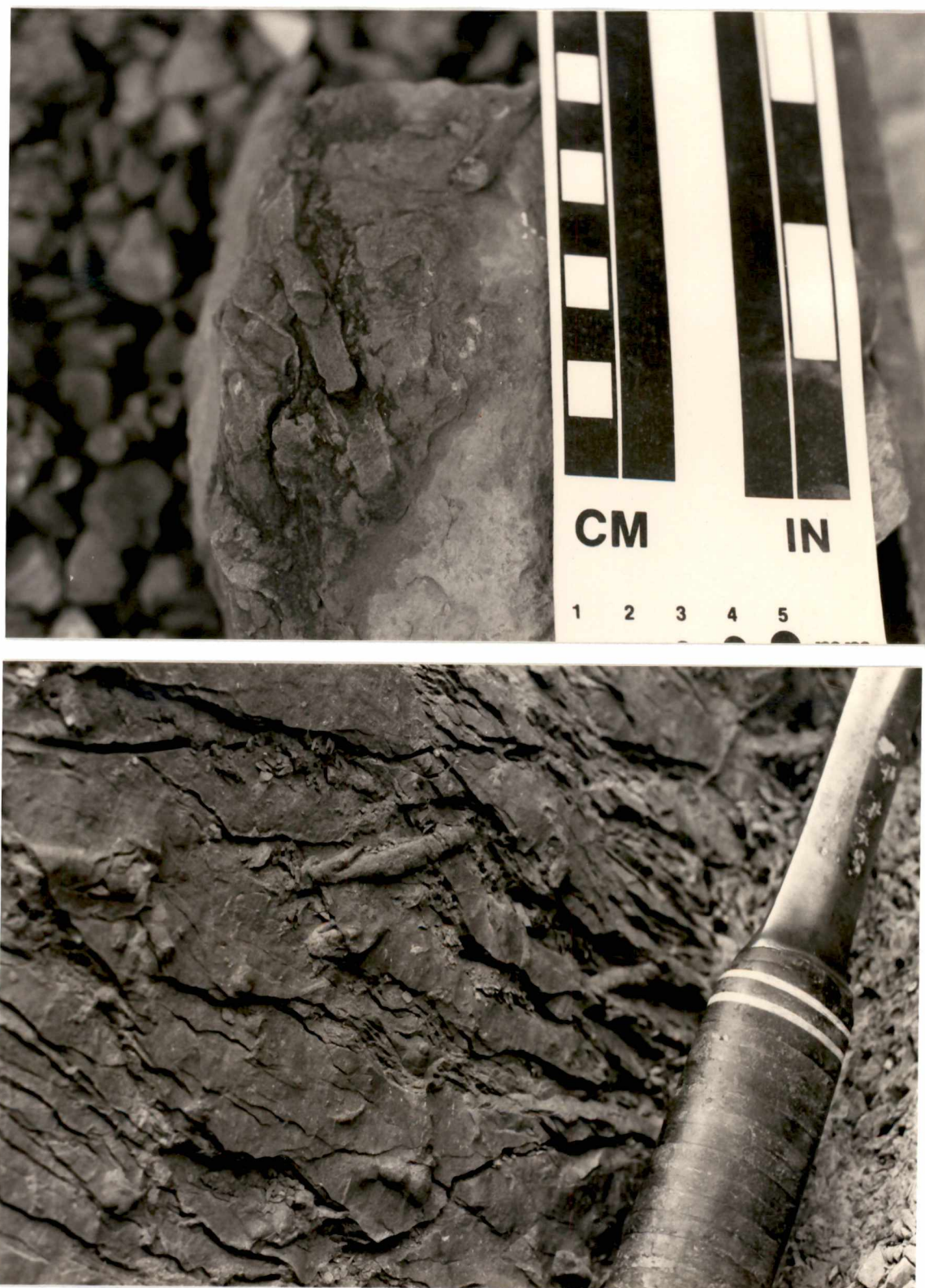


Figure 42. Horizontal Trace Fossils. Upper Photo - *Paleophycus*? (Note Collapse Structures). Lower Photo - *Planolites*?

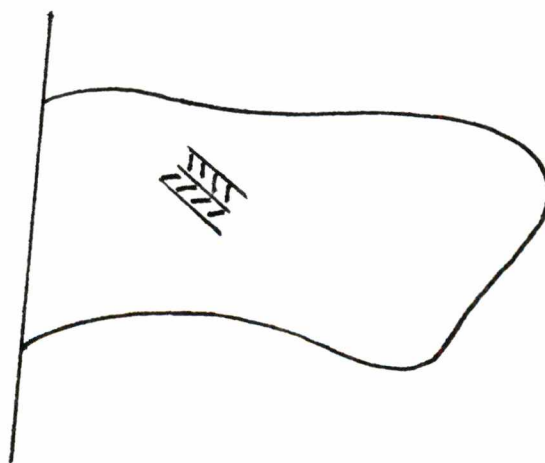
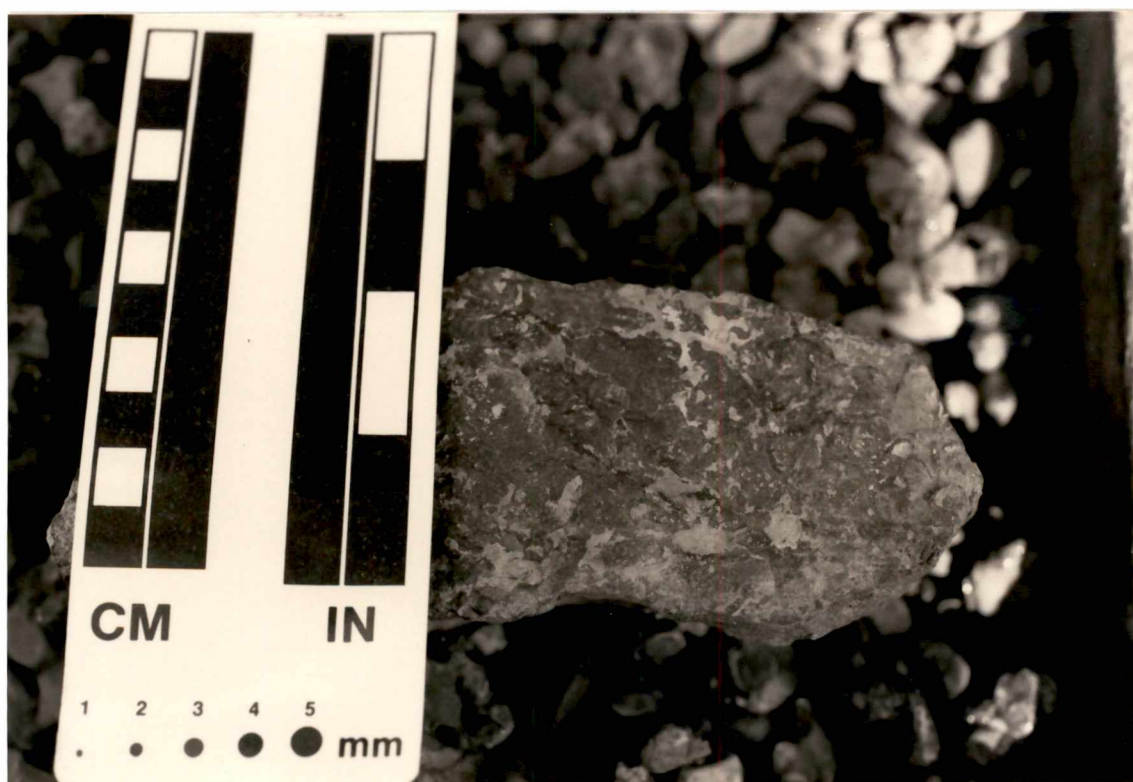


Figure 43. Gyrochorte Trace Fossil.

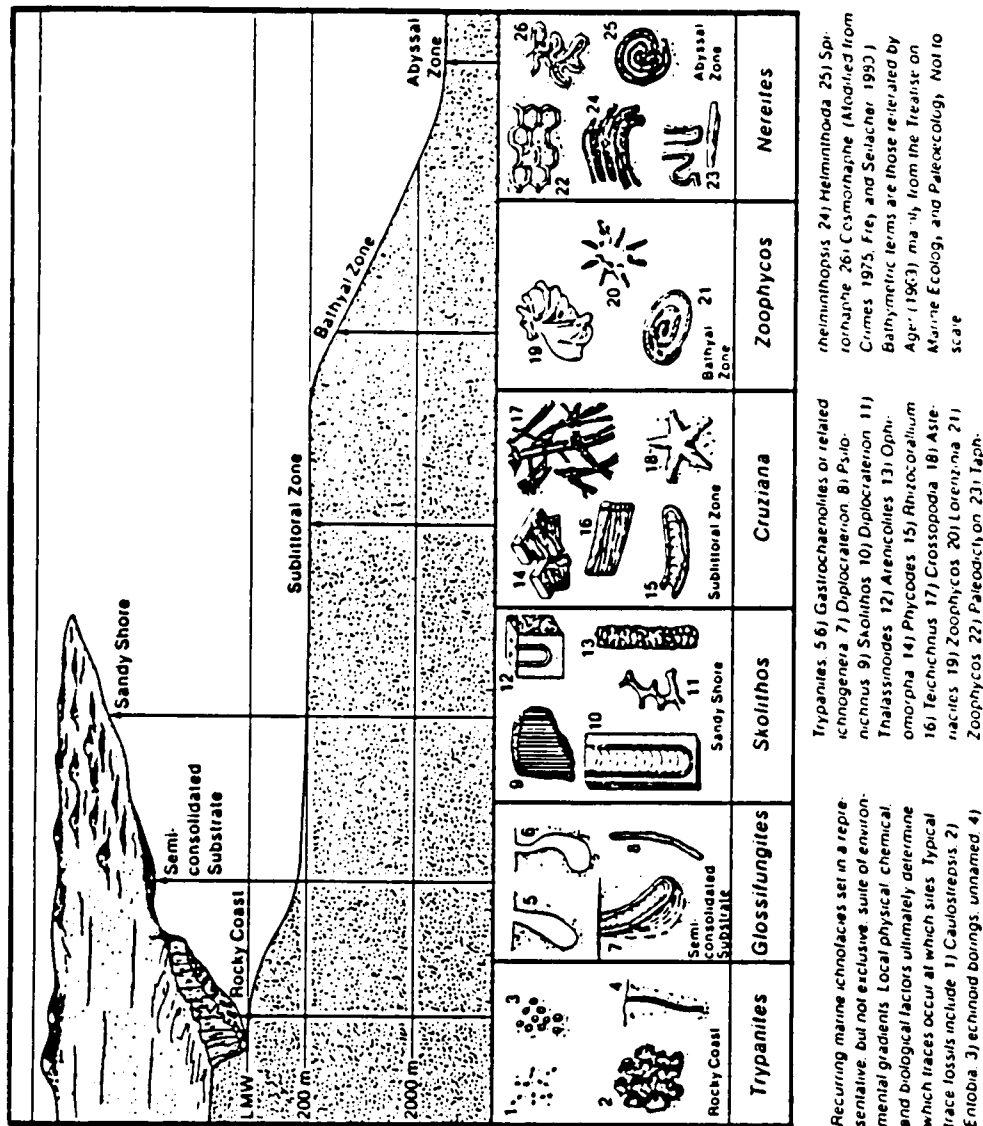


Figure 44. Marine Ichnofacies and Positions Relative to Shore (Taken from Walker, 1984).

Typical benthic behavior

Characteristic trace fossil.

Scoyenia Ichnofacies

- Lacustrine , fluvial deposits
- Periodically become emergent

Small horizontal, lined, back-filled feeding burrows; Curved to tortuous; Sinuous crawling traces; Vertebrate tracks.

Trypanites Ichnofacies

- Consolidated marine littoral and omission surfaces (Rocky coasts, etc.)

Cylindrical to tear-or U-shape to irregular domiciles. Gnawings of algal grazers.

Glossifungites Ichnofacies

- Protected, moderate energy settings or in settings or areas of somewhat higher energy. Marine littoral and sublittoral.

Vertical, cylindrical, or tear shaped borings. Diversity typically low.

Skolithos Ichnofacies

- Lower littoral to infralittoral, high-energy conditions
- Shifting sediments
- Subject to abrupt erosion or deposition.

Vertical, cylindrical, or U-shaped dwelling burrows. Mostly suspension feeders. Diversity low.

Cruziana Ichnofacies

- Below daily wave base but above storm wave base
- Quieter, offshore conditions

Abundant crawling traces; Both suspension and deposit feeders. Diversity and abundance generally high.

Zoophycus Ichnofacies

- Below storm wave base to deep water

Efficient grazing traces; Low diversity.

Nereites Ichnofacies

- Bathyal to abyssal

Complex grazing traces.

Figure 45. Trace Fossil Associations and their Environmental Significance. Modified from Frey and Pemberton, 1984.

assemblages are not present at Whiteoak Mountain. Of the other three assemblages listed in Figure 45, Cruziana appears best developed in the Rockwood. However, the deposition of high-energy storm sands might have resulted in Skolithos-type tracemakers invading the usually quiet, low-energy Cruziana-type environment. Frey and Pemberton (1984) discussed this phenomenon in which periodic storm scour incorporates higher-energy deposits with lower-energy deposits. The increased energy is represented by the encroachment of Skolithos-type conditions in a normally Cruziana-type environment. However, the overall bedding style of the Rockwood sands is different from the typical Skolithos ichnofacies and storm sandstone beds tend to be overprinted by Cruziana-type traces. One small section where an actual Skolithos-ichnofacies did occur was at the top of Facies FC, which has been interpreted as being deposited in shallow-water above fairweather wave-base. The Skolithos ichnofacies interpretation was based on higher percentage of dwelling over feeding structures, coarser-grained lithologies, high-angle sedimentary structures, and stratigraphic position. One of the important aspects to consider when studying trace fossils is not to make bathymetric interpretations based upon just the trace fossils themselves (Frey and Pemberton, 1984). The evaluation of physical sedimentary structures and stratigraphic position must also be considered. One feature of interest was the storm sandstone beds commonly were partially burrowed, whereas the intervening mudstones were uncommonly so. This

may be related to the oxygen content of bottom waters and will be discussed in detail in the next section.

Paleoxygenation Levels on the Rockwood Shelf - The amount of bioturbation was distributed erratically throughout the Rockwood Formation and did not uniformly increase in an offshore or onshore direction. Many distal portions of the section were extremely lacking in evidence of the existence of biological activity (bioturbation non-existent in some sequences). One exception to this general lack of evidence for organisms was Facies MB, in which burrowing was extreme. Excluding facies MB, bioturbation was low to non-existent in the mudstone strata, and was typically concentrated at the tops of beds in the intervening storm sandstone beds. In addition to the general lack of bioturbation, skeletonized organisms were also scarce.

The factors controlling the abundance and distribution of benthic organisms could be wave energy, salinity, temperature, substrate, oxygen content, etc. (Levington, 1982). Cluff (1980) conducted a paleoenvironmental study on the New Albany Shale Group of Illinois and concluded the most important factors controlling the distribution of benthic organisms were wave energy, bottom oxygenation and bottom topography. Of the preceding three elements, oxygen content was the most important environmental restriction in the offshore areas of the New Albany Sea (Cluff, 1980).

The low levels of bioturbation and rarity of body fossils within the Rockwood Formation can be related to reduced oxygen levels in the water. Other factors (such as temperature, etc.) may have contribut-

ed to the paucity of organisms, however, in light of recent studies on ancient marine basins (e.g., Cluff 1980; Cotter, 1983), oxygen levels seemed to have had the strongest effect on the biota. Study within modern environments indicates that macrobenthic organisms do not exist below a certain level of dissolved oxygen (Savrda and Bottjer, 1986). Analysis of ocean waters reveals different levels of oxygen produced by density stratification, which insulates bottom waters from atmospheric oxygen (Byers, 1977). Oceanic basins with this type of stratification normally contain three layers (Byers, 1977): the aerobic zone; the dysaerobic zone; and the anaerobic zone (Fig. 46).

One of the interesting aspects of the decrease in oxygen with depth are the changes in faunal composition, which can be used to indicate relative water depth. Major faunal changes occur within the pycnocline, where dissolved oxygen drops below 2ml/l (Byers, 1977). Comparison of the dysaerobic zone to the aerobic zone reveals that the less-oxygenated zone contains communities with lower diversity, generally smaller body size, a greater dominance by infauna and fewer calcified species (Byers, 1977). Within the anaerobic zone there is a complete absence of organisms (Fig. 46).

Savrda and Bottjer (1986) discussed how primary sedimentary structures are destroyed in oxygen-rich zones. Thus, a lack of sedimentary structures may imply oxygen-rich conditions, whereas preservation of sedimentary structures may indicate oxygen-poor conditions. The majority of the mudstone strata in the Rockwood were dominantly

Aerobic Zone - Mixed surface layer, well-oxygenated, approximately extends down to 50m of water depth. Shelly fauna and infaunal bioturbation present.

Dysaerobic Zone - A stratified layer (pycnocline) in which oxygen decreases rapidly with depth, approximately 100m in thickness. Shelly fauna lacking, however, bioturbation by infauna still present.

Anaerobic Zone - A stagnant zone in which there is no oxygen, extending from approximately 150m to ocean bottom. Shelly fauna and bioturbation lacking. Sediments are laminated.

Figure 46. Different Levels of Oxygen Produced by Density Stratification and Dominant Characteristics of Each Zone. (Byers, 1977).

fissile to rarely blocky, implying relatively oxygen deficient conditions (Byers, 1974). In contrast, virtually all primary structures were destroyed in Facies MB, where mudstone strata was blocky and rarely fissile, indicating more oxygen-rich conditions.

Calcified species within the mudstone strata of the Rockwood are scarce except in Facies MB where there is an abundance of brachiopods, and in Facies FC and QA, where a limited number of species were detected. The lack of calcified species and absence to low amounts of bioturbation implies dysaerobic to slightly anaerobic conditions prevailed for most of Rockwood deposition. The rare instances in which body and trace fossils were common indicate rare increases in oxygen content of the waters on the Rockwood Shelf.

Several authors have used burrow size to estimate relative oxygen levels. As the level of oxygen decreases, the size of organisms inhabiting the environment concurrently decreases. Savrda et al, (1984) have measured burrow diameters and documented that average diameters and range of diameters decrease with increasing depth and decreasing oxygen levels. Burrow diameters were measured for trace fossils in the Rockwood and the results are shown in Figure 47. Burrow diameters show a maximum in Facies FC, AH, QA, and show a general decrease in sub-facies Hs, Facies MB and a further decrease in sub-facies Hm.

If one assumes that the sea during Rockwood deposition was, for the most part, dysaerobic to slightly anaerobic, one question to be asked is how did the sea become poorly oxygenated? In general, open

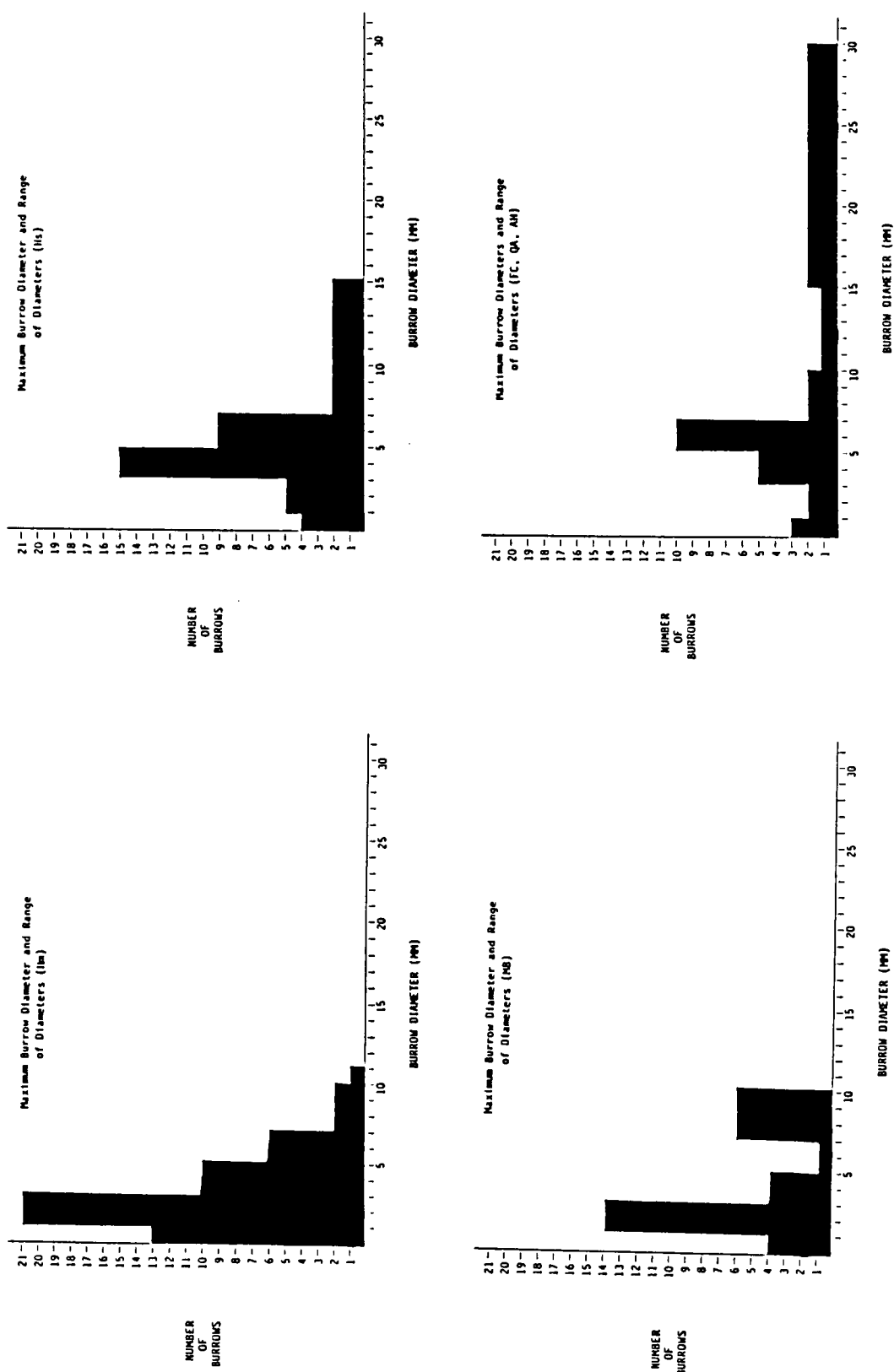


Figure 47. Maximum Burrow Diameter and Range of Diameters for the Rockwood Formation.

oceans are well-mixed by surface waves and thermal currents (Byers, 1977). Semi-enclosed seas are easily stagnated by restrictions in mixing, both at the surface and at depth. In general, oxygen will not diffuse rapidly through the water column, so the oxygenation of deeper waters requires vertical currents that carry surface water downward. Typical vertical currents are thermal ones, produced by the cooling of surface water which sinks, causing an overturn of shallow water (Byers, 1977).

The sinking of cool waters can be related to climatic factors. It has been hypothesized (Berry and Wilde, 1978) that the major mechanism by which the deep ocean is "ventilated" is due to the formation of ice at high latitudes. The creation of ice results in dense, well-oxygenated water sinking and delivering oxygen to deep waters of the low to middle latitudes. Berry and Wilde's (1978) model proposed that during times of glaciation, dense, oxygenated water supplies oxygen to deeper waters, and conversely during non-glacial times there is a lack of dense cold water and anoxic conditions prevail. So it appears that the amount of oxygen reaching the deep ocean in modern environments depends on the amount of ice being formed at the poles (Berry and Wilde, 1978).

Data from the literature indicate that the Early Silurian was a non-glacial period that was typified by warm, tropical conditions (Berry and Wilde, 1978). In contrast, the Middle to Late Ordovician was a glacial period that reached a maximum at the end of the Ordovician (Berry and Boucot, 1973). It appears that in the Early

Silurian, deglaciation took place and resulted in a rise in sea-level (McKerrow, 1979). Such rises in sea-level during non-glacial times result in extensive seas covering continental shelves, which are typically oxygen-deficient (anoxic) (Berry and Wilde, 1978). Silurian seas were anoxic (in general) due to a reduction in "ventilation" of the deep ocean waters, and a possible restricted access to the open ocean during this time in North America may have compounded the situation (Berry and Wilde, 1978).

It is speculated that the dysaerobic to slightly anaerobic nature of the Rockwood basin can be related to the deglaciation event that occurred during the Early Silurian, which resulted in oxygen-deficient seas. The aerobic inclination of Facies MB seems somewhat out of place compared to most of the Rockwood which is oxygen deficient. Possibly this facies represents a perturbation in Silurian climatic conditions, allowing for a cooling trend that resulted in a brief period of "ventilation" of the deep ocean waters. Another possible scenario could be that increased mixing due to higher storm frequency and greater storm magnitude might result in a lowering of the oxygen minimum zone.

One interesting aspect of the distribution of bioturbation in the Rockwood is the apparent greater occurrence of bioturbation in the storm sandstone beds, and apparent decrease of bioturbation in the associated shale. This may be attributed to storm currents temporarily oxygenating dysaerobic-anaerobic areas through the introduction of new water. Savrda et al, (1984) discussed the ability of

turbidity currents to momentarily oxygenate the sea floor, resulting in short periods of bioturbation by organisms that migrate into these areas or are brought in by the current. It must be pointed out that this phenomenon may be a recognition problem in that it is easier to detect bioturbation in sandstone beds than in shale. The amount of bioturbation in the shale may have been under-estimated.

General Paleocurrent Analysis

Paleocurrent measurements from sedimentary structures can indicate the direction of flow, paleoslope, paleogeography, and sand-body trends. A wide range of sedimentary structures can be used in a paleocurrent analysis, some of which only indicate the sense of current flow, whereas others yield both sense and direction. Examples from the first group that were measured in this study include trends of wave ripples and gutter casts. Examples from the second group include cross-strata, flute casts, and asymmetrical ripple cross-laminations. Each time a measurement was taken in the field, the structural dip and strike were also tabulated. If the dip was in excess of 10° , each measurement was corrected on a stereographic net. The method used to correct for structural deformation was taken from Tucker (1982).

After tectonic dip was removed, the azimuths were grouped into 15° classes and plotted on a rose diagram, with a suitable scale along the radius for the number of readings. A computer program (by Maher and Dott, 1979) was employed to determine vector mean (θ), the

magnitude of the resultant vector (r), the angular deviation (s), and the F-statistic (F). The results were plotted on Figure 48.

Bidirectional Structures - Bipolar paleocurrent structures were represented by trends of wave-ripple crests and gutter casts. The wave-ripple crests in Figure 48 exhibit two dominant and diametrically opposite trends. The NE-SW (40.85° , 220.85°)-trending ripple crests indicate the sense of current flow was NW-SE (probably onshore storm waves?). In contrast, the NW-SE (143.85° , 323.85°)-trending ripple crests indicate the sense of current flow was NE-SW (possibly alongshore waves?). The gutter casts show a strong concentration of azimuths in a NE-SW orientation. Analysis of the gutters indicates they tapered to the NE, which denotes flow was to the SW (possibly alongshore geostrophic flows?). Paleocurrent measurements were also taken from the east limb of the fold where beds are steeply dipping to overturned. The trends of the wave ripples are concentrated into two distinct groups, similar to the west limb of the fold. Wave ripples crests trending NE-SW (22.5° , 202.5°), indicate sense of flow to the NW-SE. Conversely, wave ripple crests trending NW-SE (134.95° , 314.95°), indicate a sense of flow to the NE-SW. Gutter casts were also measured on the east limb, and indicated flow in a NE-SW (8.9° , 188.9°) sense. Tapering of gutters implies flow was directed to the SW.

Unidirectional structures - Unidirectional structures were not nearly as abundant as bidirectional structures. For most paleocurrent

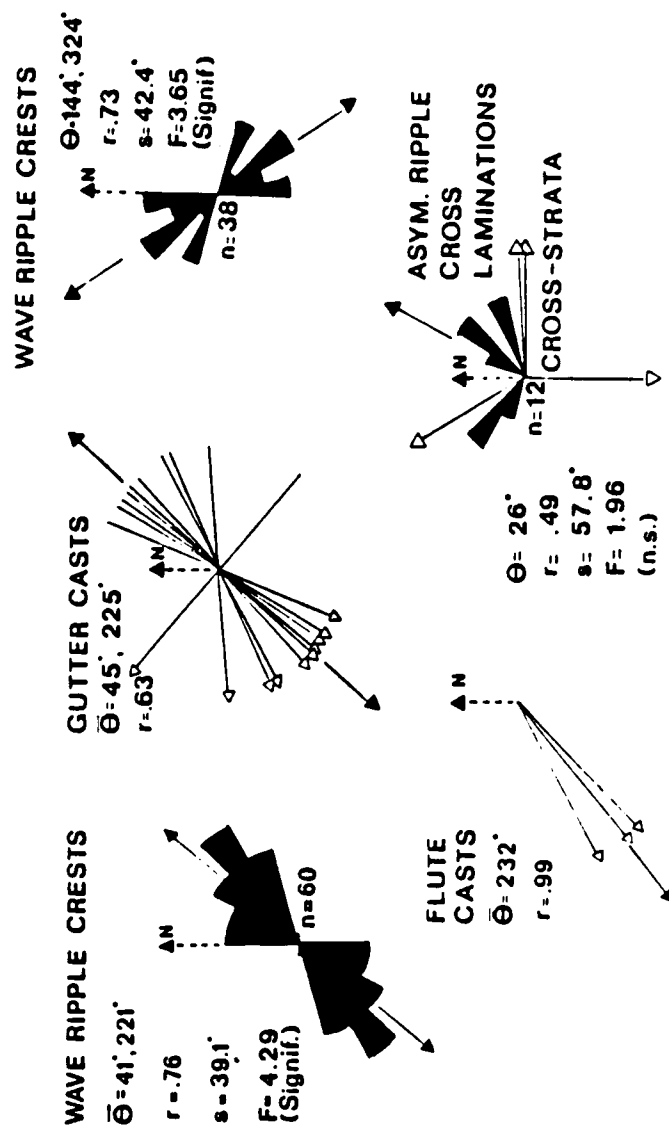


Figure 48. Results of Paleocurrent Analysis.

studies to be statistically viable, twenty-five to thirty data points are usually the minimum necessary (Tucker, 1982). Eight asymmetrical ripple cross-laminations and four trough cross-laminations measurements were collected, equaling twelve altogether, which falls well short of the twenty-five to thirty needed for a meaningful study. The trough cross-laminations had a resultant vector mean of 271.8° , compared to an 11.9° vector mean for the ripple cross-laminations. Combining these two cross-strata data sets reveals a vector mean of 26° . A few rare flute casts were measured all of which indicated direction of flow to the SW (232.3°).

CHAPTER IV

PROXIMALITY TRENDS

Introduction

The proximity concept was introduced by Aigner and Reineck (1982) in their study of storm processes in the North Sea. They concluded that the main characteristics of storm sequences were controlled by water depth and distance from a shore. Storm effects are inferred to decrease with distance from shore and with increasing water depth. Aigner and Reineck (1982) delineated three facies belts (coastal sand zone; transition zone; shelf mud zone), which were based on detailed analysis of the following parameters and their systematic changes with distance from shore (Fig. 49).

Percentage of Sand - The percentage of sand should decrease with increasing distance from shore and conversely the amount of mud should increase. This trend can be attributed to the decreasing capacity of storm-induced currents to move sand into deeper, more offshore environments.

Frequency of Storm Layers - The number of storm layers should reach a maximum (or optimum) in the transition zone. Landward of the transition zone, in the coastal sand facies, the frequency of storm layers decreases for two reasons. First of all, storm layers in nearshore zones tend to be highly amalgamated due to storm beds being destroyed and reworked into succeeding ones. A second reason for low

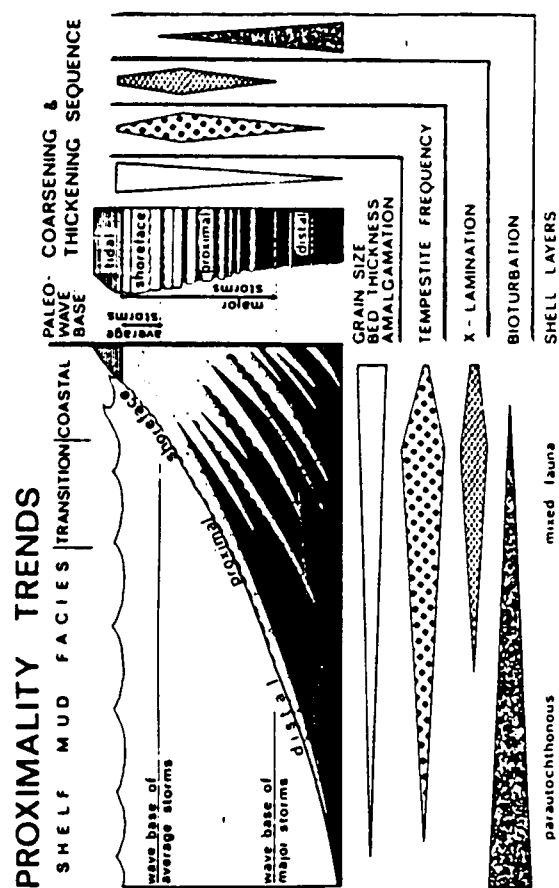


Figure 49. Proximality Concept of Aigner and Reineck (1982).

frequency is that proximal storm sands tend to be very thick (several decimeters), resulting in the number of storm sands per meter of section to be reduced. In distal areas (shelf mud zone), the frequency is reduced because of the increased distance from land (sediment influx decreases with distance from shore) and increased water depth (wave effects decrease with depth, leading to a decrease in erosion and suspension of sediment).

Percentage of Wave-Ripples - The percentage of wave ripples should reach a maximum in the transition zone, just as with storm-bed frequency. Wave ripples are not commonly preserved in shallow, proximal facies due to abundant reworking by subsequent storm events. In distal, deeper water wave ripples are rare to absent due to absence of oscillatory currents.

Storm Layer Thickness - The thickness distribution of storm sands follows a gradual transition from thicker beds in proximal areas to thinner beds in more distal areas. Both the mean and maximum thickness should follow this pattern.

Percentage of Graded Beds - The percentage of graded beds should increase in an offshore direction. These graded beds (similar to turbidites) should show a maximum below storm wave base.

Amount of Bioturbation - In general, the amount of bioturbation should be at a minimum in proximal areas due to more frequent reworking, and also should be restricted to the tops of storm beds.

The amount of bioturbation should increase offshore, due to the overall lower-energy environment of deeper waters.

Coastal Sand Facies - The coastal sand facies represents the most proximal zone of the three facies belts. It is characterized by fine- to medium-grained sands that contain parallel laminations and small-scale ripple bedding. In addition, shell and pebble lags, megaripples, and flaser bedding is common. The shoreface storm sands contained within this facies exhibit erosive bases, followed by shell lags, horizontal laminations, and wave-ripple laminations. Bioturbation is generally at a minimum and tends to be concentrated at the tops of beds. Amalgamation of storm sands is very common.

Transition Facies - Within the transition facies storm sands commonly contain rippled upper surfaces, interbedded mud is more prevalent and graded bedding is rarely present. This zone is characterized by thick (cm to a few dm) storm sands, termed "proximal" sands by Aigner and Reineck (1982) due to their close position to the shoreface source area. The bases of such storm beds are sharp and erosive, commonly containing gutter casts. These proximal storm beds (or tempestites) typically consist of a basal shell lag, followed by horizontal laminations and/or low-angle laminations that, according to Aigner and Reineck (1982), may represent HCS. These storm beds are also generally of a finer grain-size than shoreface sands. Most of the proximal tempestites are overlain by non-bioturbated mud, which represents the final stages of the storm.

Shelf Mud Facies - The shelf mud facies is dominated by silty mud sequences which contain thin, silty-sandstone storm beds. These sands are horizontally laminated and are commonly graded. Bases of beds generally contain shell lags, and are commonly overlain by non-bioturbated muds.

Application to the Rockwood Shelf - The proximity concept of Aigner and Reineck (1982) was applied to the Rockwood Formation in order to provide a more detailed interpretation of the storm dominated, shallow marine setting inferred for the Rockwood Shelf. The analysis of the proximity parameters for each Rockwood facies led to a more accurate determination of each facies shelf position (ex: distal, proximal). These parameters support the inference that Facies H and MB represent deposition below fairweather wave base, and Facies FC, QA, and AH indicate deposition above fairweather wave base. The vertical stacking of these facies records an upward transition from distal to proximal tempestites, indicating the occurrence of repeated progressive shallowing.

Analysis of Figures 50 and 51 reveal how distal facies (shelf-mud zone) are overlain by more proximal facies (transition zone, coastal-sand zone) in the lower, middle and upper portions of the Rockwood Formation. The arrangement of the distal, proximal, and shoreface storm sequences are an indicator of the relative sea-level changes that occurred within the Rockwood.

The determination of distal, proximal, and shoreface storm deposits was based upon the parameters listed in Figure 52. Distal

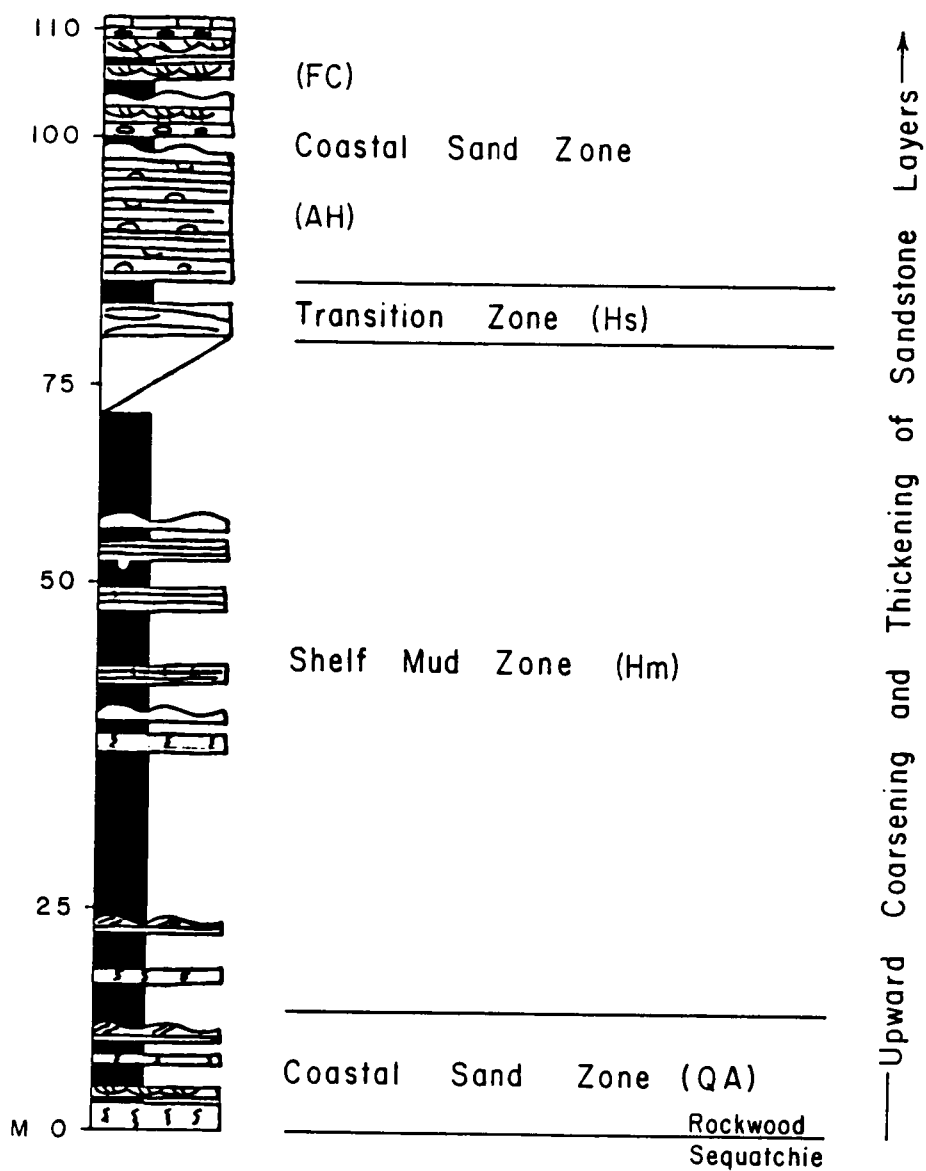


Figure 50. Upward Transition from Distal to Proximal and Shoreface Tempestites.

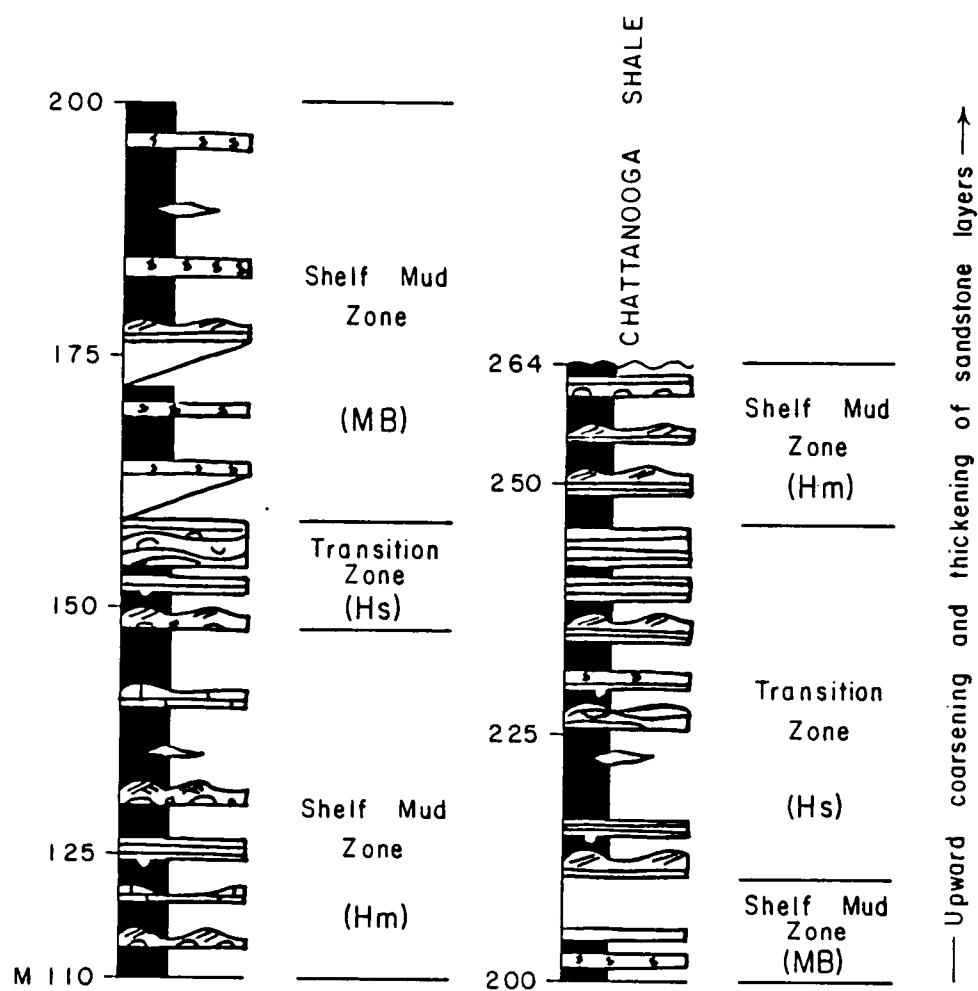


Figure 51. Vertical Stacking of Distal and Proximal Tempestites.

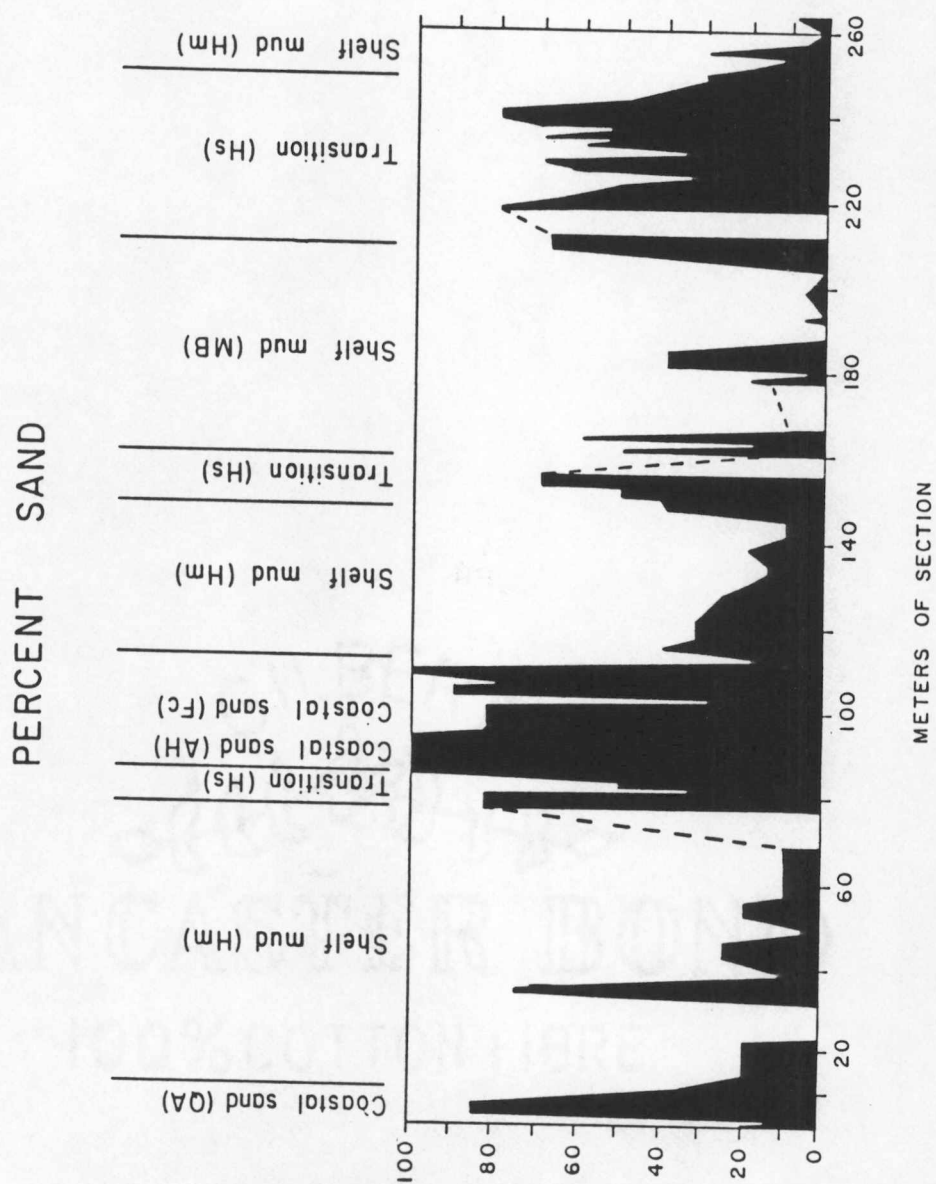
	Percent Sand	Frequency Wave Ripples	Frequency Storm Beds	Bioturbation	Frequency Graded Beds	Mean Bed Thickness	Maximum Bed Thickness	Proximality Classification
Subfacies HM	3-50%; 14-16% Average	Mod/low to Moderate	Low to Mod/low	Low to Mod	Low to Very High	20-24mm	200mm	Shelf Mud Zone
Subfacies HS	50-83%; 70% Average	Mod to Mod/high	Mod to Mod/high	Mod/low to Mod/high	Low to Moderate	44mm	600mm	Transition Zone
Facies MB	0-88%; 11-33% Average	Very Low	Low	Very High	Undetected	25mm	160mm	Shelf Mud Zone?
Facies AH	90-100%; 95% Average	Very Low	Very Low	Very Low	Low	100mm	500-600mm	Coastal Sand Zone
Facies FC	11-100%; 83-90% Average	Mod/low to Mod	Low to Mod/high	Low to Mod/high	Undetected	50mm	500mm	Coastal Sand Zone
Facies QA	9-85%; 83% Average	Mod/low	Mod/low	Mod to High	Low	35-40mm	120mm	Coastal Sand Zone

Figure 52. Determination of Distal, Proximal, and Shoreface Storm Deposits Based on Parameters Listed Above.

tempestites (Hm, MB?), within the shelf-mud zone, were characterized by thinner sandstone beds, lower storm-bed frequencies, and lower percentage of wave ripples (Fig. 53, 54, 55). Overall the percentage of sandstone was low and the amount of bioturbation ranged from low to very high. Graded beds were common in the shelf-mud zone, and reached a maximum in the middle of the Rockwood section.

In contrast, proximal tempestites (Hs) were characterized by a higher sandstone-to-shale ratio, thicker beds, higher storm-bed frequency, and higher percentage of wave ripples (Fig. 53, 54, 55). The amount of bioturbation ranged from moderately low to moderately high, and the frequency of graded beds was low to moderate. The evaluation of these parameters indicates a more proximal (transition zone) location compared to the distal (shelf-mud zone) facies.

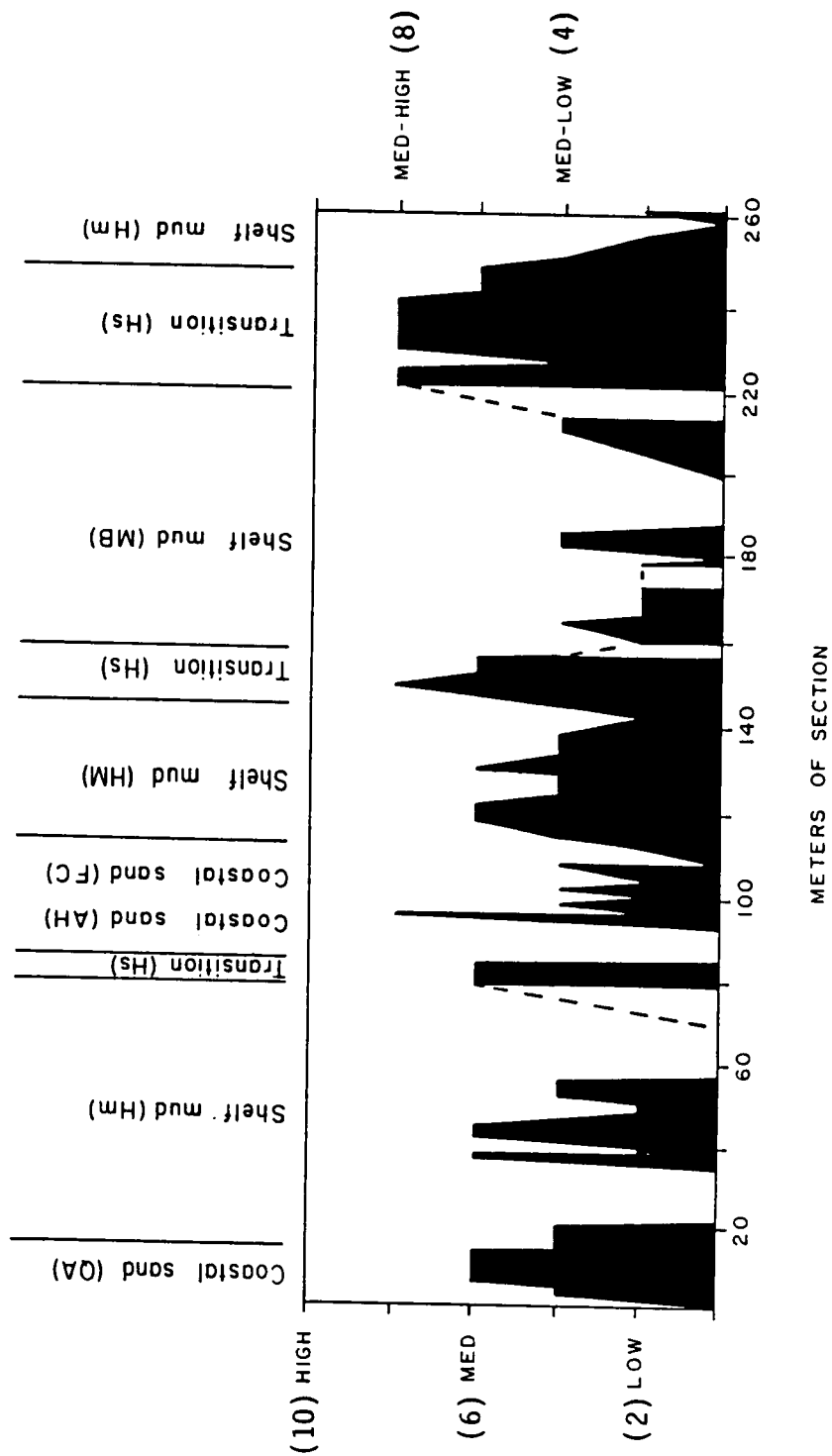
The coastal sand facies (FC, AH, QA) represent the most landward and shallowest of all facies. The sandstone strata are commonly thickly bedded, amalgamated in part, have a high sandstone-to-shale ratio, low storm-bed frequency, and low percentage of wave ripples (Fig. 53, 54, 55). Bioturbation ranges in abundance from low to high, and graded beds are rare. Grain size is at a maximum in this zone (compared to the rest of the section) and the presence of high-angle cross-bedding indicates deposition above fairweather wave base.



A - Percentage of Sand.

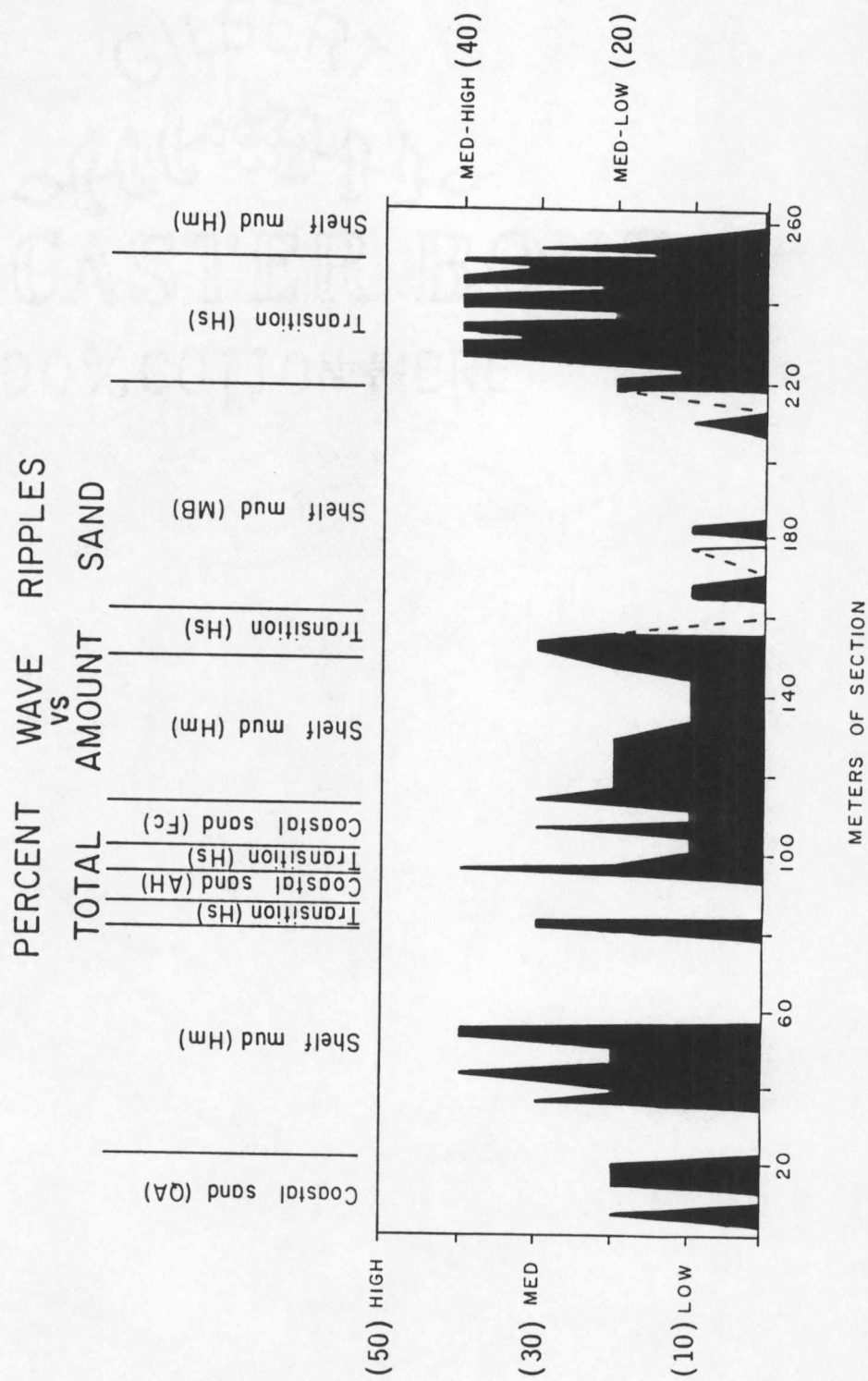
Figure 53. The Application of the Proximity Parameters on the Rockwood Formation.

STORM BED FREQUENCY (PER METER OF SECTION)



B - Storm Bed Frequency.

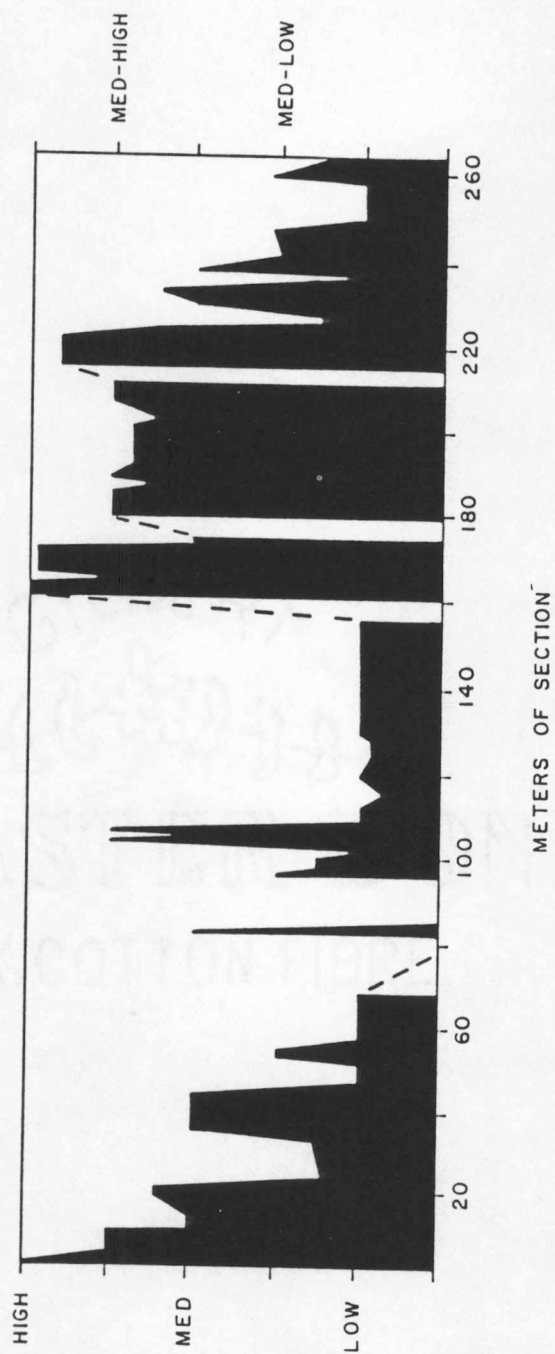
Figure 53. Continued.



C- Percentage of Wave Ripples.

Figure 53. Continued.

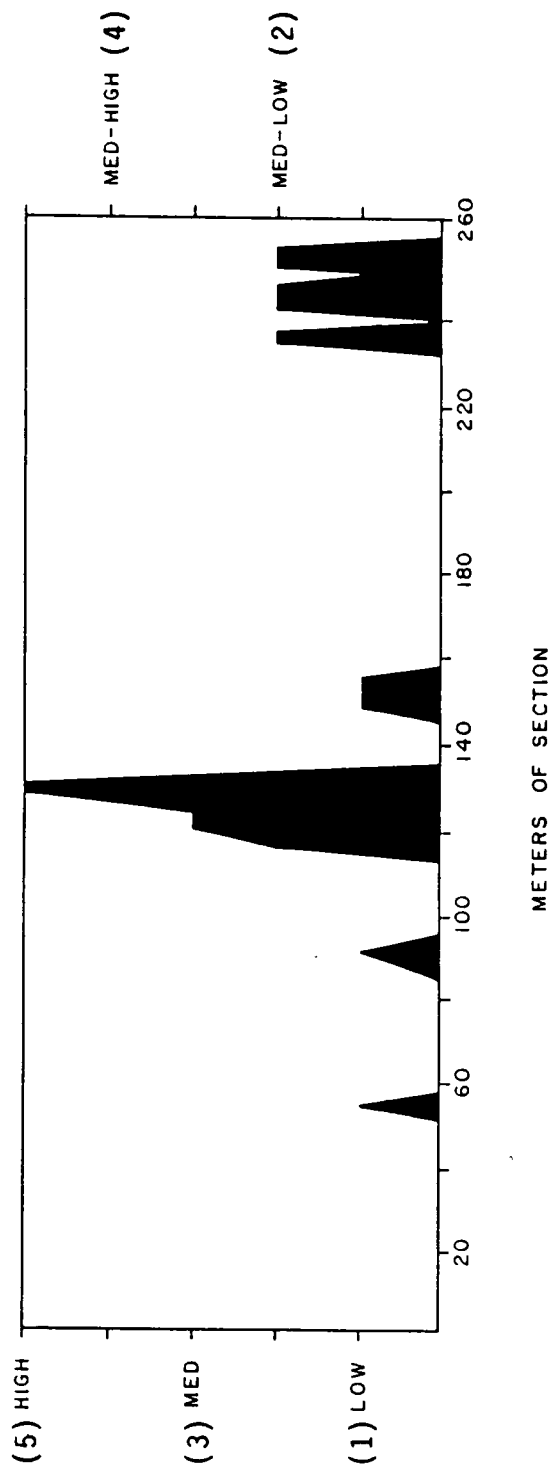
AMOUNT OF BIOTURBATION



D - Amount of Bioturbation.

Figure 53. Continued.

FREQUENCY OF GRADED BEDS (PER METER OF SECTION)



E - Frequency of Graded Beds.
Figure 53. Continued.

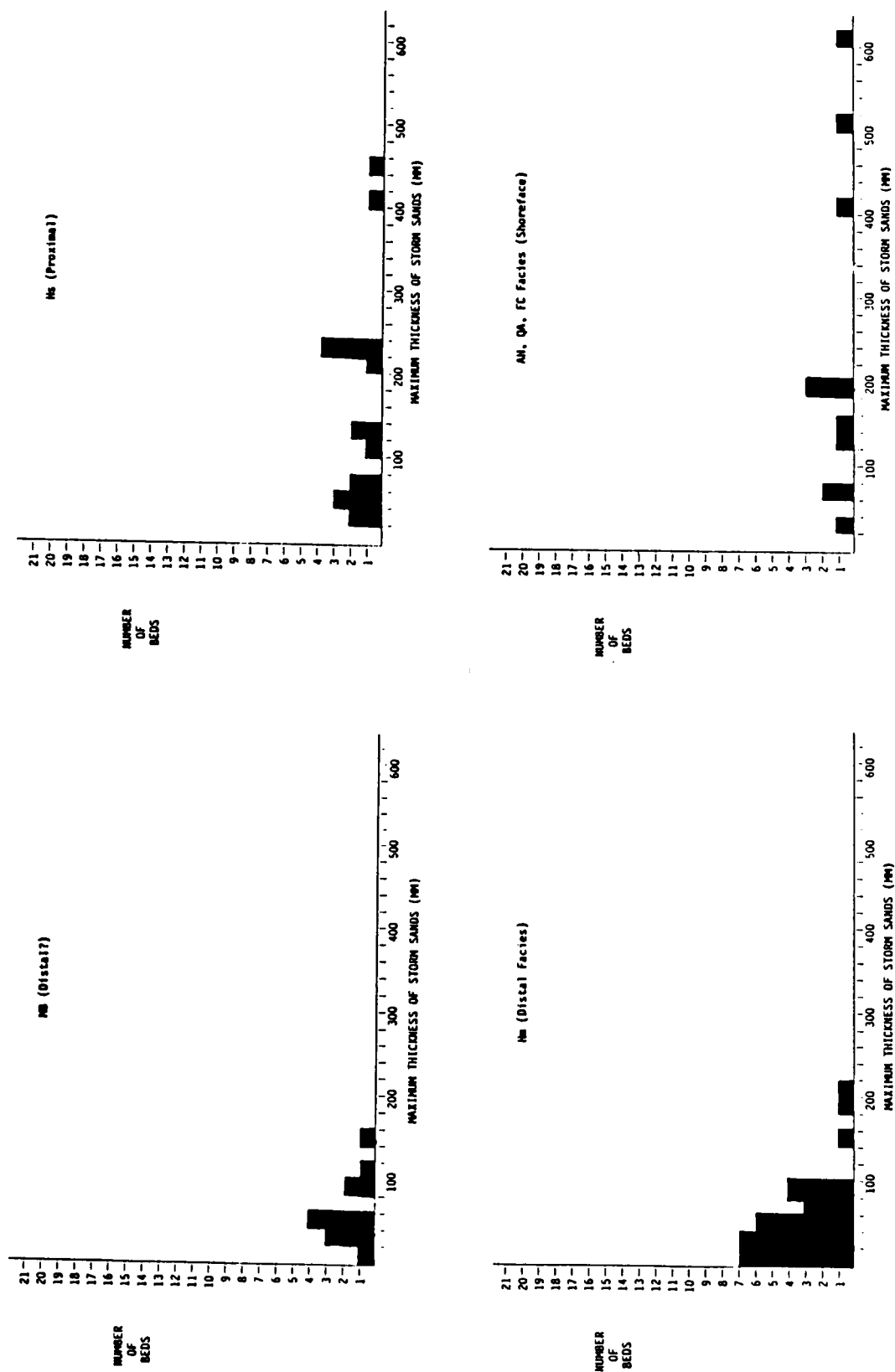


Figure 54. Maximum Thickness of Storm Sands for the Rockwood Formation.

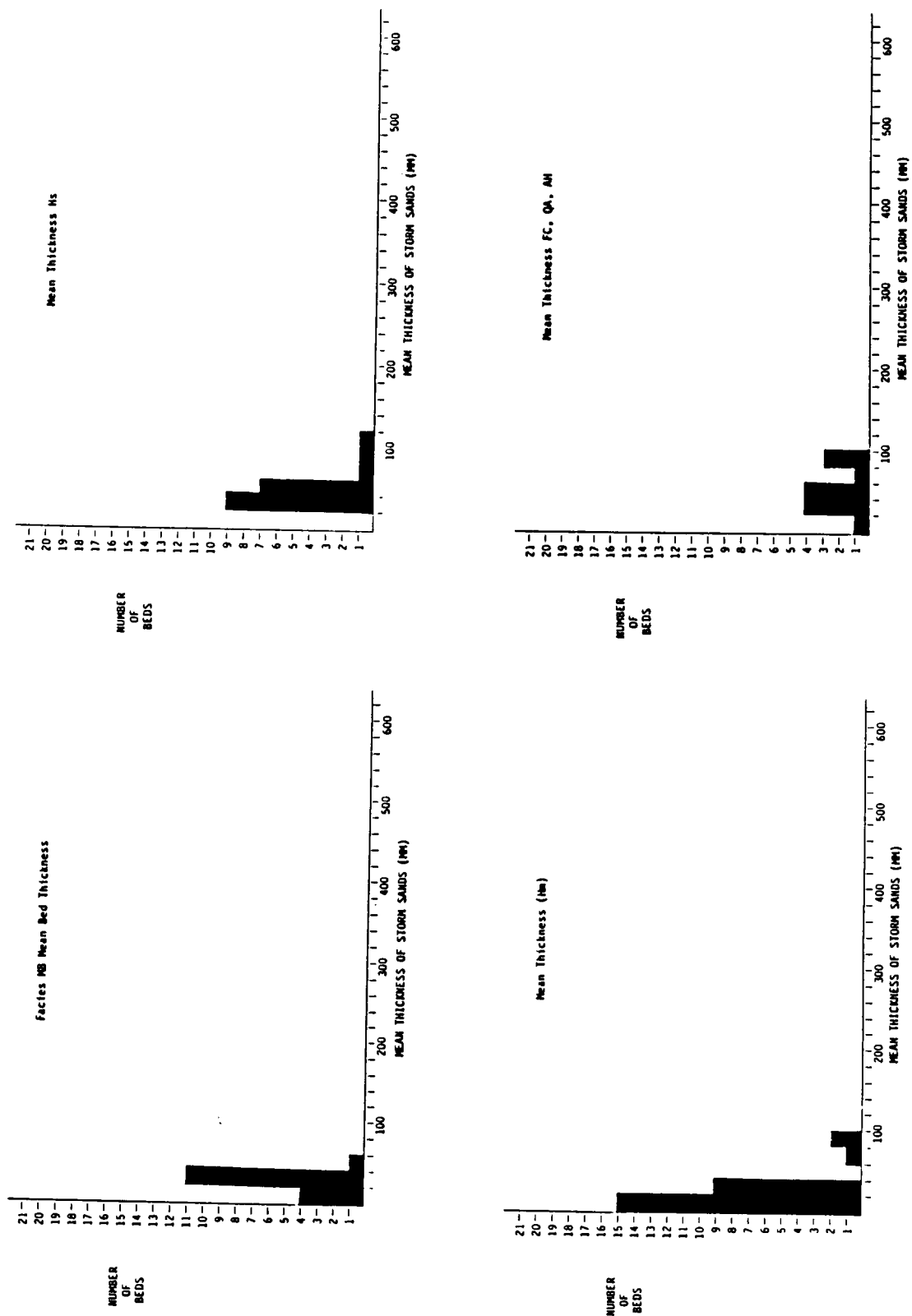


Figure 55. Mean Thickness of Storm Sands for the Rockwood Formation.

CHAPTER V

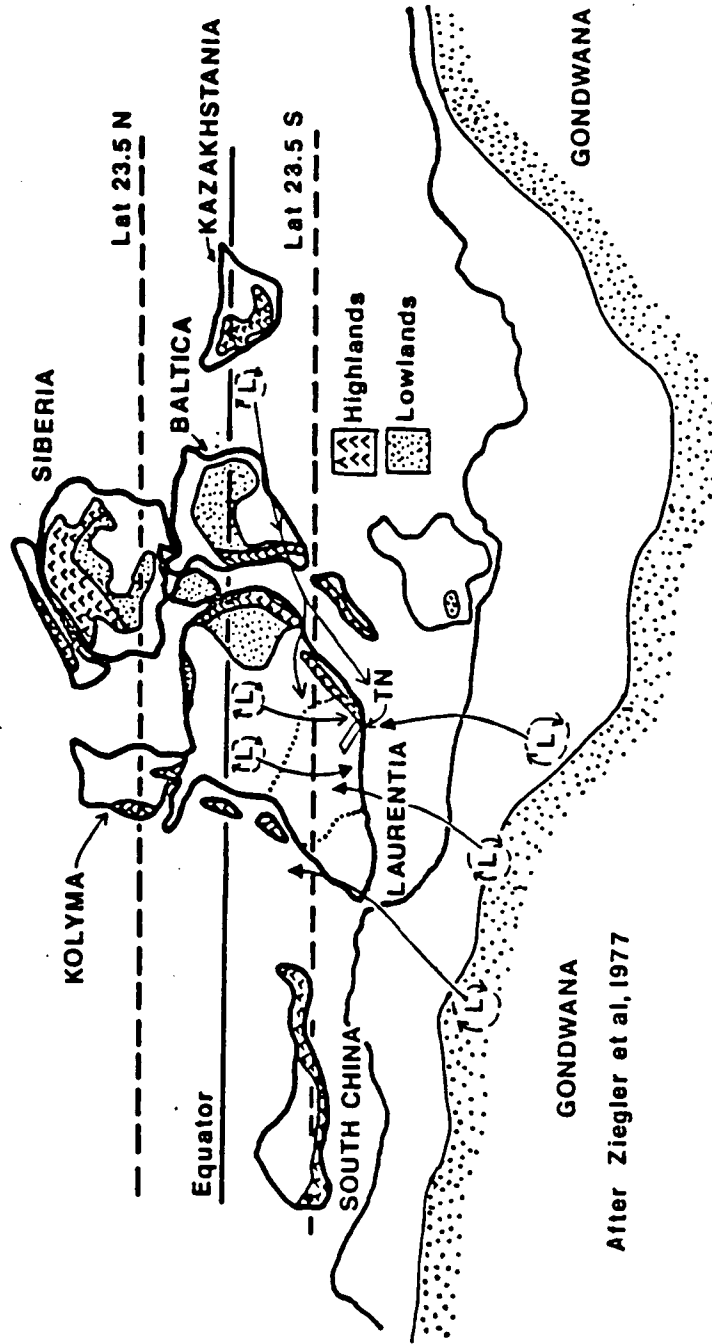
ORIGIN OF THE ROCKWOOD

Depositional Model

The Rockwood Shelf was affected by a variety of hydrodynamic processes including tidal, alongshore, and various storm currents. Deposition on the shelf was dominated by storm processes, with a subordinate amount by fairweather wave and tidal processes. Before an analysis can begin on the synthesis of these processes into a depositional model, a knowledge of the paleogeography and paleoclimatology of the Lower Silurian in east Tennessee is necessary.

Paleogeography and Paleoclimatology - Extensive work has been conducted on Silurian paleogeographic positions of the continents and paleoclimate by Ziegler et al, (1977; 1979). Their studies suggest a paleolatitude position for east Tennessee of 30° south of the paleoequator (Fig. 56). Such a position places the Rockwood Shelf environment southwest of highland source areas, which were in the declining stages of the Ordovician Taconic orogeny. In this setting, east Tennessee would have been influenced by sub-tropical, high-pressure conditions, which were warm and characterized by marked seasonal variations in rainfall. Atmospheric circulation patterns were modeled (by Ziegler et al., 1977; 1979) for both winter and summer conditions. Summer winds, more than likely, were trade winds

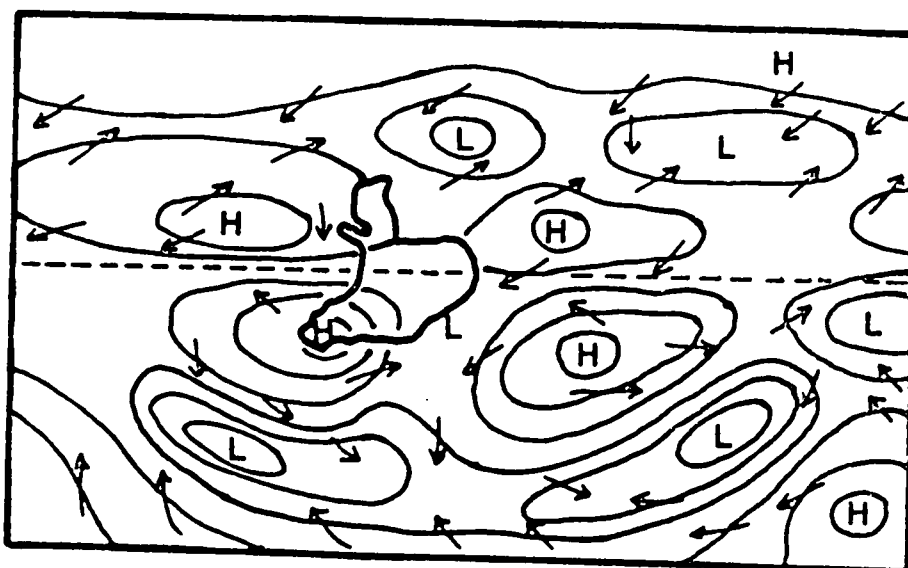
EARLY SILURIAN PALEOGEOGRAPHY & PALEOCLIMATOLOGY



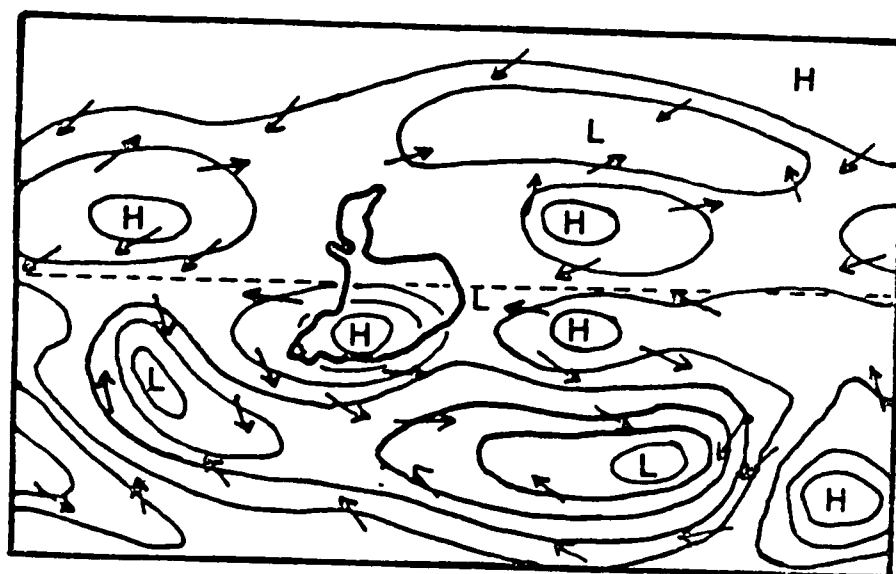
After Ziegler et al, 1977

A - Paleogeographic Positions of the Continents. Low's are Hypothesized Storm Tracks.

Figure 56. Early Silurian Paleogeography and Paleoclimatology (Taken from Driese, et al, 1986a, b).



Southern Hemisphere Summer



Southern Hemisphere Winter

After Ziegler et al, 1977

B - Atmospheric Circulation Patterns for Summer and Winter Conditions.

Figure 56. Continued.

that approached from the east. In contrast, winter winds probably approached from the southwest.

The paleoshoreline during Rockwood time has been postulated to trend in a northeast-southwest direction (Driese, 1986 a, b). Driese (1986 a, b) has applied Swift and Niedoroda's (1985) storm-surge (coastal set-up) model to the Rockwood Shelf (Fig. 57), and it appears that winds from the west, northwest, and northeast would have resulted in coastal set-up conditions. The result of such a set-up would be the generation of an offshore-oriented bottom-return flow. This then would evolve into a southwesterly directed geostrophic flow. It will be shown in the following section that paleocurrent data support the existence of a southwesterly oriented geostrophic flow, in addition to onshore storm waves (NW-SE) and alongshore waves (NE-SW).

Interpretation of Paleocurrent Data - In general there were two wave-ripple-crest trends in the Rockwood, those oriented parallel (to slightly oblique) to paleoshoreline and those oriented perpendicular to paleoshoreline. These ripple crests were analyzed in terms of their position relative to the proposed shoreline. In the distal facies, NW-SE trending ripples (perpendicular to shoreline) were slightly more common than NE-SW ripples (parallel to oblique to shoreline). Conversely, in more proximal facies, ripple crests were dominated by NE-SW trending ripples (parallel to oblique to shoreline), with a subordinate amount of NW-SE trending ripples (perpendicular orientations with respect to shoreline). An amazingly similar

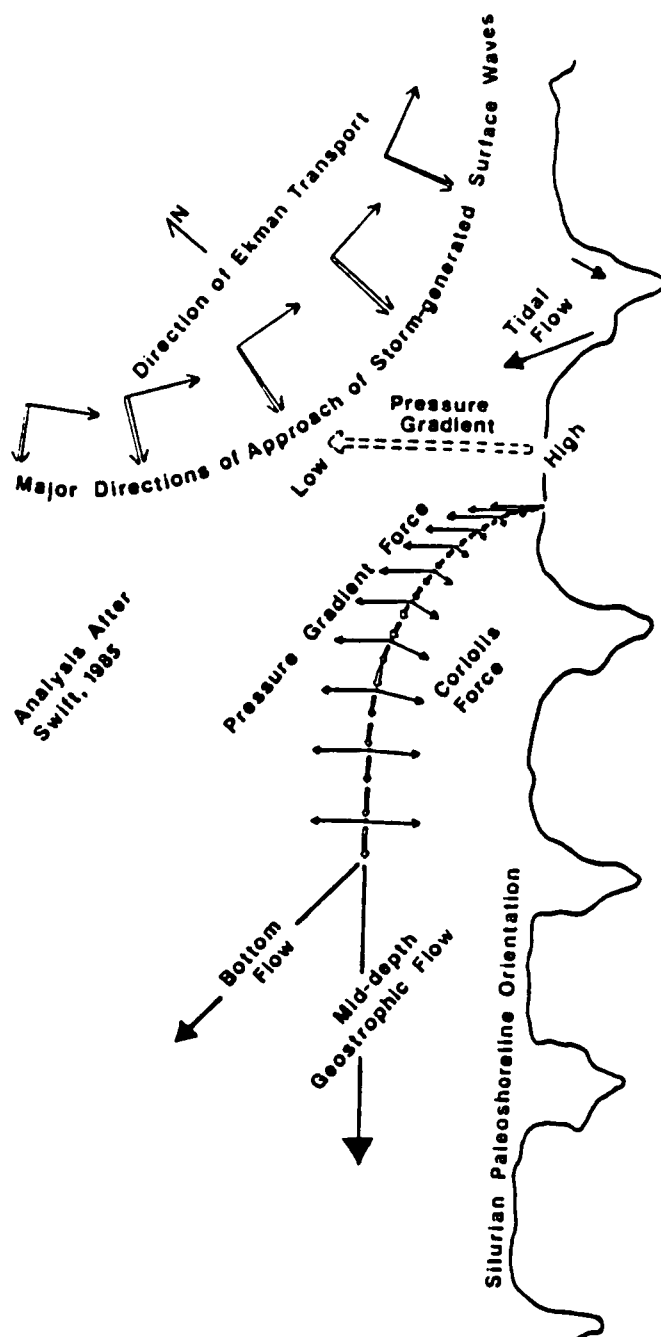


Figure 57. Application of Swift and Niedoroda's (1985) Coastal Set-up Model to the Rockwood Shelf (taken from Driese et al., 1986 a, b).

pattern was documented by Aigner (1985) from his study of the South German Basin. He also noted a greater percentage of parallel-oriented wave-rippled crests in nearshore areas, and of perpendicular-oriented wave-rippled crests in distal zones. This type of pattern indicates that in distal portions of the shelf, alongshore winds and storm systems were producing alongshore wave trains in deeper water. Then in response to the Coriolis force, alongshore winds would drive the water towards shore, resulting in the greater percentage of parallel wave-ripple orientations in the more proximal settings.

Both the gutter casts and flute casts detected at the bases of the storm beds indicated flow was to the southwest. This direction was more or less parallel with the paleoshoreline, indicating the presence of very erosive, alongshore, bottom-hugging flows. This erosive flow may be the result of storm-surge-ebb (relaxation) flows, which evolved into geostrophic flows that traveled parallel to isobaths. Most of the erosive structures indicating flow to the southwest were associated with the more distal portions of the section. This implies it may have taken a finite travel distance for the Coriolis force to deflect the relaxation flow and create the geostrophic current. Proximal portions of the section were lacking in erosive features (such as gutter casts) on the soles of storm beds, which may indicate the geostrophic flow had not completely evolved within that portion of the shelf.

Dynamic Zones of the Coastal Ocean - The differences in paleocurrent data (wave ripple crests, gutter casts, flute casts) between the distal and proximal portions of the section may be a function of different coastal zones. Swift and Niedoroda (1985) have hypothesized that the shoreface and inner shelf consist of distinct dynamic zones (Fig. 58). The inner most zone seen in Figure 58 is the surf-zone, which was not detected at the section on Whiteoak Mountain. Seaward of the surf-zone lies the friction dominated zone, which is a turbulent sector where the effect of bottom friction influences all flows. In this zone the effects of the Coriolis force are reduced due to shallow water depth and strong turbulence. The result of these factors is to cause the currents to flow shore-normal, or along the horizontal pressure gradient. Beyond the friction zone lies the geostrophic zone. The differences in the dynamics that characterize these two zones are mainly a function of water depth. Here in the geostrophic zone, friction has less of an effect, and the influence by the Coriolis force is greater. In this zone, currents tend to flow normal to the horizontal pressure gradient, or shore-parallel. According to Swift and Niedoroda (1985) the friction-dominated zone extends to approximately 10m of water depth. In comparison, the geostrophic zone does not extend any farther landward than about 30-50m of water depth. In between these two zones lies a transition zone that contains characteristics of both sectors.

Swift and Niedoroda's (1985) model for coastal zones can be applied to the Rockwood Shelf. The distal portion of the Rockwood

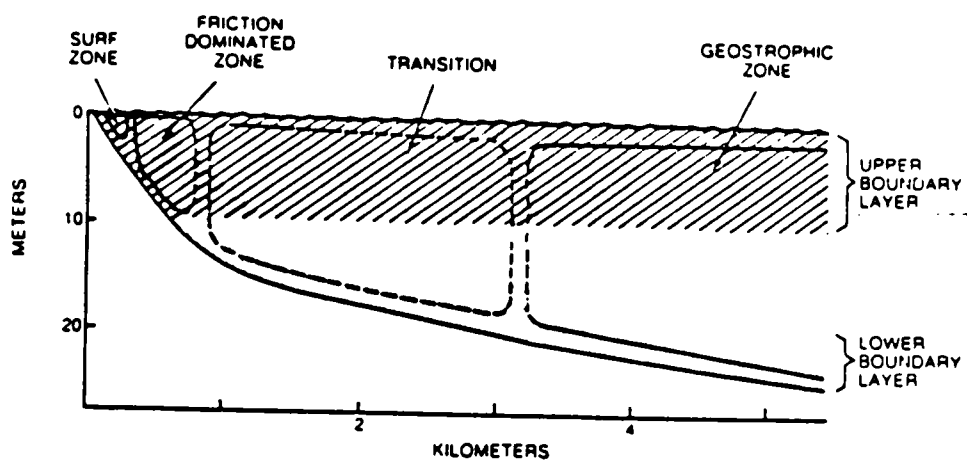


Figure 58. Dynamic Zones of the Coastal Ocean (Swift and Niedoroda, 1985).

Formation represents deposition within the geostrophic-dominated zone, in which the effects of friction were reduced and the Coriolis force was a dominant factor. The southwest direction of gutter casts and flute casts, and the dominance of wave-ripple crests perpendicular to shore (sense of flow NE-SW) are in accordance with Swift and Niedoroda's predicted model for the direction of flow in the geostrophic zone. In addition to the NW-SE trending ripple crests (perpendicular to shore), a high percentage of the ripple crests were oriented to the NE/SW (parallel to shore). The presence of the shore-parallel ripple crests (though not as abundant as the shore-perpendicular ripple crests) indicates the influence of the friction-dominated zone where currents tend to flow shore-normal. The encroachment of the friction-dominated zone in the distal portion of the Rockwood section is probably a function of intensity of the forcing mechanisms. Extreme conditions may result in expansion or contraction of these zones, depending upon the conditions (Swift and Niedoroda, 1985).

In contrast, the proximal portion of the Rockwood was dominated almost exclusively by shore-parallel crests. This indicates the greater effect by bottom friction on all flows in this part of the Rockwood Shelf. A subordinate amount of shore-perpendicular ripple crests were detected, supporting the influence of the Coriolis force in this sector, although it was of lesser importance.

Individual Strata and Hydrodynamic Processes - In addition to the hydrodynamic information that can be gained from paleocurrent data,

the analysis of the individual strata unveils much about the flows that created them. In general, the strata of the Rockwood can be classified into three hydrodynamic regimes: (1) deposition above fairweather wave-base; (2) deposition below fairweather wave-base but above storm wave-base; and (3) deposition below storm wave-base(?).

Some of the strata within the most distal (and deepest?) part of the section lacked evidence for oscillatory flow. Typically these beds were horizontally laminated or graded. The absence of wave formed features implies deposition may have been below storm wave-base. These beds were probably deposited by storm-generated unidirectional flows and were not reworked by storm waves due to great water depth.

The strata that did contain evidence for oscillatory flow indicates deposition above storm wave-base (below fairweather wave-base) by combined-flow currents. It can be assumed that the flows that created the beds below storm wave-base were also responsible for the beds above storm wave-base, however, beds above storm wave-base were reworked by oscillatory flow, leading to their complex, combined nature. Features indicative of combined flow currents were form-discordant wave-ripples, HCS, micro-HCS, and graded bedding. Within this realm, both the action of the unidirectional flow transporting the material and storm waves impacting the sea bottom influenced the resultant sedimentary structures. The degree of influence by oscillatory wave currents appears to be a function of water depth. As the intensity of the wave (oscillatory) component changes, so does the

corresponding shelf strata. Swift and Niedoroda (1985) have devised a model (Fig. 36, p. 72), which shows the distribution of strata-types in a shallow shelf environment. There are three zones (excluding the graded mud beds) in their model that appear to be differentiated upon the characteristic sedimentary structure. The cross-bed zone indicates deposition above fairweather wave-base. The hummocky zone is below fairweather wave-base and indicates a regime where the wave orbital current component is high relative to the mean flow component (Swift and Niedoroda, 1985). The deposition of HCS probably was the result of geostrophic storm flows combined with wave orbital currents (Swift, et al., 1983). The graded bed zone is seaward of the hummocky zone and is characterized by beds deposited from suspension by tidal or storm flows. These flows were typically combined flows, but the absence of hummocks suggests the ratio of the wave orbital current component to the mean flow component was very low. It is postulated here that Swift and Niedoroda's model can be applied to the sequence of features seen in the Rockwood. Figure 59 is a hydrodynamic model (for the Rockwood Formation), which is a combination of Swift and Niedoroda's coastal zone model and distribution of strata-type model. The sequences deposited above fairweather wave-base, in the friction-dominated zone, were Facies FC, QA, and possibly AH(?), where deposition was dominated by tidal and storm currents. The sequences deposited below fairweather wave-base, in the transition and geostrophic zones, were sub-facies Hs, Facies MB, parts of sub-facies Hm, and possibly Facies AH(?), where the influence of

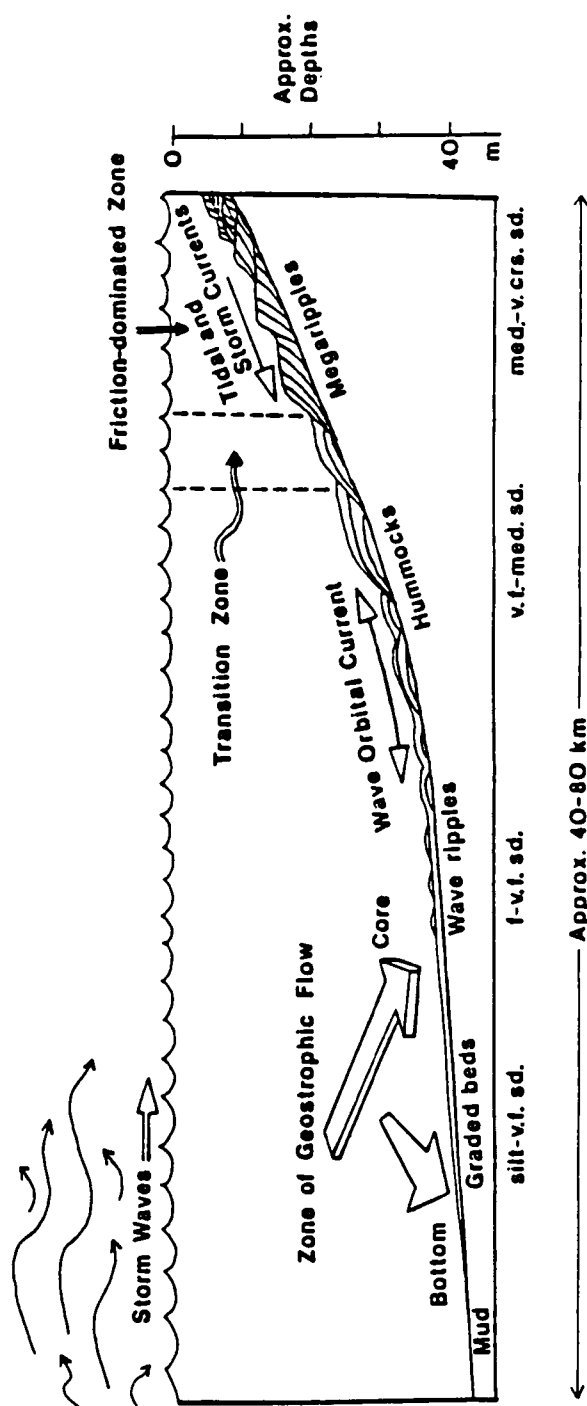


Figure 59. Hydrodynamic Model for the Rockwood Formation. (Driese et al., 1986a, b, (in preparation)).

wave-orbital current is high and deposition is dominated by storm flows. Farther seaward lies the zone of graded beds, in the geostrophic zone, where the influence of oscillatory currents is reduced. This is analogous to the more distal portions of the section (parts of sub-facies Hm) where wave-formed features are rare.

Fairweather Processes - The majority of the preceding discussion has investigated the effects of storm flows on the Rockwood Shelf. However, most of the Rockwood Formation is composed of mudstone strata that indicates fairweather deposition. Figure 60 depicts the postulated fairweather conditions that existed in this shallow-marine setting. During fairweather periods below fairweather wave-base, the sea-floor was dominated by suspension sedimentation of fines and partial bioturbation of storm beds. Above fairweather wave-base fairweather tidal and wave reworking of storm sand sequences occurred. This reworking of storm sequences above fairweather wave-base erases most of the evidence for storms in this setting.

Relation of the Rockwood to Equivalent Strata

The purpose of this section was to correlate the Lower Silurian Rockwood Formation at Whiteoak Mountain to equivalent rocks to the east (Clinch Sandstone), the north (Tuscarora Formation; Medina Group; Clinton Group) and to the south (Red Mountain Formation). Biostratigraphic correlation between Formations was difficult because of the general lack of body fossils. Lithostratigraphic correlations were made between similar facies sequences.

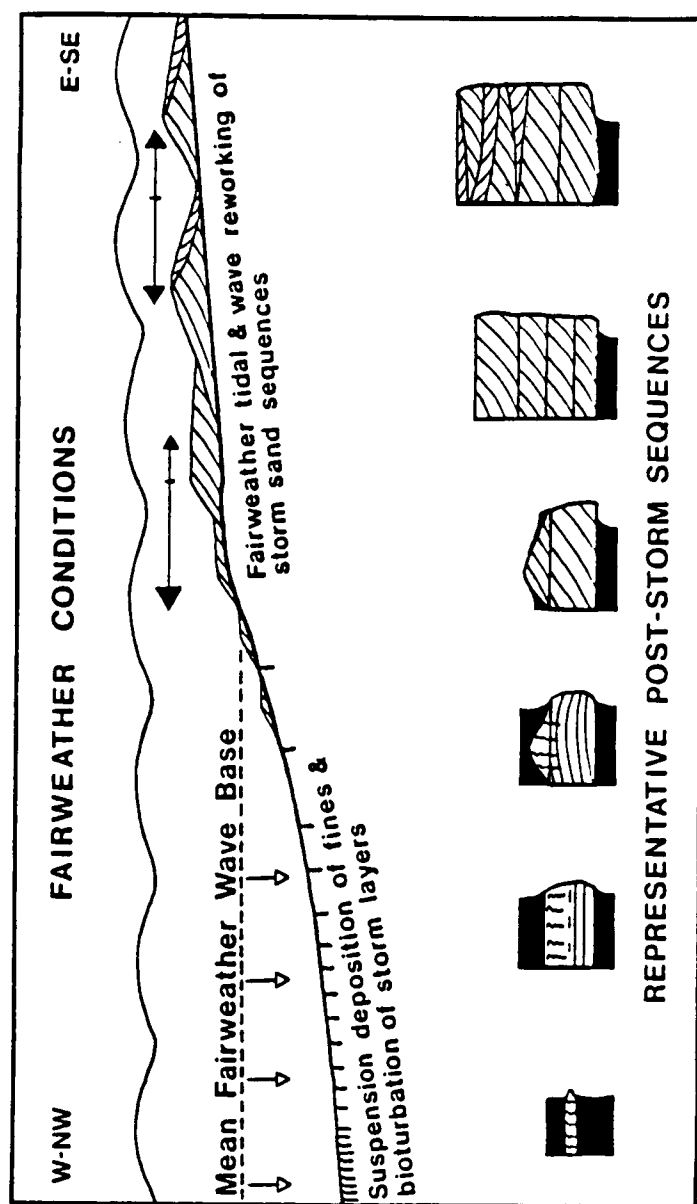


Figure 60. Postulated Fairweather Conditions on the Rockwood Shelf (Driese, 1986a, b).

It has generally been thought that the Rockwood is contemporaneous with the Clinch Sandstone, which lies to the east and represents deposition in littoral environments (Miller, 1976; Thompson, 1984). However, the age of the Upper Rockwood (C3-C5) is younger than the Clinch Sandstone (C2-C3, Berry and Boucot, 1970), implying only the lower Rockwood may be equivalent. The Clinch Sandstone is divided up into a basal Hagan Shale Member (intercalated sandstone and shale), and overlying Poor Valley Ridge Member (super-mature quartz-arenite) (Fischer, pers. comm.). In some areas to the east and north (e.g., along Powell Mountain, near Duffield Virginia) where erosion along an unconformity surface has not removed too much section, a maroon-red, heavily bioturbated silty sandstone and mudstone interval containing mudcracks (indicating emergence) caps the Poor Valley Ridge member (Marks, pers. comm.). This vertical succession of facies indicates an upwards shoaling event. Similarly, the lower Rockwood represents a shallowing event where distal mud facies (Hm) are overlain by more proximal facies (Hs) and coastal sand facies (AH, FC). Possibly the heavily bioturbated, mud-cracked emergent interval at the top of the Clinch at Powell Mountain is equivalent to Facies FC in the middle of the Rockwood, which represents the shallowest conditions in the Formation.

A similar emergent facies was described by Cotter (1983) in central Pennsylvania overlying the Tuscarora Formation, which is a Lower Silurian Clinch Sandstone equivalent. The interval was termed the Castanea Member by Cotter (1983) and is a thin, regressive red-bed

sequence interpreted as a progradational coastal sand/mud flat complex. The top of the Tuscarora has been dated at mid-Llandoveryan (C2-C3), which correlates with a eustatic regression during that same time (C2-C3; McKerrow, 1979). Possibly the eustatic regression during C2-C3 time that resulted in the progradation of the Castanea Member, also was responsible for the emergent-mud cracked interval capping the Clinch along Powell Mountain and the shallowing event detected in the middle of the Rockwood. However, this is only a supposition and would need to be substantiated by fossil data.

In central Pennsylvania the offshore equivalent of the Tuscarora is the Medina Group, which exhibits a sequence of facies similar to the lower Rockwood. The Medina Group is composed of the Whirlpool Sandstone, the Cabot Head Shale, and the Grimsby Formation (Laughrey, 1983). The basal Whirlpool Sandstone represents a transgressive sandstone resting on older deltaic coastal-plain sediments of the Queenstown Formation (Upper Ordovician). Shelf muds of the lower most Cabot Head Shale overlie the Whirlpool. A progradation of the shoreline resulted in deposition of silty-sands and lower shoreface sands of the upper Cabot Head. These units are succeeded upwards by middle and upper shoreface and nearshore sands of the lower most Grimsby. The uppermost Grimsby formed in a prograding coastal sand/mud complex. The Grimsby Formation has been interpreted to be equivalent to the Castanea Member of the Tuscarora Formation (Laughrey, 1983). The progradational, vertical stacking of facies is analogous

to the lower Rockwood and other Lower Silurian Formations, such as the Clinch and Tuscarora.

Resting on top of the Medina Group in the northern Appalachian basin is the "Middle" Silurian (Upper Llandoveryan) Clinton Group. The Clinton Group was formed by a transgression of the sea (during C4 time, Cotter 1983) in the Upper Llandovery of central Pennsylvania. Fossil evidence from the Rockwood suggests mid-Upper Llandoveryan to possibly late-Upper Llandoveryan age, indicating the upper Rockwood may be equivalent to at least part of the Clinton Group. Additional evidence supporting a correlation between the two was the transgression that occurred just above Facies FC in the middle of the Rockwood section. It is postulated that this event correlates with the transgression (during C4 time) that initiated the deposition of the Clinton Group in central Pennsylvania.

Equivalent rocks to the south of Whiteoak Mountain are represented by the Lower and Middle to Upper Llandoveryan Red Mountain Formation. Sequences of facies within the Red Mountain Formation at Ringgold, Georgia correlates well with those at Whiteoak Mountain. The base of the Red Mountain is characterized by a transgressive sequence that is succeeded upwards by interbedded sandstones and shales. Overlying these facies are littoral environments, indicating a shallowing event occurred in the middle of the section. This shoaling upwards sequence may correlate with the shallowing event in the lower half of the Rockwood. Chowns (1972) indicated that the upper Red Mountain Formation is mid-to-Upper Llandoveryan, which cor-

relates well with the speculated age dates for the upper Rockwood. Similar facies are present in the two Formations, such as the maroon-burrowed Facies in the upper Rockwood and the red-shale facies in the upper Red Mountain.

It must be emphasized that the preceding discussion of the possible equivalency of the Rockwood to other strata was based largely on loose age constraints. Accurate time lines based on fossil data are lacking in the Silurian sequences of the Appalachian basin, leaving many correlations to be based on similar facies associations. More fossils need to be collected and dated to provide more reliable correlation.

Modern Analogue(s)

One of the more difficult tasks with the study of the Rockwood Shelf environment was trying to find an adequate modern analogue. The difficulty of such an analogy between the modern and ancient lies in the inherent complex nature of marine shelves. Most modern marine shelves are extremely complex and poorly understood and are typified by many depositional processes (such as tidal currents, wave activity, etc.). In addition, the Holocene transgression has left most of the world's shelves in a state of disequilibrium. The combination of these factors has resulted in modern shelves serving as poor analogues to what is seen in the ancient. Processes operating on modern storm-dominated shelves and tropical shelves where iron is forming are summarized in Figure 61. Unfortunately none of these modern

Author(s)	Location	Setting	Product	Depositional Conditions
Johnson (1978) Kulm et al., (1975) Smith and Hopkins (1972)	Oregon- Washington Shelf	Inner, Middle and Outer Shelf	Sand Facies - Relict sand and gravels; Intense bioturbation; horizontal laminations common. Mixed Sand and Mud Facies. Biogenically reworked sand and Mud. Mud Facies - found in middle to outer shelf environments.	Storms effect inner, middle and outer shelf environments with variable intensity. Tides and semi-permanent cur- rents are of minor importance. During fair-weather periods, biogenic reworking is intense.
Johnson (1978) Swift et al., (1983) Beardsley and Butman (1974)	Atlantic Shelf of Eastern North America	Inner and Middle Shelf	Shelf is represented by a complex sand ridge topography that is a result of detach- ment and reworking of a bar- rier shoreline during Holocene transgression.	Dominant physical mechanism are storm-induced currents. Winter winds create coastal set-up conditions, resulting in seaward flowing gradient currents. Superimposed storm wave activity enhances the eros- ive nature of these storm flows.
Aigner and Reineck (1982) Aigner (1985)	Helgoland Bight (North Sea)	Inner to Middle Shelf	Systematic distribution of storm beds, with thicker, amalgamated tempestites indi- cating nearshore conditions, and thinner tempestites inter- calated with mud representing more distal conditions.	Lateral sediment transport from nearshore to shelf regions by seaward-directed gradient- currents.
Hayes (1967) Morton (1981)	Gulf of Mexico	Inner to Middle Shelf	Proximal storm deposits consist mainly of sand. The number and thickness of discrete storm lay- ers decreases between proximal and distal units. Distal zones reveal beds with erosional con- tacts containing shell lags, parallel laminations, and small scale ripple cross laminations.	Storm dominated basin with a low amount of wave and tidal activity. Seaward directed flows evolving into geostrophic flows have been documented.
Porrenga (1976)	Niger Delta (Africa)	Inner Middle and Outer Shelf	Zoned distribution of goethite, chamosite, glauconite. Minerals temperature and depth control- led. Chamosite detected form- ing in tests of organisms.	Open marine setting (low wave energy). Iron transported by continental erosion via the Niger River.

Figure 61. Processes Operating on Modern Storm Dominated Shelves.

environments sufficiently explains the features contained within the Rockwood Formation. Factors discounting these as suitable modern analogues are relict sediments, improper hydrodynamic settings and lack of iron sedimentation (except in the case of the Niger Delta). The comparison of the Rockwood to ancient storm sequences proved more fruitful and will be discussed in the following section.

Relation to Similar Storm Sequences

Suitable modern analogues were scarce for the Rockwood, whereas similar ancient storm sequences were abundant. This may be attributed to the rare event (storm deposition) being over-represented in the rock record. In the following discussion two ancient storm sequences will be analyzed and compared to what is seen in the Rockwood Formation.

Aigner's (1985) study of the Upper Muschelkalk (Middle Triassic) of the South-German Basin revealed dynamic processes similar to those in the Rockwood. The Muschelkalk carbonate environment was dominated by episodic, high-energy storm-events that affected the details of stratification and controlled the overall facies organization. The combination of paleocurrent data and the analysis of facies sequences allowed for the reconstruction of the hydraulic regime. Storm tracks in the Muschelkalk were probably alongshore, (inferred from wave ripples, bipolar tool marks, gutter casts, and cross-bedding foresets). Such alongshore storm tracks would create a combined geostrophic bottom flow traveling parallel to shore, similar to what has been

documented in the North Atlantic by Swift et al, (1983). These combined (geostrophic) flows explain the bipolar impacts and gutter casts at the bases of distal tempestites. Winds would also drive water landwards, to the right of the wind, in response to the Ekman transport (Coriolis effect). The resultant seaward flow was documented by onshore-offshore oriented storm channels, in addition to sole marks and imbrication in proximal tempestites.

The hydrodynamic model of combined (geostrophic) flow for the Muschelkalk correlates well with the data collected from the Rockwood. In addition, both Aigner's (1985) study and the present study on the Rockwood support Swift et al's, (1983) hypothesis that combined-flow currents should be the typical response of ancient epi-continental seas to storms.

The ancient sequence that correlates best with the Rockwood is the "Middle" Silurian Rose Hill, Keefer, and Mifflintown Formations of central Pennsylvania (Cotter, 1983). The "Middle" Silurian was divided up into heterolithic (interbedded sandstone or grainstone and mudstone) and monolithic (mudstone, sandstone, or grainstone) associations. Cotter interpreted the heterolithic association to represent storm deposition. The monolithic associations were strongly influenced by sea-level changes. When sea-level lowered, hematite-chamosite-rich sediments or quartz arenite (megaripples) formed and when sea-level rose, black (anaerobic) shale covered the area. Many of the bedding sequences of the heterolithic association were similar to the ones in the Rockwood. For example, Cotter documented hummock-

like wavy surfaces, starved-hummocks, HCS, graded beds with shell lags, and gutter casts.

It appears that the Rockwood depositional environment was most closely related to the "Middle" Silurian sequence of central Pennsylvania, described by Cotter (1983). The similarity of individual strata and the abundance of iron-rich sediments allowed for a suitable comparison.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Deposition of the Lower Silurian Rockwood Formation occurred within a subtidal, shallow marine environment. The shallowest, most nearshore portion of the shelf was dominated by megarippled and rippled sand shoals (Facies FC) deposited above fairweather wave base, and subtidal, lower shoreface storm sands (Facies AH) deposited below fairweather wave base. In this shallow, nearshore environment, conditions were favorable for the transportation and concentration of iron. Tidal currents and both fairweather-wave and storm-wave flows affected this environment. The effect of storms was to erode this nearshore environment, and transport sand and skeletal debris (some of which was replaced by iron) below fairweather wave base, out into deeper portions of the shelf.

Conditions below fairweather wave-base were for the most part, quiet and placid, with little agitation. Oxygen was typically limited and restricted the occupancy of soft-bodied infauna and calcified species. Occasionally storm flows deposited sharp-based sandstone and bioclastic limestone beds in this environment. The abundance of skeletal debris within the storm beds implies skeletal sand banks were present in the nearshore environment, associated with the megarippled and rippled sand shoals. The storm beds deposited above storm wave-base exhibit features indicative of combined-flow currents

such as form-discordant wave ripples, HCS, micro-HCS, and some graded bedding. Within this realm, both the action of the unidirectional flow transporting the material and storm waves impacting the sea bottom influenced the resultant sedimentary structures. Once the storm flows occurred below storm wave base, the effects of oscillatory currents were greatly reduced. In these areas, beds were typically graded and contained horizontal laminations, and were deficient in such wave-formed features as symmetrical ripples, hummocky bedding and form-discordant wave ripples.

The most probable transporting mechanism by which sand and skeletal debris was transported from the nearshore zone out into the dysaerobic-slightly anaerobic environment was by storm-surge-ebb currents that evolved into geostrophic flows. Such flows were a consequence of coastal set-up conditions, caused by the pile-up of water onshore, which resulted in a seaward-directed storm-surge-ebb current. Paleocurrent evidence suggests that as the unidirectional flow was moving seaward (farther away from the friction dominated zone), the Coriolis force became more prominent, and the flow entered the geostrophic zone where it evolved into a shore-parallel geostrophic flow.

Fairweather flows, such as tidal and alongshore flows, transported sand in the nearshore environment above fairweather wave base. Typical fairweather winds were from the southeast and southwest and resulted in coastal set-down conditions. Effects of storm flows were probably intense in this environment, but the constant day-by-day

reworking by tidal and wave processes have erased any trace. Below fairweather wave base, during periods of non-storm conditions, deposition was dominated by mud.

No single modern analogue was wholly comparable with the features detected in the Rockwood Formation at Whiteoak Mountain. The difficulty of such analogies between the modern and ancient lies in the inherent complex nature of marine shelves. The analysis of comparable parts of several ancient (Upper Muschelkalk (Middle Triassic), South German Basin; "Middle" Silurian, central Pennsylvania) and modern (Helgoland Bight (North Sea); Gulf of Mexico; Niger Delta) analogues provided insight into the processes and environments that influenced the Rockwood depositional system.

The importance of the study of the Rockwood formation is that it provides insight into the climatic, depositional, and environmental factors that dominated during Early Silurian time. The Silurian period is typically considered to have been a time when epeiric seas were widespread and sedimentation was commonly autochthonous and indicative of the climate at the depositional site (Ziegler et al., 1977). The Rockwood reflects these general characteristics with the initial drowning of the Rockwood Shelf (due to world-wide deglaciation), commencing in the general rise of sea-level through Rockwood time. The concentration of iron sediments indicates that the climate was mild and that widespread transgressions of the continents had occurred. In addition, this study of the Rockwood is valuable in that it adds to the general understanding of the depositional condi-

tions that existed in this Lower Silurian shelf environment in North America. The three general facies belts of the Lower Silurian in east Tennessee proposed by Driese et al, (1986 a, b) were partially represented in the section at Whiteoak Mountain. Of the three facies sequences (megarippled sand banks; hummocky storm shelf; skeletal sand banks/ shelf) both the megarippled sand banks (Facies FC, QA?) and hummmcky storm shelf (Facies AH, Hs, Hm, MB?) were well represented in the section. No evidence was detected for the westernmost skeletal sand bank/shelf facies, which was probably a function of the section at Whiteoak Mountain being situated too far to the east.

In conclusion, it appears additional research is necessary in several areas. The effects of modern-day storms need to be studied in much greater detail by geologists, oceanographers, and marine geologists. One of the focuses of such an undertaking should be to investigate offshore sediment transport in different hydrodynamic settings. In addition, laboratory flume studies are necessary on the nature and effects of combined-flow currents in terms of both siliciclastic and carbonate sediment.

REFERENCES

REFERENCES

- Aigner, T., 1985, Storm depositional systems: Springer-Verlag Berlin Heidelberg, p. 1-174.
- Aigner, T., and Reineck, H.E., 1982, Proximity trends in modern storm sands from the Helgoland Bight (North Sea) and their implications for basin analysis: *Senckenbergiana Maritima*, v. 14, p. 183-215.
- Amsden, T.W., 1955, Lithofacies map of the Lower Silurian deposits in central and eastern United States and Canada: *Am. Assoc. Petroleum Geol. Bull.*, v. 39, p. 60-74.
- Beardsley, R.C., and Butman, B., 1974, Circulation on the New England continental shelf: Response to strong winter storms: *Geophys. Res. Lett.*, 1, p. 181-184.
- Berry, W.B.N., and Wilde, P., 1978, Progressive ventilation of the oceans—an explanation for the distribution of the Lower Paleozoic black shales: *Am. Jour. Sci.*, v. 278, p. 257-275.
- Berry, W.B.N., and Boucot, A.J., 1973, Glacio-eustatic control of Late Ordovician-Early Silurian platform sedimentation and faunal changes: *Geol. Soc. America, Bull.*, v. 84, p. 275-284.
- , 1970, Correlation of the North American Silurian rocks: *Geol. Soc. America Spec. Paper* 102, 289 p.
- Bhattacharyya, D.P., and Kakimoto, P.K., 1982, Origin of ferri-ferous ooids: an SEM study of ironstone ooids and bauxite pisoids: *Jour. Sed. Petrology*, v. 52, no. 3, p. 849-857.
- Blatt, H., Middleton, G.V., and Murray, R.C., 1972, Origin of sedimentary rocks: Prentice-Hall, New Jersey, 634 p.
- Brenchley, P. J., 1985, Storm influenced sandstone beds: *Mod. Geology*, v. 9, 369-396.
- Brenchley, P.J., and Newall, G., 1982, Storm influenced inner-shelf sand lobes in the Caradoc (Ordovician) of Shropshire, England: *Jour. Sed. Petrology*, v. 52, p. 1257-1269.
- Burchard, E.F., 1913, The red iron ores of east Tennessee: *Tenn. Div. Geol. Bull.*, v. 16., 173 p.
- Byers, C.W., 1977, Biofacies patterns in euxinic basins: A general model, in Cook, H.E., and Enos, P. (eds.), *Deep-water Carbonate*

Environments: Soc. Econ. Paleontologists and Mineral., Special Publication 25, p. 5-17.

_____, C.W., 1974, Shale fissility: relation to bioturbation: Sedimentology, v. 21, p. 479-484.

Castano, J.R., and Garrels, R.M., 1950, Experiments on the deposition of iron with special reference to the Clinton iron ore deposits: Econ. Geology, v. 45, p. 755-770.

Chowns, T.M., 1972, Molasse sedimentation in the Silurian rocks of Northwest Georgia, in Chowns, T.M., (compiler), Sedimentary Environments in the Paleozoic Rocks of Northwest Georgia: Georgia Geol. Soc., Guidebook no. 11, p. 13-23.

Cluff, R.M., 1980, Paleoenvironment of the New Albany Shale Group (Devonian-Mississippian) of Illinois: Jour. Sed. Petrology, v. 50, p. 767-780.

Cotter, E., 1983, Silurian depositional history in Silurian Depositional History and Alleghenian Deformation in the Pennsylvania Valley and Ridge (Guidebook): Harrisburg, PA, 48th Annual Field Conf. of Penn. Geologists, p. 3-28.

Cundiff, Jerry A., 1951, Petrography of the Clinch Sandstone of northeast Tennessee: M.S. thesis, Univ. of Tennessee.

Dott, R.H., and Bourgeois, J., 1982, Hummocky stratification: Significance of its variable bedding sequences: Geol. Soc. America Bull., v. 93, p. 663-680.

Driese, S.G., Fischer, M.W., Easthouse, K.A., and Marks, G.T. (in preparation), Paleoenvironmental reconstruction of an Early Silurian shelf: model for shelf sandstone sequences, Southern Appalachians.

Driese, S.G., 1986a, Fairweather and storm shelf sequences, Rockwood Formation (Silurian), East Tennessee: Appalachian Basin Industrial Associates Program, v. 10, p. 133-175.

_____, 1986b, Fairweather and storm shelf sequences, Rockwood Formation (Silurian), East Tennessee: Geol. Soc. America, Abst. with Progs., v. 18, p. 218-219.

Driese, S.G., Fischer, M.W., and Easthouse, K.A., 1986, Silurian siliclastic and carbonate storm-shelf sequences, East Tennessee: 3rd Annual Mid-year Meeting of S.E.P.M., Raleigh, NC, Abstracts Volume III, p. 31.

- Driese, S.G., Fischer, M.W., Easthouse, K.A., and Schoner, A.E., 1986b, Tidal and storm wave deposition in Lower Silurian shelf sequences, East Tennessee: *Am. Assoc. Petroleum Geol. Bull.*, v. 70, p. 583-584.
- Driese, S.G., 1985, Marine shelf storm deposits, Rockwood Formation (Silurian), East Tennessee: *Geol. Soc. American, Abst. with Progs.*, v. 17, p. 89.
- Fischer, M.W. (in progress), Sedimentology of the Lower Silurian Clinch Sandstone along Clinch Mountain, northeastern Tennessee: M.S. thesis, Univ. of Tennessee.
- Folk, R.L., Andrews, P.B., and Lewis, D.W., 1970, Detrital sedimentary rock classification and nomenclature for use in New Zealand: *New Zealand Jour. Geology and Geophysics*, v. 13, p. 937-968.
- Frey, R.W., and Pemberton, S.G., 1984, Trace fossil facies model, in Walker, R.G. (ed.), *Facies Models*, 2nd edition: *Geoscience Canada Reprint Series 1*, p. 189-207.
- Frey, R.W., and Chowns, T.M., 1972, Trace fossils from the Ringgold road cut (Ordovician and Silurian), Georgia, in Chowns, T.M. (compiler), *Sedimentary Environments in the Paleozoic Rocks of Northwest Georgia*: *Georgia Geol. Soc., Guidebook no. 11*, p. 25-55.
- Hallam, A., and Bradshaw, M.J., 1979, Bituminous shales and oolitic ironstones as indicators of transgressions and regressions: *Jour. Geol. Soc. London*, v. 136, p. 157-164.
- Hamblin, A.P., and Walker, R.G., 1979, Storm dominated shallow marine deposits: The Fernie-Kootenay (Jurassic) transition, southern Rocky Mountains: *Canadian Jour. of Earth Sciences*, v. 16, p. 1673-1690.
- Harms, J.C., 1969, Hydraulic significance of some sand ripples: *Geol. Soc. America Bull.*, v. 80, p. 363-396.
- Hayes, M.O., 1967, Hurricanes as geological agents, south Texas coast: *Am. Assoc. Petroleum Geol. Bull.*, v. 51, p. 937-942.
- Hunter, R.E., and Clifton, H.E., 1982, Cyclic deposits and hummocky cross-stratification of probable storm origin in Upper Cretaceous rocks of Cape Sebastian area, southwestern Oregon: *Jour. Sed. Petrology*, v. 52, p. 127-144.

- Hunter, R.E., 1970, Facies of iron sedimentation in Clinton Group, in Fisher, G.W., et al, (eds.), Studies of Appalachian Geology, Central and Southern: Wiley-Interscience, New York, p. 101-121.
- James, H.L., 1966, Chemistry of the iron-rich sedimentary rocks in Data of Geochemistry, 6th edition: Geol. Survey Prof. Paper 440-w, p. w1-w61.
- Johnson, H.D., 1978, Shallow siliclastic seas: in Reading, H.G., (ed.), Sedimentary Environments and Facies: New York, Elsevier, p. 207-258.
- Kelling, G., and Mullin, P.R., 1975, Graded limestones and limestone-quartzite couplets: Possible storm deposits from the Moroccan Carboniferous: Sed. Geology, v. 13, p. 161-190.
- Komar, P.D., 1974, Oscillatory ripple marks and the evaluation of ancient wave conditions and environments: Jour. Sed. Petrology, v. 44, p. 169-180.
- Kreisa, R.D., 1981, Storm generated sedimentary structures in sub-tidal marine facies with examples from Middle and Upper Ordovician of southwestern Virginia: Jour. Sed. Petrology, v. 51, p. 823-848.
- Kulm, L.D., Rousch, R.C., Harlett, J.C., Neudeck, R.H., Chambers, D.M., and Runge, E.J., 1975, Oregon continental shelf sedimentation: Interrelationships of facies distribution and sedimentary processes: Jour. Geology, v. 83, p. 145-176.
- Kumar, N., and Sanders, J.E., 1976, Characteristics of shoreface storm deposits: modern and ancient examples: Jour. Sed. Petrology, v. 46, p. 145-162.
- Laughrey, C.D., 1983, Lower Silurian clastics in the subsurface of northwestern Pennsylvania in Silurian depositional history and Alleghenian Deformation in the Pennsylvania Valley and Ridge (Guidebook): Harrisburg, PA, 48th Annual Field Conf. of Penn. Geologists, p. 89-98.
- Leeder, M.R., 1982, Sedimentology: Allen and Unwin, London, 344 p.
- Levell, B.K., 1980, A late Pre-Cambrian tidal shelf deposit, the Lower Sandfjord Formation, Finnmark, North Norway: Sedimentology, v. 27, p. 539-557.
- Levington, J.S., 1982, Marine Ecology: Prentice Hall, Englewood Cliffs, New Jersey, 526 p.

- Maher, L.J., and Dott, R.H., 1979, Program for analysis of directional orientation data (for generalized basic): Univ. of Wisconsin, unpub. computer program.
- Marks, G.T. (in progress), The lithology and paleoenvironmental interpretation of the Clinch Sandstone at Powell Mountain, southwest Virginia: M.S. thesis, Univ. of Tennessee.
- McKerrow, W.S., 1979, Ordovician and Silurian changes in sea-level: Geol. Soc. London Quat. Jour., v. 136, p. 137-145.
- Meckel, L. D., 1970, Paleozoic alluvial deposition in the central Appalachians: a summary, in Fisher, G.W., et al, (eds.), Studies of Appalachian Geology, Central and Southern: New York, Interscience Publishers, p. 49-67.
- Milici, R.C., 1978, The Whiteoak Mountain synclinorium along Interstate 75, at Green Gap, Tennessee, in Milici, R.C. (ed.), Field Trips in the Southern Appalachians: Tenn. Div. of Geology, v. 37, p. 16-19.
- Milici, R.C., and Wedow, H., 1977, Upper Ordovician and Silurian stratigraphy in Sequatchie Valley and parts of the adjacent Valley and Ridge: U.S.G.S. Prof. Paper 996, 38 p.
- Miller, R.L., 1976, Silurian nomenclature and correlations in Southwest Virginia and Northeast Tennessee: U.S.G.S. Bull., 1405-H, 23 p.
- Morton, R.A., 1981, Formation of storm deposits by wind-forced currents in the Gulf of Mexico and the North Sea: in Nio, S.D., et al, (eds.), Holocene Marine sedimentation in the North Sea Basin: Spec. Publ. Int. Assoc. Sedimentol., No. 5, p. 385-396.
- Mount, J.F., 1982, Storm-surge-ebb origin of hummocky cross-stratified units of the Andrews Mountain Member, Campito Formation (Lower Cambrian), White-Inyo Mountains, Eastern California: Jour. Sed. Petrology, v. 52, no. 3, p. 941-958.
- Nicholson, F.H., 1978, Sedimentology of the Clinch Sandstone, Northeastern Tennessee and Southwestern Virginia: M.S. thesis, Univ. of Kentucky.
- Pettijohn, F.J., Potter, P.E., and Siever, R., 1972, Sand and Sandstone: New York, Springer-Verlag, 618 p.
- Porrenga, D.H., 1967, Glauconite and chamosite as depth indicators in the marine environment: Marine Geology, v. 5, p. 494-501.

- Sandin, Walter, 1960, A facies study of the Red Mountain Formation of Northwest Georgia: Ga. Min. Newsletter, v. 13, p. 106-107.
- Savrda, C.E., and Bottjer, A.J., 1986, Trace-fossil model for reconstruction of paleo-oxygenation in bottom waters: *Geology*, v. 14, p. 3-6.
- Savrda, C.E., and Bottjer, D.J., and Grosline, D.S., 1984, Development of a comprehensive oxygen-deficient marine biofacies model: Evidence from Santa Monica, San Pedro, and Santa Barbara Basins, California continental borderland: *Am. Assoc. Petroleum Geol. Bull.*, v. 68, p. 1179-1192.
- Schoner, A.E., 1985a, The sedimentology and sedimentary petrology of the Lower Silurian Clinch Sandstone at Beans Gap, Grainger County, Tennessee: M.S. thesis, Univ. of Tennessee, 227 p.
- , 1985b, The Clinch Sandstone (Lower Silurian) along Highway 25E at Beans Gap, in Walker, K.R. (ed.), *The Geologic History of the Thorn Hill Paleozoic Section (Cambrian-Mississippian), Eastern Tennessee*: Univ. of Tennessee, Dept. of Geol. Sci., *Studies in Geology* 10, p. 100-110.
- Schoner, A.E., and Driese, S.G., 1985, Sedimentology of the Clinch Sandstone at Beans Gap, Grainger County, Tennessee: *Geol. Soc. America, Abst. with Progs.*, v. 17, p. 134.
- Seilacher, A., 1967, Bathymetry of trace fossils: *Marine Geology*, v. 5, p. 413-428.
- Sheldon, R.P., 1970, Sedimentation of iron-rich rocks of Llandovery age (Lower Silurian) in the Southern Appalachian Basin in Berry, W.B.N., Boucot, A.J., (eds.), *Correlation of the North American Silurian rocks*: *Geol. Soc. Amer. Spec. Paper* 102, p. 107-112.
- Smith, D.J., and Hopkins, T.S., 1972, Sediment transport on the continental shelf of Washington and Oregon in light of recent current measurements, in Swift, D.J.P., et al, (eds.), *Shelf Sediment Transport: Process and Product*: Dowden, Hutchinson and Ross, Stroudsburg, p. 143-180.
- Swift, D.J.P., and Niedoroda, A.H., 1985, Fluid and sediment dynamics on continental shelves, in Tillman, R.W., et al (eds.), *Shelf Sands and Sandstone Reservoirs*: S.E.P.M. Short Course Notes No. 13, p. 47-136.
- Swift, D.J.P., Figueiredo, A.G., Freeland, G.J., and Oertel, G.F., 1983, Hummocky cross-stratification and megaripples: a geological double standard: *Jour. Sed. Petrology*, v. 53, p. 1295-1317.

- Thompson, J.R., 1984, Depositional environments of the Sequatchie and Rockwood Formations: M.S. thesis, Univ. of Tennessee, 199 p.
- Tillman, R.W., 1985, A spectrum of shelf sands and sandstones, in Tillman, R.W., et al (eds.), Shelf Sands and Sandstone Reservoirs: S.E.P.M. Short Course Notes No. 13, p. 1-46.
- Tucker, M.E., 1982, The field description of sedimentary rocks: Wiley, New York, 112 p.
- Van Houten, F.B., and Bhattacharyya, D.P., 1982, Phanerozoic oolitic iron-stones: Geologic record and facies model: Ann. Rev. Earth Planet. Sci., v. 10, p. 441-457.
- Walker, R.G., 1985, Geological evidence for storm transportation and deposition on ancient shelves, in Tillman, R.W., et al (eds.), Shelf Sands and Sandstone Reservoirs: S.E.P.M. Short Course Notes No. 13, p. 243-303.
- , 1984, Shelf and shallow marine sands, in Walker, R.G. (ed.), Facies Models, 2nd edition: Geoscience Canada Reprint Series 1, p. 141-170.
- Walker, R.G., Duke, W.L., and Leckie, D.A., 1983, Hummocky stratification: Significance of its variable bedding sequences: Discussion and reply: Geol. Soc. America Bull., v. 94, p. 1245-1251.
- Wedow, H. Jr., 1960, Sequatchie and Rockwood formations in Southeast Tennessee and part of Northwest Georgia [abs.]: Geol. Soc. America Bull., v. 71, no. 12, p. 2028.
- Whisonant, R.C., 1977, Lower Silurian Tuscarora (Clinch) dispersal patterns in Western Virginia: Geol. Soc. America Bull., v. 88, p. 215-220.
- Whittaker, J.H.M., 1973, "Gutter Casts," a new name for scour-and-fill structures: with examples from the Llandoveryian of Ringerike and Malmoya, Southern Norway: Norsk Geog. Tidsskr., v. 53, p. 403-417.
- Yeakel, L.S., Jr., 1962, Tuscarora, Juniata and Bald Eagle paleocurrents and paleogeography in the central Appalachians: Geol. Soc. America Bull., v. 73, p. 1515-1450.
- Ziegler, A.M., Scotese, C.R., McKerrow, W.S., Johnson, M.E., and Bambach, R.K., 1979, Paleozoic paleogeography: Ann. Rev. Earth Planet. Sci., v. 7, p. 473-502.

- Ziegler, A.M., Hansen, K.S., Johnson, M.E., Kelly, M.A., Scotese, C.R., and Van der Voo, R., 1977, Silurian continental distributions, paleogeography, climatology, and biogeography, in McElhinney, M.W. (ed.), The Past Distribution of Continents: Tectonophysics, v. 40, p. 13-51.

APPENDIX

APPENDIX

(Section 1--east limb)

STRATIGRAPHIC SECTION OF THE ROCKWOOD FORMATION AT GREEN GAP, WHITEOAK MOUNTAIN, TENNESSEE

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	4A-11	3.0m	264.27m	The sandstone/shale ratio of this interval is 1:10 to 1:15. Only three sandstone beds occur in this zone, ranging in thickness from 50 to 150mm. The sandstone beds are very fine-grained, maroon to orange in color, horizontally laminated, with flat bases and wave rippled tops, and contain rare trilobite fossils at the bases of beds. The dominant lithology in this interval is an olive green to green brown to dark gray mudstone that is medium to thickly laminated, internally massive, blocky to hackly, low to moderately bioturbated, and contains impressions of brachiopods. Five mm by 10mm siltstone lenses are present throughout the interval. Rare 2mm by 5mm siltstone pebbles are present 1/2 meter below the contact with the Chattanooga Shale. Sample 4A-4 at 264.0m Sample 4A-3 at 262.1m
Hm	4A-10	1.0m	261.27m	This interval is composed entirely of gray to yellow mudstone that is thin to thickly laminated, internally massive, blocky to hackly, and is moderately to low/moderately bioturbated. This zone is extremely fossiliferous, with such varieties as trilobites, crinoids, brachiopods, belemnites, and gastropods. Sample 4A-2 at 260.34m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	4A-9	2.5m	260.27m	The sandstone/shale ratio for this interval varies from 1:20 to 1:30. The sandstone is gray to light gray, very fine-grained to silty, horizontally to symmetrically ripple cross-laminated, thinly to very thinly bedded, and occurs as lenses within the mudstone. The mudstone is gray to dark gray, thin to thickly laminated, internally massive, dominantly fissile to rarely blocky and mostly non-bioturbated. Overall the bioturbation for this interval is low, the storm bed frequently is low, and the percentage of wave ripples is low to moderately low.
Hm	4A-8	0.5m	257.77mm	The sandstone/shale ratio for this interval varies from 1:6 to 1:8. The sandstone beds are light gray to white, very fine-grained to silty, horizontally to symmetrically ripple cross-laminated, and very thinly bedded (10-25mm, 15mm average). The sandstones are generally flat-based with wave-rippled tops and contain sinuous to circular horizontal burrows (10-20mm diameter by 60-70mm length) at bases of beds. The interval is dominated by mudstone that is gray, thinly laminated, internally massive, fissile and non-bioturbated. Overall the bioturbation for this interval is low, the storm bed frequency is low, and the percentage of wave ripples is moderate to moderately low.
Hm	4A-7	1.0m	257.27m	The sandstone/shale ratio for this interval is 1:1 to 1:2. The sandstone beds are slightly maroon-gray, very fine-grained to silty, horizontally laminated to hummocky cross-laminated, flat-based with wave-rippled to flat upper surfaces, and thinly to medium-bedded (30-220mm, 75-100mm

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				average). The mudstone is light to dark gray, slightly silty, medium laminated, internally massive, fissile, and non-bioturbated. Overall the bioturbation is low, storm bed frequency is moderately low, and wave ripple percentage is moderate.
Hm	4A-6	1.6m	256.27m	The sandstone/shale ratio for this interval is 1:10. The sandstone beds are light gray, very fine-grained, horizontal to ripple cross-laminated (symmetrical and asymmetrical), uneven bases with gutter casts in part, wave rippled tops, and heavily weathered fossil (brachiopods, crinoids) lags at the bases of beds. Horizontal burrowing common at bottoms of beds (1-3mm diameter by 20mm length, straight tubes). The mudstone is greenish-gray to gray, medium to thickly laminated, massive, blocky, and bioturbated. Overall the bioturbation is low to moderately low in abundance, low to moderate storm-bed frequency, and moderate to high percentage of wave ripples.
Hm	4A-5	1.0m	254.67m	The sandstone/shale ratio for this interval is 1:3. The sandstone is gray, very fine-grained, flat-based, flat-topped, horizontal to low-angle cross-laminated, with brachiopod-crinoid fossil lags at the base of beds. The sandstone beds are thin to very thinly bedded (10-30mm, 20mm average). The mudstone is gray to olive green, silty, in part, thin to thickly laminated, fissile and non-bioturbated in the lower 0.5m and blocky to bioturbated in the top 0.5m. Rare crinoid columnals are present in the top 0.5m. Overall the bioturbation is low in abundance, the storm-bed frequency

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				is moderately low, and the percentage of wave ripples is low.
	4A-4	3.0m	253.67m	Covered interval.
Hm	4A-3	0.5m	268.70m	The sandstone/shale ratio for this interval is 1:2. The sandstone beds are maroon, very fine-grained, horizontal to ripple cross-laminated (symmetrical and asymmetrical), flat-based, wave-rippled upper surfaces, very thin to thinly bedded (20-90mm, 40mm average), and fossil debris (brachiopods, crinoids) at tops and bases of beds. The mudstone is gray, slightly silty, thin to moderately laminated, massive, fissile, and non-bioturbated. The abundance of bioturbation in this interval is low, the storm bed frequency is moderate and the percentage of wave ripples is moderate to moderately high.
	4A-2	0.4m	250.67m	Covered.
Hm	4A-1	2.0m	250.27m	The sandstone/shale ratio for this interval is 1:2. The sandstone is gray to maroon-gray, very fine-grained to silty, and internally is mostly massive to horizontally laminated, with occasional wave-formed ripples with unidirectional lamination. The sandstone beds are generally thickly laminated to very thinly bedded (5-30mm thick, 10-20mm average), with flat horizontally burrowed bases (1-3mm diameter by 3-5mm length; 2-5mm diameter by 20-40mm length; 7-10mm diameter by 20-40mm length) that contain brachiopods and crinoid columnals. The tops of beds have either sharp

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				contacts with the overlying mudstone, where the beds are either flat or wave-rippled, or gradational contacts due to biogenic reworking. The mudstone is gray to rarely olive-brown, silty in part, thin to moderately laminated, internally massive, blocky to fissile and non-bioturbated to moderately bioturbated. Overall the amount of bioturbation is moderate to moderately low in abundance, the storm bed frequency is moderate, and the percentage of wave ripples is moderate. Sample 4A-1 at 249.9m
	3A-15	1.5m	248.27m	Covered.
Hs	3A-14	3.1m	246.77m	The sandstone/shale ratio for this interval is 1:1. The sandstone is gray, very fine-grained to silty, horizontally laminated with wave-formed ripples exhibiting unidirectional cross-laminations. The sandstone beds are very thinly to medium bedded (10-120mm, average 30-40mm), with undulating to flat bases and straight to sinuous horizontal burrowing (10mm diameter by 40mm length; 5-7mm diameter by 15mm length; 7-10mm by 30mm length) at the tops and bottoms of beds. The tops of beds are either flat or wave rippled to gradational with overlying mudstone. Excellent fossil lags are very common in this interval composed of brachiopods, crinoid columnals, trilobite fragments, gastropods, and <u>Tentaculites</u> . Several layers are composed of gastropods along with silt and very fine sand. The mudstone is gray, silty in part, thin to moderately laminated, massive to rarely horizontally laminated, fissile, poorly indurated,

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				and non-bioturbated. Overall the amount of burrowing is low to moderately low, the frequency of storm beds is moderately low, and in the first 1.5m the percentage of wave ripples is low changing to a moderate to moderately high value in the last 1.5m.
Hs	3A-13	1.2m	243.67m	The sandstone/shale ratio for this interval is 4:1 to 5:1. This zone is capped by a 0.45m sandstone bed that represents the top of a thickening-upward sequence. The sandstone beds are dark gray, very fine- to fine-grained, horizontally to hummocky cross-laminated, with flat to undulating bases and flat to wave- and current-rippled upper surfaces. The thicknesses of the sandstone beds range from very thinly bedded to thickly bedded (20-450mm, 60-65mm average) with scattered iron-replaced fossils throughout. Straight to slightly sinuous horizontal burrows (1-3mm diameter by 10mm length) are present at the bases of the beds. The mudstone is gray, silty in part, thin to moderately laminated, massive, fissile to slightly blocky, and horizontally burrowed in part. Overall the amount of bioturbation is low to moderately low, the frequency of storm beds is moderate, and the percentage of wave ripples is low.
Hs	3A-12	3.0m	242.47m	The sandstone/shale ratio for this interval ranges from 2:1 to 4:1. The sandstone is gray, very fine-grained, horizontally to hummocky cross-laminated, with flat to undulating tops that contain both wave and current ripples. The sandstone beds are very thickly laminated to medium-bedded (5-150mm, 30-50mm average) and pinch and swell in thickness

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				over a scale of a meter or two. Horizontal burrowing (1-3 diameter by 15mm length; 5-7mm diameter by 25mm length; straight tubes) is common at the tops and bases of beds with sub-vertical to vertical burrows (1-3mm diameter by 5mm length) also present, which may indicate escape structures. The bases of many of the sand beds contain 0.5mm thick lags that contain iron-replaced fossil debris. In addition, several of the sand beds contained 2mm by 5mm gray mud ships concentrated at the bases of the beds. The mudstone is moderately silty to rarely sandy, gray to dark gray, thin to thickly laminated, massive to horizontally laminated, massive to horizontally laminated, blocky to rarely fissile, and partly bioturbated. Overall the amount of bioturbation is low to moderately abundant, the storm bed frequency is moderate and the percentage of wave ripples varies from moderately low in the bottom 2 meters to moderately high in the top meter. Sample 3A-8 at 241.20m
Hs	3A-11	1.0m	239.47m	The sandstone/shale ratio for this interval is 1:1. The sandstone is gray, very fine-grained to silty, horizontally to hummocky cross-laminated with asymmetrical and rare symmetrical ripple cross-laminations. The sandstone layers are very thinly bedded to thinly bedded (10-40mm, 20-25mm average) with flat bases that occasionally contain fossil lags (brachiopods, crinoid columnals) and flat tops that are wave- and current-rippled in part. Horizontal burrowing (1-3mm diameter by 10mm length; 5-7mm diameter by 20mm length; straight tubes) is present at the tops and bases of

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				beds. The mudstone is gray, silty in part, thin to moderately laminated, hackly, and partly bioturbated. Overall the amount of bioturbation is low to moderately low, the storm-bed frequency is moderate to moderately high and the percentage of wave ripples is low to moderately low.
Hs	3A-10	1.8m	238.47m	The sandstone/shale ratio for this interval ranges from 2:1 to 4:1. The sandstone is gray to greenish-gray, silty to very fine-grained in the lower 0.8 meters, and very fine- to fine-grained in the upper 1.0 meter of the interval. The layers are horizontally to hummocky cross-laminated with excellent symmetrical ripple cross-laminations in part. The sandstone beds are very thinly to thickly bedded (20-400mm, 50mm average), with flat bases to undulating upper surfaces that are wave-rippled in part. Bases of beds commonly contain fossil lags (brachiopods, crinoid columnals), gutter casts, and horizontal burrows (1-3mm diameter by 15mm length; 5-7mm diameter by 30mm length; 30mm diameter by 90mm length; straight tubes). Other biogenic features were sub-vertical to vertical burrows (1-4mm diameter by 10-30mm length) that may indicate escape structures. The mudstone is light gray to dark gray, thin to moderately laminated, massive to horizontally laminated, blocky, and horizontally burrowed. Overall the amount of bioturbation is moderate, the storm bed frequency is moderately high and the percentage of wave ripples is low moderate. Sample 3A-4 at 236.9m Sample 3A-5 at 237.5m Sample 3A-6 at 238.2m Sample 3A-7 at 238.2m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hs	3A-9	2.0m	236.67m	The sandstone/shale ratio for this interval is 1:1. The sandstone is gray to maroon-gray, very fine-grained to silty, horizontally to hummocky cross-laminated with symmetrical and asymmetrical ripple cross-laminations. The sandstone layers are very thinly to thinly bedded (10-45mm, 20mm average), exhibiting a strong pinch and swell character (hummock-like, wavy surfaces). The bases of beds are commonly flat to undulatory, displaying gutter casts and loading features. Horizontal burrowing occurred at the tops and bases of beds (1-3mm diameter by 5-15mm length; 5-7mm diameter by 20mm length; straight tubes). The mudstone is blue-gray to dark gray, grading to siltstone in part, thin to moderately laminated, massive to rare horizontal laminations, blocky to hackly, and horizontally burrowed. Overall the abundance of burrowing is low to moderately low, the storm-bed frequency is moderate to moderately high, and the percentage of wave ripples is moderate.
Hs	3A-8	2.0m	234.67m	The sandstone/shale ratio for this interval varies from 1:1 to 3:1. The sandstone is gray, very fine-grained to silty, horizontally to hummocky cross-laminated, with flat to undulating bases (loading features?) and wave-rippled upper surfaces. The sandstone layers are very thinly bedded to medium bedded (20-200mm, 30-50mm average) and exhibit a strong pinch and swell character (hummock-like beds). Horizontal burrowing is present, predominantly at the tops and bottoms of the beds. The mudstone is dark gray to gray, grading to siltstone in part, thin to moderately laminated, massive, blocky, and horizontally burrowed. Overall, the

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				horizontal burrowing is moderately abundant, the storm bed frequency is moderately high, and the percentage of wave ripples is moderately high.
Hm	3A-7	1.0m	232.67m	The sandstone/shale ratio for this interval varies from 1:2 to 1:3. The sandstone is gray, very fine-grained to silty in part, horizontally to hummocky cross-laminated, with flat to undulating bases (loading?) and flat to wave-rippled surfaces. The sandstone layers are thinly laminated to thinly bedded (1-60mm, 10-20mm average) with slightly curved horizontal burrows (5-7mm diameter by 30mm length) and vertical burrows (5mm diameter by 15mm length). The mudstone is gray to light-gray, silty in part, thin to moderately laminated, massive to horizontally laminated, blocky to fissile, and has a low to moderate amount of bioturbation. Within the mudstone are 1 to 2mm thick gray siltstone lenses. Overall, the amount of bioturbation is moderate, the storm bed frequency is low to moderate, and the percentage of wave ripples is low to moderate. Sample 3A-3 at 232.43m
Hs	3A-6	1.0m	231.67m	The sandstone/shale ratio for this interval varies from 3:1 to 4:1. The sandstone is gray, very fine-grained, horizontally to hummocky cross-laminated, with flat to undulating bases and wave-rippled upper surfaces, in part. The sandstone layers are very thin to thinly bedded (10-70mm, 25-30mm average), exhibit a pinch-and-swell character, and are amalgamated in part. Horizontal burrows occur as straight simple tubes (10mm diameter by 20mm length; 2mm diameter by

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				5mm length) at the tops of beds. Vertical and sub-vertical burrows are also present (0.5mm diameter by 3mm length). The mudstone is dark gray, grading to siltstone, thin to moderately laminated, massive, blocky, and slightly burrowed. Overall, the amount of burrowing is moderately low, the storm bed frequency is moderately high, and the percentage of wave ripples is moderate.
Hs	3A-5	2.8m	230.67m	The sandstone/shale ratio for this interval varies from 1:1 to 2:1. The sandstone is gray to maroon-gray, very fine-grained to silty, horizontal to hummocky cross-laminated, with flat to undulating bases, and wave-rippled upper surfaces. The sandstone layers are thickly laminated to thinly bedded (5-90mm, 20-30mm average), and exhibit a strong, pinch-and-swell character. Horizontal burrowing dominated in this interval (1-3mm diameter by 10mm length; 5-7mm diameter by 20mm length) with subordinate amounts of sub-vertical and vertical burrows (0.5mm diameter by 3-4mm length). The mudstone is gray to gray-green, grades to siltstone in part, thin to thickly laminated, massive, hackly, and appears moderately burrowed. Overall the amount of bioturbation is low to moderately low, the storm-bed frequency is moderate to moderately high, and the percentage of wave ripples varies from moderate to high.
Hm	3A-4	1.6m	227.87m	The sandstone/shale ratio for this interval is 1:2. The sandstone is gray, very fine-grained, horizontally to hummocky cross-laminated, with flat to undulating bases and wave-rippled upper surfaces. The sandstone layers are very

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				thinly bedded to medium-bedded (10-140mm, 25-40mm average) with tool marks (1-2mm by 3-4mm) on the bases of some beds. Simple, straight horizontal burrows (1-3mm diameter by 5-10mm length) are present along with straight vertical tubes (1-3mm diameter by 8mm length). Interval is capped by a 140mm hummocky cross-laminated bed. The mudstone is dark gray, silty in part to rarely sandy, thin to moderately laminated, internally massive to horizontally laminated, and appears mostly non-bioturbated. Overall the amount of bioturbation is low to moderately low, the frequency of storm beds is high to moderately high, and the percentage of wave ripples is moderate to moderately high.
Hm	3A-3	3.0m	226.27m	The sandstone/shale ratio for this interval varies from 1:1 to 1:3. The sandstone is gray, very fine-grained, horizontally to hummocky cross-laminated, and several of the beds pinch and well laterally. The sandstone layers are thickly laminated to thinly bedded (5-60mm, 20mm average) with gutter casts and tool marks at the base of some beds. The tops and bottoms of beds are horizontally (1-3mm diameter by 10mm length), vertically and sub-vertically (1mm diameter by 5-10mm length) burrowed. Wave ripples are rare in this interval which may be attributed to the biogenic reworking at the tops of beds. The mudstone is gray, grading to siltstone, rarely sandy, moderately laminated, massive to rarely horizontally laminated, blocky to hackly, and is moderately burrowed. Overall the bioturbation in this interval is moderately abundant, the storm-bed frequency is moderately low, and the percentage of wave ripples is very low.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hs	3A-2	3.5m	223.2 7m	The sandstone/shale ratio for this interval varies from 2:1 to 3:1. The sandstone is gray, very fine-grained to silty, horizontally to hummocky cross-laminated and several of the beds pinch-and-swallow laterally. The sandstone layers are thickly laminated to thinly bedded (5-70mm, 10-30mm average) with flat to uneven bases (partly due to loading) and flat to wave-rippled upper surfaces. Biogenic reworking dominates in this interval, with horizontal (5-7mm diameter by 10-50mm length; 1-2mm diameter by 3-5mm length) simple straight tubes common and subordinate amounts of vertical and sub-vertical burrows (0.5mm diameter by 2-5mm length; 1-3mm diameter by 10-15mm length; 5mm diameter by 15mm length). The contacts with the sandstone beds and the overlying mudstone are commonly gradational due to bioturbation. The mudstone is gray to gray-maroon, grading to siltstone in part, thin to blocky, and bioturbated. Overall the bioturbation in this interval is moderately extensive to extensive, the storm-bed frequency is moderate, and the percentage of wave ripples is moderately low to very low.
MB	3A-1	4.0m	219.77m	The sandstone/shale ratio for this interval varies from 3:1 to 4:1. The sandstone is gray to maroon-gray, very fine-grained, horizontally to wave-ripple cross-laminated to massive in part. The sandstone layers are very thinly bedded to thinly bedded (10-70mm, 30mm average) with flat to uneven bases (due to bioturbation) and wave-rippled to burrow disrupted upper surfaces. Hummocky cross-laminated beds occur near the top of the interval along with an excellent gutter cast bed at 218.75m. The sandstone beds are wavy to

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				amalgamated, which may be a function of the bioturbation. The amount of bioturbation within this interval is extensive with straight, sinuous and branching horizontal burrows (5-7mm diameter by 10-50mm length; 1-2mm diameter by 3-5mm length) the most common varieties. In lesser amounts are simple, straight vertical tubes (1-3mm diameter by 10-20mm length) which may represent escape structures. The mudstone is gray to gray-maroon, grading to siltstone, rarely sandy in part, thin to moderately laminated, internally massive to horizontally laminated, and burrowed. Overall the bioturbation is very high in abundance, the storm-bed frequency is moderately high and the percentage of wave ripples is moderately low. Sample 3A-1 at 217.3m
	2C-24	1.15m	215.77m	Covered.
MB	2C-23	0.25m	214.62m	The sandstone/shale ratio for this interval is 2:1. The sandstone is tan to gray, very fine-grained, horizontally laminated to massive, flat-based to irregular (wavy) upper surfaces and rare wave ripples. Horizontal burrowing is common (1-3mm diameter by 10mm length; 5-7mm diameter by 10-20mm length) at the tops and bottoms of beds. The mudstone is gray, grades to siltstone, thinly laminated, massive, blocky, and bioturbated. This interval defines the ridge for this outcrop. Overall the amount of bioturbation is moderate to moderately high, the frequency of storm beds is moderately low, and the percentage of wave ripples is very low.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
	2C-22	4.1m	214.37m	Covered.
MB	2C-21	0.4m	210.27m	The sandstone/shale ratio for this interval is 2:1. The sandstone is gray, very fine-grained, massive to horizontally laminated, with flat bases and burrowed disrupted upper surfaces. The sandstone layers are thickly laminated to thinly bedded (10-50mm, 20-30mm average). The mudstone is gray to maroon, grading to siltstone and sandy siltstone, thin to moderately laminated, massive, blocky, and bioturbated. The amount of burrowing is moderate to moderately high, the frequency of storm beds is moderately low and the percentage of wave ripples is low.
MB	2C-20	5.5m	209.87m	This interval is composed of mudstone, with little or no sand present. The mudstone is maroon, grading to siltstone and becomes sandy in rare instances. The mudstone is moderately laminated, massive to rarely horizontally laminated, hackly and bioturbated. Brachiopods are extremely abundant in this interval.
	2C-19	2.0m	204.37m	Covered.
MB	2C-18	2.5m	202.37m	The sandstone/shale ratio for this interval is approximately 1:20. The first 1.5m is dominated by maroon silty mudstone that is moderately laminated, hackly and burrowed, intercalated with the silty sandstone beds. The last 1.0m is composed of maroon silty mudstone that is moderately laminated, massive to rarely horizontally laminated, hackly and burrowed. Between the two intervals is a 40mm thick, very

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				fine-grained sandstone bed that is tan-brown, flat-based, flat to wave-rippled top, and is horizontally laminated. Overall the bioturbation is moderately abundant and the storm-bed frequency and percentage of wave ripples is very low.
MB	2C-17	5.0m	199.87m	This interval is composed of maroon mudstone that is silty in part, moderately laminated, massive, hackly, and bioturbated. Brachiopods are common in this interval. Gray siltstone to very fine-grained sandstone lenses are rare.
MB	2C-16	1.0m	194.87m	The sandstone/shale ratio for this interval is approximately 1:50. The interval is dominated by a maroon silty mudstone that is moderately laminated, massive, hackly, bioturbated, and contains abundant brachiopods. A single 20mm sandstone bed occurs in this interval that is maroon-gray, very fine-grained, and burrowed.
MB	2C-15	1.0m	193.87m	This interval is composed of maroon mudstone to silty mudstone that is moderately laminated, massive, hackly, and bioturbated. Brachiopods are common in this interval. Maroon-gray siltstone lenses are rare.
MB	2C-14	4.5m	192.87m	This interval is composed entirely of a maroon to light-green mudstone to silty mudstone that is medium-laminated, massive hackly, and bioturbated.
MB	2C-13	3.0m	188.37m	The sandstone/shale ratio for this interval varies from 1:1 to 2:1. The sandstone is gray to weakly maroon-gray, very

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				fine-grained, massive to horizontally laminated, and moderately indurated. The sandstone layers are thickly laminated to very thinly bedded (10-80mm, 30mm average), with flat bases that commonly contain brachiopod molds and flat to irregular (burrow disrupted) tops. Biogenic reworking is abundant in this interval, represented by simple straight horizontal burrows (1-3mm diameter by 7-10mm length). The mudstone is maroon to maroon-gray, grading to siltstone, moderately laminated, internally massive, blocky, and bioturbated. Overall the amount of bioturbation is moderately high, the frequency of storm beds is moderately low, and the percentage of wave ripples is very low.
MB	2C-11	2.0m	182.37m	This interval is composed entirely of maroon mudstone to silty mudstone that is medium laminated, internally massive, blocky and bioturbated.
MB	2C-10	2.0m	180.37m	The sandstone/shale ratio for this interval varies from 1:3 to 1:5. The sandstone is gray to maroon, very fine-grained, massive to horizontally laminated, and several of the beds pinch-and-swell laterally. The thickness of the sandstone layers varies from very thinly bedded to thinly bedded (20-90mm, 30-35mm average). The bases of the sandstone beds are flat and the tops are flat to irregular due to biogenic reworking. Wave ripples are rare in this interval, but do occur where the bioturbation was not as extensive. Horizontal burrowing dominates in this interval (0.25-0.5mm diameter by 1.0mm length; 1-3mm diameter by 7-10mm length; 5-8mm diameter by 8-15mm length) with minor amounts of sub-

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				vertical burrows (0.25mm diameter by 1.0mm length). The mudstone is gray to maroon, grading to siltstone in part, moderately laminated, massive to horizontally laminated, blocky, and bioturbated. Overall the burrowing is moderately extensive, the storm-bed frequency(?) is low, and the percentage of wave ripples is low to very low.
MB	2C-9	1.0m	178.37m	This interval is composed entirely of maroon mudstone that becomes silty in part and is moderately laminated, internally massive, blocky, and bioturbated.
MB	2C-8	1.0m	177.37	The sandstone/shale ratio for this interval varies from 1:5 to 1:7. The sandstone is gray, very fine-grained, horizontally laminated, with flat to wave-rippled tops. Horizontal burrows are common (1-3mm diameter by 7-10mm length; 5-8mm diameter by 10-15mm length) on the tops and bottoms of beds. The sandstone layers vary in thickness from very thinly bedded to thinly bedded (20-40mm, 25-30mm average). The mudstone is maroon, silty in part, moderately laminated, internally massive, blocky, and bioturbated. The amount of bioturbation in this interval is low, and the percentage of wave ripples is low.
	2C-7	4.5m	176.37m	Covered.
MB	2C-6	5.0m	171.87m	The sandstone/shale ratio was difficult to determine for this interval due to the slope debris (colluvium), but was approximated at 1:10 to 1:20. This interval is dominantly composed of maroon mudstone to siltstone that is moderately

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				to thickly laminated, massive, blocky, and bioturbated. Rare in this zone are 10-15mm thick, very fine-grained, gray sandstone beds (lenses old in part) that exhibit horizontal to low-angle cross-laminations (hummocky?) and are flat-based burrowed tops. Overall the amount of biogenic reworking is extensive.
MB	2C-5	1.0m	166.87m	The sandstone/shale ratio for this interval is 1:2. The sandstone is gray, very fine-grained, horizontally to low-angle cross-laminated (hummocky?), and some beds are composed of horizontal laminations. The sandstone layers are very thin to thinly bedded (20-40mm, 25-30mm average) with flat bases that contain brachiopod molds and irregular burrowed upper surfaces. Horizontal, simple straight tubes dominate the bioturbation for this interval (1-3mm diameter by 7-10mm length; 5-8mm diameter by 10-20mm length). The last 0.5m is less burrowed and wave ripples are more common. The mudstone is gray, silty in part, thin to moderately laminated, massive to horizontally laminated, blocky, and bioturbated. Overall the amount of biogenic reworking is moderately high, the frequency of storm beds is moderately low, and the percentage of wave ripples is low.
MB	2C-4	1.0m	165.87m	The sandstone/shale ratio is difficult to determine in this interval due to abundant slope debris (colluvium) and is approximated to be 1:10. This interval is dominantly composed of maroon mudstone to siltstone that is moderately laminated, internally massive, blocky, and burrowed. Intercalated with the mudstone and siltstone are very thin to

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				thinly bedded (20-40mm, 25mm average) sandstone beds (and lenses) that are very fine-grained to silty and horizontally laminated in part. The amount of bioturbation is moderately extensive and have reworked the beds to the extent that the determination of whether they are storm beds or not could not be ascertained.
MB	2C-3	3.0m	164.87m	The sandstone/shale ratio for this interval is 1:1. The sandstone is gray, very fine-grained, massive to horizontally laminated, with rare low-angle laminations (hummocky?). The sandstone layers are very thinly bedded to medium-bedded (10-100mm, 20-30mm average) with flat bases that contain brachiopod molds, and wavy upper surfaces that are burrowed. The bioturbation in this interval is extensive with an abundance of both horizontal and vertical burrows. The horizontal burrows are of four varieties: Sinuous s-shaped to u-shaped (1-3mm diameter, covering a 10mm area); semicircular (2-5mm diameter by 10-15mm length); branching-tree-like (0.5-1.0mm diameter by 10mm length); and simple straight tubes (2-3mm diameter by 5-10mm length; 5-8mm diameter by 20-50mm length). The vertical burrows are dominated by small (1-3mm diameter by 5-10mm length), simple straight tubes that may be U-shaped. The mudstone is light gray to dark gray, silty in part, thin to moderately laminated, internally massive, blocky, and extensively horizontally burrowed by simple (1-3mm diameter by 5-10mm length) straight tubes. The amount of bioturbation was high, which destroyed any wave ripples that might have been present. Sample 2C-1a at 162.80m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
MB	2C-2	1.0m	161.87m	The sandstone/shale ratio is difficult to determine for this interval, but is approximated to be 1:5. The sandstone is gray, very fine-grained, horizontal, to low-angle cross-laminations (hummocky?) with some laminations disrupted by burrowing. The sandstone layers are very thin to thinly bedded (20-60mm, 30mm average), and are flat-based with burrowed upper surfaces. Horizontal burrows (1-3mm diameter by 10mm length) dominate with subordinate amounts of subvertical burrows (1-2mm diameter by 5-6mm length). The siltstone is gray, rarely sandy, medium to thickly laminated, massive to horizontally laminated, blocky and partially burrowed. The burrowing in this interval has destroyed any wave ripples that might have existed and made the detection of storm beds next to impossible. Sample 2C-1 at 161.2m
	2C-1	3.0m	160.87m	Covered.
Hs	2B-26	1.25m	157.87m	The sandstone/shale ratio for this interval varies from 2:1 to 3:1. The sandstone is tan to slightly maroon-gray to orange-brown, very fine- to fine-grained, horizontally to hummocky cross-laminated and is well-indurated. The sandstone layers are very thinly bedded to medium-bedded (20-200mm, 50-60mm average) with flat bases and undulating upper surfaces that are wave-rippled in part. Several of the bases of the sandstone beds contain molds of brachiopods. Horizontal burrowing dominates in this interval (1mm diameter by 3-4mm length, simple straight tubes) with minor amounts of vertical burrows (2mm diameter by 5-7mm length).

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				The siltstone is gray, rarely sandy, thin- to medium-laminated, fissile, and non-bioturbated. Overall the amount of bioturbation is moderately low to very low, the storm-bed frequency is moderately low, and the percentage of wave ripples is moderate to moderately low.
Hs	2B-25	2.0m	156.62m	The sandstone/shale ratio for this interval varies from 1:1 to 2:1. The sandstone is gray to slightly maroon-gray, very fine- to fine-grained, massive to horizontally laminated to hummocky cross-laminated, and symmetrical to asymmetrical ripple cross-laminated in part. The sandstone layers are very thinly bedded to medium-bedded (20-200mm, 30-45mm average) with flat bases that contain brachiopod molds and wave rippled to amalgamated upper surfaces. Two varieties of horizontal burrows are common: curved, U-shaped burrows (1-3mm by 8-10mm); and simple slightly curved tubes (5mm diameter by 50mm length). The mudstone is gray to dark gray, grades to siltstone in part, very thin to moderately laminated, internally massive to horizontally laminated, blocky to fissile, and non-bioturbated to weakly bioturbated. Overall the amount of bioturbation for the interval is low to moderately low, the storm-bed frequency is moderate, and the percentage of wave ripples is moderate.
Hs	2B-24	1.0m	154.62m	The sandstone/shale ratio for this interval is 1:1. The sandstone is gray, very fine- to fine-grained, horizontally to ripple cross-laminated and is graded in part. The sandstone layers are very thinly to medium-bedded (20-180mm, 40-45mm average) with flat bases and symmetrical to asymmetrical upper surfaces. Several of the beds dramatically pinch-and-swell over the distance of a few meters (laterally).

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				Both horizontal (1-3mm diameter by 4-7mm length) burrows and vertical (1-2mm diameter by 4-7mm length) burrows occur in this interval. The intervening siltstone is dark gray to light gray, thin to thickly laminated, internally massive to horizontally laminated and low-angle cross-laminated. Bioturbation is rare to absent in the siltstone. Overall the bioturbation for this interval is very low to moderately low, the storm-bed frequency is moderate to moderately low, and the percentage of wave-ripples is moderate to moderately low.
Hs	2B-23	2.0m	153.62m	The sandstone/shale ratio for this interval is 1:1. The sandstone is light gray to gray to tan, very fine- to fine-grained, and horizontally, hummocky, and ripple cross-laminated. The sandstone layers are very thin to thinly bedded (10-60mm, 25-35mm average), with flat to uneven bases (loading features) and flat to wave-rippled tops. Several of the sandstone beds appear completely massive due to bioturbation. Graded beds are common in this interval being composed of either fossil debris (crinoid columnals, brachiopods) and granule size grains (quartz, phosphate?) or mud chips (1-2mm diameter by 2-5mm length). Horizontal burrowing dominates this interval (0.25-1.0mm diameter by 5mm length; 5mm diameter by 20mm length) with subordinate amounts of vertical and sub-vertical burrows (0.5-1.0mm diameter by 5-20mm length). The mudstone is gray, grading to siltstone, thin to medium-laminated, blocky, bioturbated, internally massive with 1-2mm thick sandstone lenses that are very fine-grained and horizontally laminated. Overall the amount of bioturbation for the interval is moderate to moderately low, the storm-bed frequency is moderate and the percentage of wave ripples is low. Sample 2B-19 at 152.52m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	2B-22	3.0m	151.62 m	The sandstone/shale ratio for this interval varies from 1:1 to 1:2. The sandstone is gray to tan, very fine- to fine-grained, and horizontally, micro-hummocky, and wave-ripple cross-laminated. The sandstone layers are thinly laminated to thinly bedded (2-80mm, 25-30mm average) with flat to uneven bases and uneven to wave-rippled tops. Erosional structures such as flute casts, groove casts, and tool marks are common on the bases of beds. Many of the beds are graded with quartz granules at the base and fossil lags composed of hematite replaced brachiopods, crinoid columnals, and Tentaculites(?). The fossil granule lags are generally 0.5-5mm thick and grade up into very fine to fine sandstone. Many of the beds pinch-and-swell drastically and a few pinch out all together. The amount of bioturbation in the sands is low, with horizontal burrowing (1mm diameter by 10mm length; 3mm diameter by 20-40mm length; simple straight tubes and grooves) at the tops and bottoms of beds. The upper contacts with the overlying mudstone are either sharp, or gradational due to biogenic reworking. Amalgamation of these sandstone beds are common resulting in the discontinuous nature of several mudstone layers. The mudstone is gray to tan to orange-brown, silty in part, thin to very thinly bedded, fissile to blocky, massive to horizontal to low-angle cross-laminated, and nonbioturbated to weakly bioturbated. Within the mudstone are lenses of siltstone that are 2mm to 4mm wide and 2mm to 1cm in lateral extent, and contain limonite-replaced fossils (crinoid columnals, brachiopods?) and very fine to coarse quartz (phosphate?) sand. Overall the amount of burrowing for this interval is very

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				low to moderately low, the storm-bed frequency is moderately abundant, and the percentage of wave ripples is low to moderately low. Sample 28-18 at 150.1m
Hm	28-21	6.6m	148.62m	The sandstone/shale ratio varies from 1:10 to 1:12. The sandstone is gray to tan, silty to very fine-grained and horizontally to micro-hummocky cross-laminated. The sandstone layers are thickly laminated to very thinly bedded (2-20mm, 10mm average) and tend to pinch-and-swell in thickness laterally. The bases of beds are either flat or contain gutter casts. Several of the beds contain black mud chips that appear to be concentrated at the bases of beds. The upper surfaces are either flat, wavy, or contain asymmetrical ripple cross-laminations. The mudstone is gray to olive-green/gray to brown to rarely red/brown, silty in part, thin to thickly laminated, massive, blocky to fissile, and weakly to non-bioturbated. Overall the amount of biogenic reworking is low, and the percentage of wave ripples is low.
Hm	28-20	2.4m	142.02m	The sandstone/shale ratio varies from 1:4 to 1:5. The sandstone is gray, very fine-grained to silty, horizontal to low-angle cross-laminated and the beds generally pinch-and-swell laterally. The sandstone layers are thickly laminated to thinly bedded (5-35mm, 10-15 average) and have flat to wavy tops. Mud chips (1mm diameter by 2mm length) are common within the sands and tend to be concentrated at the bases of beds. Bioturbation is rare with horizontal straight tubes (1mm diameter by 5-10mm length) on the under-

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				sides of beds and very rare vertical straight tubes (3mm diameter by 6-10mm length). The mudstone is gray to rarely red/brown, silty, massive, blocky to fissile, thin to thickly laminated, and weakly to non-bioturbated. Overall the amount of biogenic reworking is low, the frequency of storm beds is moderately low, and the percentage of wave ripples is low.
Hm	28-19	2.8m	139.62m	The sandstone/shale ratio varies from 1:5 to 1:6. The sandstone is gray, very fine-grained to silty, horizontal to low-angle cross-laminated and contains wave-rippled upper surfaces, in part. The sandstone layers are thickly laminated to thinly bedded (5-30mm, 10mm average) and they pinch-and-swell laterally. The sandstone layers pinch-and-swell so drastically that beds pinch-out all together, leaving wave-rippled sandstone lenses within mudstone. Much of the bedding in this interval is either wavy or lenticular. A few of the wavy beds are extremely fossil-rich limestone containing gastropods, enchinoderms, and medium to coarse quartz sand. The undersides of sandstone beds commonly contain gutter casts and horizontal burrows (1-2mm diameter by 10-20mm length; simple straight tubes). Within the sandstone beds are dark gray to black mud chips (1-3 mm diameter by 4-10mm). The mudstone is olive gray to light brown, thin to medium-laminated, massive, dominantly fissile to slightly blocky, and non-bioturbated to slightly bioturbated. Overall the biogenic reworking is low, the frequency of storm beds is moderately low, and the percentage of wave ripples is low.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	2B-18	2.1m	136.82m	The sandstone/shale ratio for this interval is 1:5. The sandstone is gray to slightly reddish-gray, very fine-grained to silty, horizontal to low-angle to hummocky cross-laminated, and the beds pinch-and-swell laterally. The sandstone layers are thickly laminated to thinly bedded (3-45mm, 10mm average) with irregular bases that commonly contain gutter casts and wave-rippled upper surfaces. Many of the gutter casts are completely isolated in the mudstone, along with wave-rippled sandstone lenses (starved ripples). Good fossil lags are common at the bases of beds composed of abraded skeletal debris. Bioturbation within the sands is scarce, with horizontal (2mm diameter by 5-10mm length) and vertical (2mm diameter by 10mm length), simple, straight tubes present. The mudstone is gray to brown to red/brown, thin to thickly laminated, massive, fissile to blocky to rarely hackly, and non-bioturbated to slightly bioturbated. Overall the amount of bioturbation is low, the frequency of storm beds is moderately low, and the percentage of wave ripples is low.
Hm	2B-17	3.85m	134.72m	The sandstone/shale ratio for this interval varies from 1:3 to 1:5. The sandstone is gray to maroon-brown, very fine-grained to silty, and contains horizontal to low-angle to micro-hummocky cross-laminations. One of the more striking features of this interval is the abundance of graded beds. Most of the beds in this interval contain a fossil lag, that is anywhere from 0.25-5mm thick, composed of gastropods, brachiopods, <i>Tentaculites</i> , trilobite fragments, and fine- to coarse-grained quartz grains. Above the fossil lag within

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				each bed is very fine sand or siltstone that grades upwards into non-bioturbated mudstone. The sandstone layers are thinly laminated to very thinly bedded (2-20mm, 9-10mm average), with flat bases and flat to wave-rippled to hummock-like upper surfaces. Some of the sandstone/siltstone beds contain small (1mm diameter by 2-5mm length) mudstone lenses, resembling flaser bedding. Bioturbation is rare, with a few occurrences of vertical burrows (3mm diameter by 10mm length), which may be escape traces. A few horizontal burrows are present at the base of beds (2mm diameter by 20mm length; 1mm diameter by 30mm length; 0.5 mm diameter by 5mm length), all of which are simple straight to slightly curved tubes. The interbedded mudstone is gray to brown to red-brown, thin to medium-laminated, massive, fissile to slightly blocky, and mostly non-bioturbated. Within the mudstone are red-brown, very fine-grained to silty sandstone lenses that exhibit horizontal to low-angle laminations. Overall the bioturbation is low, the storm-bed frequency is moderately abundant, and the percentage of wave ripples is low to moderately low. Sample 2B-16 at 131.5m
Hm	2B-16	2.85m	130.87m	The sandstone/shale ratio for this interval varies from 1:2 to 1:3. The sandstone is gray, very fine-grained to silty, and occurs in discontinuous layers and lenses (lenticular bedding) that contain horizontal, low-angle and ripple cross-laminations. The sandstone layers and lenses are thickly laminated to very thinly bedded (5-10mm, 7-8mm average), with flat to uneven bases that contain flute casts in part,

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				and flat to wave-rippled upper surfaces. Graded beds are common in this interval, typically composed of a 1mm thick fossil lag consisting of iron-replaced (limonite, glauconite?) gastropods, other skeletal fragments, and medium to coarse quartz sand. Above the fossil lag within each bed, the layers graded upwards into very fine sand or siltstone, and finally into non-bioturbated mudstone. The amount of biogenic reworking is low, with slightly curved to simple straight tubes (5mm diameter by 40mm length; 1mm diameter by 7-10mm length) occurring on the tops and bottoms of beds. A typical feature of many of the beds are 0.25mm diameter by 1.0-2.0mm gray mud chips dispersed throughout the layers. The mudstone is dark gray to gray/green to brown to reddish-brown, silty in part, thin to thickly laminated to very rarely very thinly bedded, massive to horizontally laminated, blocky to hackly to partly fissile, and weakly bioturbated. Overall the amount of biogenic reworking is low, the storm-bed frequency is moderately low, and the percentage of wave ripples is moderately low.
Hm	2B-15	6.5m	128.02m	The sandstone/shale ratio for this interval is 1:2. The sandstone is gray to tan, very fine-grained, with horizontal to low-angle to micro-hummocky cross-laminations. The sandstone layers are thickly laminated to medium-bedded (3-100mm, 10-30mm average), with flat bases containing gutter casts, in part, and flat to wave-rippled tops. This interval slightly thickens upwards and is capped by a fossiliferous ironstone. The ironstone is hematite-cemented, with limonite-replaced trilobite fragments that are in parallel

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				alignment. Several other hematite-cemented ironstones are present in this interval, all of which pinch-and-swell dramatically and may have wave-rippled(?) upper surfaces. In addition to the ironstones, the sandstone beds pinch-and-swell laterally and occasionally form discontinuous layers. Many of the sandstone beds contain fossil lags composed of gastropods, Tentaculites, and crinoid columnals. The amount of biogenic reworking is low, with horizontal burrows (1mm diameter by 5-10mm length, simple straight tubes), vertical (3mm diameter by 6mm length; 1mm diameter by 15mm length, straight tubes) and sub-vertical (1-2mm diameter by 10-15mm length, straight tubes) varieties present. The mudstone is dark gray to brown to rarely red-brown, silty in part, thin to medium-laminated, massive to horizontally laminated, fissile to slightly blocky, and non-bioturbated. Within the mudstone are very fine-grained sandstone and siltstone lenses, giving parts of the interval a lenticular bedding appearance. Overall the amount of biogenic reworking is low, the storm-bed frequency is moderate, and the percentage of wave ripples is moderately low. Sample 2B-14B at 125.0m Sample 2B-14A at 124.5m
Hm	2B-14	4.1m	121.52m	The sandstone/shale ratio for this interval is 1:2. The sandstone is gray, very fine-grained to silty, and contains horizontal to low-angle cross-laminations and micro-hummocky cross-laminations in part. The sandstone layers are thickly laminated to thinly bedded (5-45mm, 15-20mm average), with flat to uneven bases containing gutter casts, in part, and

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				flat to wave-rippled upper surfaces. Several of the beds contain abundant limonite(?) -replaced crinoid columnals and other skeletal debris, disseminated throughout each layer. In a few rare instances, the fossil debris is concentrated at the base of the beds (lag zone, 1mm thick). In addition to the fossil debris, small (0.25mm diameter by 2-3mm length) dark gray mud chips occurred within the beds. The amount of bioturbation within the beds is low, with horizontal branching burrows (5mm diameter by 20mm length), horizontal, simple straight tubes (1mm diameter by 5mm length), and sub-vertical simple tubes (3-5mm diameter by 10-15mm length) being the only varieties. The mudstone is gray to dark-gray to brown to red-brown, silty in part, thin to medium-laminated, massive to horizontally laminated, fissile to blocky, and appears mostly non-bioturbated. Overall the amount of biogenic reworking is low, the storm-bed frequency is moderately high, and the percentage of wave ripples is moderately low.
Hm	28-13	3.9m	117.42m	The sandstone/shale ratio varies from 1:1 to 1:2. The sandstone is light gray, to gray, very fine-grained to silty, and contains horizontal to low-angle and micro-hummocky cross-laminations. The sandstone layers are thickly laminated to thinly bedded (5-60mm, 20mm average), with flat to uneven bases that commonly contain gutter casts and hummock-like to wave-rippled upper surfaces. Intercalated with the sandstone and mudstone are hematite-cemented ironstones that pinch and swell dramatically. The ironstones exhibit no laminations in outcrop, but have a hummock-like geometry,

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				which may indicate they are storm beds. The wavelengths of the micro-hummocky and hummock-like beds varied from 185mm to 560mm, with an approximate average of 210mm. Bioturbation is dominated by horizontal varieties (4mm diameter by 45mm length; 2mm diameter by 15mm length) on the tops and bottoms of beds. The mudstone is dark gray to rarely reddish brown, silty, thin to medium-laminated to very rarely thickly laminated, and non-bioturbated. Overall the amount of biogenic reworking is low, the storm-bed frequency is moderate, and the percentage of wave ripples is moderate. Sample 28-13 at 113.83m
Hm	28-12	1.5m	113.52m	The sandstone/shale ratio for this interval ranges from 1:5 to 1:6. The sandstone is gray, very fine-grained to silty, with horizontal to low-angle cross-laminations, and micro-hummocky cross-stratification. Many of the sand beds contain fossil fragments throughout the layer. Several of the beds that weather to an orange/red color are hematite-cemented ironstones that are flat-based with undulatory, hummock-like upper surfaces. The wave lengths of the hummocky beds range from 1-2m. The sandstone layers are thickly laminated to very thinly bedded (3-20mm, 10mm average) and pinch-and-swell laterally. Some of the beds pinch out all together, leaving isolated lenses of wave-rippled sand (lenticular bedding). Both straight and branching horizontal grooves are present at the tops of beds (2mm diameter by 30-50mm length). The mudstone is dark gray, thin to medium-laminated, massive, fissile to very slightly blocky, and non-bioturbated. Overall the amount of biogenic reworking

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				for this interval is low, the frequency of storm beds is low, and the percentage of wave ripples is low. Sample 28-11 at 112.9m Sample 28-12 at 112.3m
FC	28-11	2.3m	112.02m	The sandstone/shale ratio for this interval is 10:1. This interval represents the highest energy environment and shallowest water conditions for the entire Formation. The sandstone is green to red with a grain size ranging from fine sand to fine-pebble gravel. The sedimentary structures are dominated by trough cross-stratification with subordinate amounts of symmetrical and asymmetrical ripples. This interval signifies the top of a regressive, shallowing and thickening upward cycle. The sandstone (conglomeratic) is thin to thickly bedded (3cm-0.5m, 5-10cm average) and contains maroon mud clasts (5mm diameter by 10mm length). The last 1.0m of this interval is devoid of shale and the beds appear amalgamated. The interval is capped by a 0.2m thick conglomeratic ironstone that is very calcareous. Bioturbation is very low due to the hypothesized high-energy environment of deposition and only a few vertical burrows (<i>Skolithos</i> ?) were detected (8mm diameter by 80mm length). The mudstone is gray, thin to medium-laminated, massive, fissile, discontinuous, and non-bioturbated. Overall the biogenic reworking is low, the frequency of storm beds may not apply here (beds may be the result of processes other than storms), and the percentage of wave ripples is low. Sample 28-8 at 110.4m Sample 28-9 at 110.6m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
FC	28-10	1.8m	109.72m	The sandstone/shale ratio for this interval varies from 2:1 to 3:1. The sandstone is gray to gray-green to red-gray, fine- to very coarse-grained, and contains occasional maroon mud clasts (5mm by 2.0-2.5mm). The sedimentary structures present in this interval include symmetrical and asymmetrical ripples, in addition to trough cross-stratified beds. In this interval rippled beds dominate over trough cross-stratified beds, which is the opposite of interval 28-11. The sandstone layers are thin to medium-bedded (20-200mm, 40-60mm average), and tend to be amalgamated, in part. The amount of burrowing in this interval is moderately extensive and the diversity of burrow types is high. Horizontal burrowers occur either as simple straight tubes (5-10mm diameter by 20-30mm length) or slightly curved to branching varieties (1mm diameter by 10-50mm length). Vertical (3-5mm diameter by 35-80mm length; <i>Skolithos</i> ?) and subvertical burrows also occur as simple straight tubes. The mudstone is gray to olive-green, thin to medium-laminated, massive, fissile, discontinuous, and may be bioturbated(?). Overall the amount of biogenic reworking for this interval is moderately high, the storm-bed frequency may not apply here (because these beds are probably a combination of tidal and storm-wave processes), and the percentage of wave ripples is moderately high.
FC	28-9	1.45m	107.92m	The sandstone/shale ratio for this interval varies from 8:1 to 10:1. The sandstone is light gray to dark gray, fine- to medium-grained, with occasional red and gray mud clasts.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				The sedimentary structures present include trough cross-laminations, and within the finer grain-size beds, symmetrical and asymmetrical ripples occur. The sandstone layers are very thinly bedded to medium-bedded (20-200mm, 40-50mm average), appear amalgamated, in part, and have a wavy appearance (episodic sedimentation?). The amount of bioturbation in the sands is moderate, with a high diversity. Horizontal burrows vary from simple straight tubes (2-5mm diameter by 20-50mm length) to horizontal tubes with a bulbous head (6mm diameter by 15mm length) to horizontal branching burrows (1mm diameter by 10mm length). Vertical burrows vary from simple straight tubes (3-5mm diameter by 20mm length) to slightly curved tubes (5mm diameter by 15mm length). Rare biogenic structures are straight to slightly curved horizontal burrows of large dimensions (15-20mm diameter by 50-60mm length). The mudstone is gray to olive-green/gray, silty in part, thinly laminated, massive, fissile, discontinuous, and non-bioturbated. Overall the amount of biogenic reworking is moderate to moderately high and the percentage of wave ripples is moderate. Sample 28-7 at 106.96m
FC	28-8	0.95m	106.47m	The sandstone/shale ratio for this interval is 10:1. The sandstone is gray to olive green, very fine- to medium-grained, and occasionally contains maroon and gray mud chips. The dominant sedimentary structures are symmetrical and trough cross-laminated beds. The sandstone layers are very thinly bedded to medium-bedded (20-200mm, 40mm average) and are amalgamated in part. The amount of bioturbation within

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				the sands is moderately extensive. Horizontal burrows are present as simple straight tubes (2mm diameter by 10-15mm length; 5-10mm diameter by 20-40mm length) and vertical burrows are also present as simple straight tubes (8mm diameter by 20mm length). The mudstone is gray, silty to massive to horizontally laminated, fissile, discontinuous, and non-bioturbated. Overall the amount of biogenic reworking is moderately high, and the percentage of wave ripples was difficult to estimate due to the amount of amalgamation of the sands.
FC	28-7	1.2m	105.52m	The sandstone/shale ratio for this interval varies from 1:8 to 1:10. The sandstone is gray, fine- to very coarse-grained, with maroon mud clasts in part. The sandstone occurs as thin beds and lenses that have wave-rippled upper surfaces and flat bases to uneven bases. The sandstone layers are thinly laminated to very thinly bedded (2-20mm, 15mm average) and are very silty in part. The amount of burrowing within the sands is moderately abundant. Simple straight horizontal burrows were common at the tops and bottoms of beds (5mm diameter by 30mm length; 1mm diameter by 5mm length). Cone-shaped vertical burrows that usually occur below sandstone beds range in size from 20mm diameter by 40mm length and 15mm diameter by 20mm length. The mudstone is gray to dark gray, silty in part, massive, fissile, and bioturbated in part. Overall the amount of biogenic reworking in the interval is moderate, and the percentage of wave ripples is low to moderately low.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
FC	2B-6	0.90m	104.32m	The sandstone/shale ratio for this interval is 5:1. The sandstone is white to red-gray, fine- to coarse-grained, with red and gray mud chips. The base of this interval contains medium-scale trough cross-stratified beds that become smaller in scale toward the top of the interval. The interval is capped by a fine-grained asymmetrical and symmetrical rippled bed. The sandstone layers are very thinly bedded to medium-bedded (20-200mm, 30-50mm average) and generally have a wavy to amalgamated appearance. The amount of bioturbation in the sands is low, with sparse amounts of horizontal, simple straight tubes (2-7mm diameter by 10-20mm length) present. The mudstone is dark gray, very silty in part to rarely sandy, thin to medium laminated, massive, fissile, and slightly horizontally burrowed. Overall the amount of bioturbation for this interval is moderately low, and the percentage of wave ripples is low.
FC	2B-5	1.6m	103.42m	The sandstone/shale ratio for this interval is 1:10. This interval is dominated by silty mudstone and siltstone with minor amounts of thin sandstone beds and lenses. The sandstone is red to olive green, very fine- to fine-grained, and contains maroon to brick-red mud clasts (2-6mm in length). The sandstone beds are commonly discontinuous, thickly laminated to thinly bedded (5-50mm, 20mm average), and are horizontally burrowed in part (2-7mm diameter by 20-40mm length; simple straight tubes). Another burrow type present includes cone-shaped, vertical burrows commonly at the bases of sandstone beds and lenses. The silty mudstone to siltstone is gray to tan, fissile to slightly blocky, thin to

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				medium-laminated, and massive and weakly bioturbated. Overall the amount of biogenic reworking is moderately low for this interval, along with the percentage of wave ripples. Sample 2B-6 at 102.5m
FC	2B-2	3.7m	101.82m	The sandstone/shale ratio for this interval varies from 2:1 to 5:1. The base of the interval is characterized by a 10-12cm, fine to very coarse, gray to dark-gray sandstone. The rest of the interval is typified by trough cross-stratified sands and ripple cross-laminated sands. The rippled sands are very fine- to fine-grained, green to slightly red, whereas the trough cross-stratified sands are medium- to coarse-grained, red, and forsets are draped by clays. Both of these bedding types contain gray to maroon, granule-size (2-4mm) grains. The sandstone layers are very thinly bedded (20-150mm, 30-40mm average) and generally have a wavy to amalgamated appearance. The amount of bioturbation within the sands appears moderately low, with slightly curved to straight tubes (horizontal: 1-3mm diameter by 10mm length; 5-7mm diameter by 15mm length) present at the tops and bottoms of beds. Intercalated with the sandstone are thinly laminated mudstone to siltstone to sandy siltstone interbeds that are gray, horizontally laminated to massive, fissile, discontinuous and weakly to non-bioturbated. Some of the clay layers are only 1-2mm thick between the coarse sands. Overall the bioturbation for this interval is low to moderately low, and the percentage of wave ripples is moderately low. Sample 2B-3 at 99.0m Sample 2B-5 at 101.5m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hs	2B-1	1.35m	98.12m	The sandstone/shale ratio for this interval is 5:1. The sandstone is dark gray to greenish/gray, very fine-grained, with horizontal to low-angle cross-laminations and excellent hummocky cross-laminations. The sandstone layers are very thinly to medium-bedded (20-120mm, 35mm average), have wave-rippled upper surfaces and gently undulating bases. Scattered throughout the sands are limonite-replaced fossils. The interbedded mudstone is gray to tan, thin to medium-laminated, massive, blocky to fissile, and weakly bioturbated in part. Overall the amount of biogenic reworking in this interval is moderately low (1-3mm diameter by 7-10mm length, horizontal burrows in the sandstone), the frequency of storm beds is moderately high and the percentage of wave ripples is moderately high. Sample 2B-2 at 97.4m
AH	2A-6	10.05m	96.77m	The entire interval is composed of gray to maroon, very fine-grained sandstone. Discontinuous, thinly laminated clay layers are present, but very rare. The sandstone is horizontally laminated, medium- to thickly bedded, very well-indurated, and contains limonite-replaced skeletal debris that defines the laminations. This may be an amalgamated hummocky sequence. Sample 2A-6 at 90.5m Sample 2A-7 at 95.1m
AH	2A-5	1.25m	86.72m	The sandstone/shale ratio for this interval is 10:1. The sandstone is maroon-gray, very fine- to fine-grained, and

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				contains skeletal debris that is both altered by limonite and unaltered. The sandstone layers are thin to thickly bedded (60-400mm, 100mm average) with flat tops and flat to undulating bases. Most of the mudstone is discontinuous due to the amalgamated nature of the sand beds. The mudstone is gray to dark gray, very silty in part, thin to medium-laminated, massive, fissile, and non-bioturbated. A few thin zones (10-50mm) of the mudstone appeared blocky and may be evidence for some amount of burrowing. Overall the amount of biogenic reworking is low, the frequency of storm beds is moderately low and the percentage of wave ripples is low. Sample 2A-4 at 85.90m Sample 2A-5 at 86.30m
Hs	2A-4	1.2m	85.47m	The sandstone/shale ratio for this interval is 1:1. The sandstone is gray, very fine-grained, with horizontal to low-angle cross-laminations and wave-rippled upper surfaces. The sandstone layers are thinly bedded (30-100mm, 40mm average) with flat bases and moderate amounts of horizontal bioturbation (10mm diameter by 40mm length; 3mm diameter by 15mm length, simple straight tubes) on the tops and bottoms of beds. The mudstone is gray, grading to siltstone in part, thin to thickly laminated to very thinly bedded, slightly blocky and moderately burrowed. Overall the amount of bioturbation is moderate, the frequency of storm beds is moderate and the percentage of wave ripples is moderate.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hs	2A-3	0.85m	84.45m	The sandstone/shale ratio for this interval is 1:1. The sandstone is orange to maroon, very fine-grained and contains abundant skeletal debris. The sandstone layers are thinly bedded to medium-bedded (60-220mm, 70-90mm average), with flat bases and tops. The sedimentary structures present are horizontal to low-angle cross-laminations and occasional hummocky cross-stratification. The sandstone beds are abundantly fossiliferous in parts (crinoids, brachiopods), are both cemented with hematite and limonite, and the thickness of the beds varies laterally. The mudstone is tan to olive green/brown to dark gray, very silty in part, thickly laminated, massive, fissile, and non-bioturbated. Overall the amount of biogenic reworking for this interval is very low, the storm-bed frequency is moderate, and the percentage of wave ripples is very low. (Note: very fine-grained sandstone lenses within shale: lenticular bedding).
Hs	2A-1	2.4m	82.30m	The sandstone/shale ratio for this interval is 5:1. The sandstone is orange to tan, very fine-grained, cemented by limonite, and contains abundant fossil debris (crinoid stems, crinoid columnals, and brachiopods). Higher up in the interval hematite cement is present, in addition to limonite cement. The sandstone layers are thinly to thickly bedded (50-600mm, 100mm average), horizontally to low-angle cross-laminated, and contain flat bases and tops with rare wave-rippled upper surfaces. The mudstone is tan to olive green-brown, silty, thin to thickly laminated to very thinly bedded, massive to horizontally laminated, blocky to fissile, and weakly to non-bioturbated. Overall the amount of

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				biogenic reworking for this interval is very low (little or none is present within the sands), the storm-bed frequency is moderate, and the percentage of wave ripples is very low. Sample 2A-1 at 81.2m Sample 2A-2 at 82.3m
	1A ¹¹ -9	10.2m	79.90m	Covered.
Hm	1A ¹¹ -8	12.2m	69.70m	The sandstone/shale ratio for this interval is approximately 1:15. Much of this interval is covered up by slope debris (colluvium) and the following description comes from the analysis of a few sparse outcrops and two small trenches excavated by the author. The dominant lithology in this interval is a gray mudstone that is thin to medium-laminated, massive, fissile to blocky and weakly to non-bioturbated. Infrequent sandstone beds are gray, very fine-grained to silty, and horizontally to low-angle cross-laminated. The sandstone/siltstone layers are very thinly bedded (10-20mm, 15mm average), have flat to rare rippled upper surfaces, and contain uneven bases that appear fluted, in part. Low amounts of horizontal (1-2mm diameter by 10mm length straight tubes) and vertical (3-5mm diameter by 10mm length) burrows are present. Overall the amount of biogenic reworking is low, the storm-bed frequency is very low, and the percentage of wave ripples is very low.
Hm	1A ¹¹ -7	5.1m	57.50m	The sandstone/shale ratio varies from 1:3 to 1:5. The sandstone is gray to light brown, very fine-grained, and horizontally to low-angle cross-laminated. The sandstone layers

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				are thickly laminated to thinly bedded (5-60mm, 20-30mm average), with asymmetrical and symmetrical rippled upper surfaces and uneven bases due to loading features and a few rare flute casts. The height/length ratio for the ripples is 4mm/100mm (ripple index 25). Some of the beds contained fossil debris (brachiopods, etc.) concentrated at the base. Horizontal burrows are present in the sand (1-5mm diameter by 10-15mm length simple straight tubes) at the tops of beds. The mudstone is gray, silty, thin to medium-laminated, massive, fissile, and non-bioturbated. Many of the contacts with the sands are gradational (due to biogenic reworking?), but may also be sharp. Overall the amount of biogenic reworking is moderately low, the frequency of storm beds is moderate to moderately low, and the percentage of wave ripples is moderate to moderately high.
Hm	1A ¹¹ -6	4.0m	52.4m	The sandstone/shale ratio for this interval is approximately 1:15. Most of this interval is covered and the following description comes from the rare outcrops found. The dominant lithology is a gray mudstone that is thin to medium-laminated, finely horizontally laminated in part, fissile, and non-bioturbated. Sparse sandstone beds are gray, very fine-grained to silty, and wave-rippled. The sandstone layers are very thinly bedded (10-20mm, 15mm average) with flat bases and horizontal and vertical burrowing at the tops of beds. Overall the amount of biogenic reworking is low, and the percentage of wave ripples is moderately low.

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	1A ¹¹ -5	5.5m	48.40m	The sandstone/shale ratio for this interval is 1:3. The sandstone is gray to tan, very fine-grained to silty, and horizontally to ripple cross-laminated. The sandstone layers are very thinly bedded (10-70mm, 15-20mm average) with flat bases and wave-rippled upper surfaces. Moderate amounts of bioturbation and a relatively high amount of diversity are present. Horizontal burrows are present either as simple straight tubes (2-5mm diameter by 10-15mm length; 5-7mm diameter by 15-20mm length), or sinuous burrows (10mm diameter by 50mm length) with a random pattern. Vertical burrows occurred as simple straight tubes (1-2mm diameter by 10mm length; 5-7mm diameter by 15mm length). The mudstone is gray to dark gray, silty, thin to medium-laminated, massive, blocky to fissile, and moderately bioturbated. Overall the amount of biogenic reworking for the interval is moderate, the storm bed frequency is moderate, and the percentage of wave ripples is moderately high. Sample 1A ¹¹ -3 at 44.93m
Hm	1A ¹¹ -4	3.0m	42.90m	The sandstone/shale ratio for this interval is approximately 1:10 to 1:15. This interval is mostly covered by slope debris and the following description comes from the sparse outcrops present. The sandstone is gray, very fine-grained, horizontally laminated and ripple cross-laminated. The sandstone layers are very thinly bedded (10-20mm, 15mm average), with flat bases and wave-rippled upper surfaces. A moderate amount of burrowing is present in the sands, dominated by horizontal varieties (1-2mm diameter by 10mm length; 5-7mm diameter by 15mm length). The mudstone is

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				gray, silty, thin to thickly laminated, massive, blocky to hackly, and appears bioturbated. Overall the amount of biogenic reworking is moderate, the frequency of storm beds is low, and the percentage of wave ripples is moderately low.
Hs	1A ¹¹ -3	3.0m	39.90m	The sandstone/shale ratio for this interval is 3:1. The sandstone is gray to tan, very fine-grained, horizontally laminated and ripple cross-laminated. The sandstone layers are very thin to thinly bedded (10-50mm, 20-25mm average), with flat bases and symmetrical to asymmetrical rippled upper surfaces. The height/length ratio of the ripples ranges from 5mm/60mm to 10-15mm/110mm. Bioturbation is common in this interval, with a high amount of diversity. Horizontal burrows included simple straight tubes of varying sizes (2-4mm diameter by 15-40mm; 5-7mm diameter by 20-50mm length). Vertical burrows are of two types: the first are straight tubes that flare at the top (Monocraterion?, 2mm diameter by 10mm length) and simple straight tubes (1-2mm diameter by 10mm length). The mudstone is gray to slightly dark gray, silty, thin to medium-laminated, with massive to rare horizontal laminations, blocky to fissile, and weakly bioturbated. Overall the amount of biogenic reworking is moderate, the storm-bed frequency is moderate and the percentage of wave ripples is moderate.
Hm	1A ¹¹ -2	13.0m	36.90m	The sandstone/shale ratio is questionable. This interval is mostly covered and the following description comes from the examination of sparse outcrops and one small trench excavated by the author. The lithology present in the interval is

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				a mudstone to silty-mudstone that is gray to light brown, thin to thickly laminated to very thinly bedded, massive to rarely horizontally laminated, blocky to fissile, and weakly to moderately bioturbated. There appears to be no sandstone in this interval(?).
Hm	1A ¹¹ -1	3.0m	23.90m	The sandstone/shale ratio for this interval varies from 1:3 to 1:4. The sandstone is gray to tan, very fine-grained, and horizontally laminated and ripple cross-laminated. The sandstone layers are very thinly bedded to thinly bedded (10-60mm, 30-40mm average), contain abundant skeletal fragments throughout, are flat-based, and exhibit wave-rippled to burrow-disrupted tops. The height/length ratio for the ripples varies from 5-10mm/80-90mm. The amount of bioturbation is extensive in this interval, but is concentrated at the tops of the beds. Horizontal burrows dominated this interval with several varieties (2mm diameter by 20-60mm length; 5-7mm diameter by 20-40mm length, simple straight tubes). The mudstone is gray, silty, thin to thickly laminated to very thinly bedded, blocky to hackly, and non-bioturbated. Overall the amount of biogenic reworking is moderate to moderately extensive, the storm-bed frequency is moderately low, and the percentage of wave ripples is moderately low to low. Sample 1A ¹¹ -2 at 22.43m
Hm	1A ¹ -2	6.5m	20.90m	The sandstone/shale ratio varies from 1:3 to 1:10. This interval represents a slight thickening-upwards sequence. The sandstone is gray to white, very fine-grained, horizon-

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				tally laminated to ripple cross-laminated. The sandstone layers are very thinly bedded to medium-bedded (10-200mm, 60mm average), with sharp, flat bases to gradational bases, and wave-rippled to burrow-disrupted upper surfaces. Top of interval is capped by a 0.2m thick hummocky(?) sandstone bed. Moderate amounts of bioturbation are dominated by straight to slightly sinuous tubes (5-8mm diameter by 15-20mm length). The mudstone is gray, grading to siltstone, thin to thickly laminated, massive, blocky to fissile, and slightly bioturbated(?). Overall the amount of biogenic reworking is moderate, the storm-bed frequency is moderately low, and the percentage of wave ripples is moderately low. Sample 1A-1 at 15.93m Sample 1A-1A at 17.03
Hm	1A-1	3.8m	14.40m	The sandstone/shale ratio is 1:2. The sandstone is light gray to gray, very fine-grained, horizontally laminated and ripple cross-laminated. The sandstone layers are very thinly bedded to medium-bedded (20-100mm, 30-40mm average), with flat to gradational bases (burrowed) and generally burrowed tops. Most of the sandstone beds are extensively burrowed with minor amounts of internal laminations present. Not all of the sandstone beds are continuous, and several pinch out laterally into lenses. Bioturbation is dominated by both horizontal (0.5mm diameter by 3-4mm length; 5mm diameter by 10-15mm length, simple straight tubes and grooves) and vertical (0.5mm diameter by 3-5mm length, straight tubes) burrows. The mudstone is gray to dark gray, thin to medium-laminated, massive to horizontally laminated, blocky and

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				bioturbated in part. Overall the amount of biogenic reworking is moderate, the storm-bed frequency is moderate, and the percentage of wave ripples is very low.
QA	1A-4	5.0m	10.60m	The sandstone/shale ratio for this interval is 6:1. The sandstone is light to dark gray to brown, silty, very fine- to fine-grained, and horizontal to ripple cross-laminated in part. Internal laminations are rare and most beds are extensively burrowed. The sandstone layers are very thinly bedded to medium-bedded (20-110mm, 40mm average) with sharp, flat bases and burrowed tops. The upper surfaces of some sandstone beds appear to contain asymmetrical ripples, but due to the bioturbation, a positive determination was not possible. Both horizontal and vertical (also sub-vertical) bioturbation is present in the silty to fine-grained sandstone (0.5-1.0mm diameter by 4-5mm length, horizontal and vertical tubes). The silty mudstone to siltstone is brown to gray, medium to thickly laminated, massive, blocky, and bioturbated. Overall the amount of biogenic reworking is moderate to moderately high, the storm-bed frequency(?) is moderate and the percentage of wave ripples(?) is difficult to determine because a non-storm origin for some beds seems likely.
QA	1A-3	3.0m	5.60m	The sandstone/shale ratio for this interval varies from 5:1 to 6:1. The sandstone is pale brown, silty, very fine- to medium-grained, and ripple cross-laminated to trough cross-laminated. Most of the beds within this interval are burrowed and internal structures are very rare. The sandstone layers are thin to medium-bedded (30-120mm, 40-50mm

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				average), flat-based and have irregular upper surfaces (burrowing). Horizontal bioturbation is abundant in this interval (0.5-1.0mm diameter by 4-5mm length, simple straight tubes; 5mm diameter by 10mm length grooves in tops of beds). The silty mudstone to siltstone is gray to brown, thin to medium-laminated, massive, blocky, and bioturbated. Overall the amount of biogenic reworking is moderate to moderately high, and the storm-bed frequency and percentage of wave ripples is questionable because a non-storm origin for some beds seems likely. Sample 1A-10 at 4.5m
QA	1A-2	1.25m	2.6m	The sandstone/shale ratio for this interval varies from 1:10 to 1:12. The sandstone is pale brown, silty to very fine-grained, and ripple cross-laminated in part. Many of the internal laminations are disrupted by horizontal and vertical bioturbation. The sandstone layers are very thin to thinly bedded (10-50mm, 20mm average), and pinch-and-swell laterally. Commonly the sandstone beds have flat to irregular bases and burrowed tops. The silty mudstone is gray to brown, rarely sandy, thin to medium-laminated, massive to rarely horizontally laminated, and burrowed. Small (2mm thick), very fine to silty sandstone (burrowed) lenses are common. Disseminated throughout the silty mudstone are granule-size phosphate grains that appear to be reworked by the bioturbation. Overall the amount of biogenic reworking for the interval is moderately high. Sample 1A-8 at 1.4m

Section 1 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
QA	1A-1	1.35m	1.35m	This interval is composed of a single sandstone/siltstone bed that represents the contact between the Upper Ordovician Sequatchie and the Lower Silurian Rockwood Formations. The sandstone is tan to orange-brown, extensively horizontally burrowed and contains a thin (5-10mm) winnowed lag of phosphate grains and fossil debris at the top of the bed. The contact with the underlying shale is gradational and the upper contact is very sharp. The burrowing has erased any trace of stratification. Sample 1A-6 at 0.52m Sample 1A-7 at 1.12m

(Section 2--east limb)

STRATIGRAPHIC SECTION OF THE ROCKWOOD FORMATION

(NOTE: Measurement and description of southbound side of road-cut.)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	1E-1	6.0m	270.4m	The sandstone/shale ratio for this interval varies from 1:3 to 1:4. The sandstone is tan to gray to slightly orange-gray, silty to very fine-grained, horizontally laminated and micro-hummocky cross-laminated. Wave ripples are extremely common, exhibiting an interference pattern. The height/length ratio of the ripples is 4mm/65-80mm. The sandstone layers are thickly laminated to very thinly bedded (3-20mm, 10-15mm average), with flat to undulating bases. Bioturbation is present at the tops and bottoms of beds, in the form of horizontal burrows (1-5mm diameter by 10-20mm length, simple straight tubes and grooves) and vertical burrows (1-3mm diameter by 5-7mm length, escape tubes?). The silty shale is blue-gray to olive-green, thin to thickly laminated, horizontally laminated and non-bioturbated. Extensive cleavage development is present in the silty-shale.
Hm	1E-2	4.0m	264.4m	The sandstone/shale ratio for this interval is 1:3. The sandstone is gray, silty to very fine grained, horizontally laminated and micro-hummocky to hummocky cross-stratified. Wave-rippled tops are extremely common and portray an interference pattern. The sandstone layers are thickly laminated to thinly bedded (5-50mm, 20mm average), with uneven bases that contain gutter casts and tool marks, in part. Fossil lags at the bases of some beds contained brachiopods,

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				gastropods and crinoid columnals. Both horizontal (1-5mm diameter by 10-20mm length, simple straight tubes) and vertical (1-3mm diameter by 5-7mm length, straight tubes) burrows are present. The shale is gray, thin to medium-laminated, massive to horizontally laminated, and probably non-bioturbated. Extensive cleavage development is evident in the shale.
Hm	1E-3	5.0m	260.4m	The sandstone/shale ratio is 1:3. The sandstone is gray to dark gray, silty to very fine-grained, horizontally laminated and micro-hummocky to hummocky cross-laminated. Wave-rippled tops are extremely common, with both an interference and parallel pattern. The sandstone layers are thickly laminated to thinly bedded (5-55mm, 20-25mm average), with flat to uneven bases and tool marks and flute casts in part. The wave ripples exhibited asymmetrical cross-laminations and height to length ratios of 6mm/80mm. Some of the silty-sandstone beds contain scattered crinoid columnals. Bioturbation is extensive in some cases, and is normally concentrated at the tops of beds. The shale is gray, silty in part, thin to thickly laminated, horizontally laminated and non-bioturbated.
Hm	1E-4	5.0m	255.4m	The sandstone/shale ratio is 1:2. The sandstone is gray, silty to very fine-grained, horizontally laminated to hummocky cross-laminated. The sandstone layers are very thinly bedded to medium-bedded (10-100mm, 30mm average), with uneven bases due to load casts, groove casts and flute casts. Upper surfaces are wave-rippled, burrowed, and amalgamated

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				in part. Scattered throughout the sand beds are limonite-replaced crinoid columnals. Wave-rippled ironstone beds are present in this interval. They are commonly low-angle to horizontally laminated, and the laminations are defined by the abundant fossil debris contained in the beds. The fossils identified in hand sample are as follows: gastropods, brachiopods, crinoids, and <u>Tentaculites</u> ? The shaly-siltstone is gray, thin to moderately laminated, and non-bioturbated. The amount of bioturbation, overall, is moderate, the frequency of storm beds is moderate to moderately high, and the percentage of wave ripples is high.
Hm	1E-5	10.0m	250.4m	The sandstone/shale ratio ranges from 1:2 to 1:3. The sandstone is gray, very fine-grained to silty and horizontally to hummocky cross-stratified. The sandstone layers are very thinly bedded (10-80mm, 20-25mm average), with flat to uneven bases (due to loading) and wave-rippled tops. The wave ripples generally exhibit an interference pattern, with height/length ratios of 9mm/80mm. Ironstone layers are present that are extremely fossiliferous. Some sandstone beds contain scattered crinoid columnals. Graded beds are common and contain fossil lags that grade upwards into very fine sand, siltstone and non-bioturbated shales. Horizontal burrows are common at the tops and bottoms of beds. The silty shale is gray, horizontally laminated, and non-bioturbated. Overall the amount of bioturbation is low, the storm-bed frequency is moderate and the percentage of wave ripples is moderate.

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	1E-6	10.0m	240.4m	The sandstone/shale ratio ranges from 1:1 to 1:3. The sandstone is gray to maroon-gray to orange-gray, silty to very fine-grained, and horizontally laminated to hummocky cross-laminated. The sandstone layers are very thinly bedded to thickly bedded (10-400mm, 75-100mm average) with flat bases and wave-rippled upper surfaces. All the sand beds are hummocky cross-stratified, have wave-rippled upper surfaces and contain scattered fossil debris that define the laminations, in part. Richly fossiliferous ironstone beds that pinch-and-swell laterally are also present. The wave ripples exhibit both an interference and a parallel pattern, and have a height/length ratio of 8mm/90mm. For the most part the wave ripples do not display internal laminations, but when they do, they are usually asymmetric. The interbedded shale is gray and appears to be non-bioturbated. Overall the amount of bioturbation is low (only detected at the tops of sandstone and ironstone beds), the frequency of storm beds is moderate, and the percentage of wave ripples is extremely high.
Hs	1E-7	11.3m	230.4m	The sandstone/shale ratio ranges from 2:1 in the lower 5 meters to 5:1 in the upper 5 meters. The sandstone is gray to maroon-gray to maroon, with limonite-replaced fossil debris, very fine- to fine-grained, and is horizontally laminated to hummocky cross-laminated. The sandstone layers are very thinly bedded to very thickly bedded (10mm-1.3 meters, 0.1-0.3 meters average) with sharp, flat bases and wave-rippled upper surfaces. Many of the beds are extremely fossil-rich and contain gastropods up to 10mm in diameter. Many of

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				these fossiliferous beds are extensively burrowed and lack any internal stratification. Other fossil varieties detected are brachiopods, Tentaculites, crinoid columnals, and trilobite fragments. The top of this interval is capped by a 1.3m sequence of amalgamated hummocky beds. Many of the sandstone and ironstone layers pinch-and-swell laterally. This interval represents one of the more richly fossiliferous sections in the Formation. The interbedded gray shale appears to be non- to weakly bioturbated. Overall the amount of biogenic reworking is moderate, the frequency of storm beds is moderate, and the percentage of wave ripples is high.
FC	1E-8	2.0m	219.10m	This interval is composed of maroon to green, medium- to very coarse-grained sandstone beds that are trough cross-stratified. The sandstone layers are 100 to 200mm thick and contain discontinuous shale layers. (There may be a fault between 1E-7 and this interval 1E-8.)
	1E-9	2.0m	217.10m	Covered. (This may be a fault zone.)
AH	1E-10	1.0m	215.10m	This interval is composed of an amalgamated hummocky sequence.
AH	1E-11	2.0m	214.10m	Covered. (This may be a fault zone.)
FC	1E-12	1.1m	212.10m	Fine- to medium-grained, maroon to green sandstone with abundant red mud chips. Overall the beds have a wavy appear-

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				ance and are rippled to amalgamated in part. The interbedded, discontinuous shale is gray and may be burrowed.
FC	1E-13	1.7m	211.9m	This interval is dominated by brown to maroon shale with abundant horizontal burrows, and cone shaped vertical burrows. Rare fine-grained maroon sandstone lenses are present.
FC	1E-14	10.0m	210.2m	This interval is dominated by sandstone that is maroon to green, fine- to medium-grained, and contains abundant red mud chips. Beds are wavy to amalgamated and the last 3 meters of the interval is devoid of shale. The last 1.0m of the interval is characterized by a green, fine- to medium-grained sandstone with red mud chips that is trough cross-stratified. Directly on top of this is a 0.1m thick pebbly conglomeratic ironstone that also appears trough cross-stratified.
Hm	1E-15	20.8m	202.2m	The sandstone/shale ratio for this interval varies from 1:2 to 1:3. The sandstone is gray to dark gray, very fine-grained to silty, horizontally laminated and micro-hummocky cross-laminated. The sandstone layers are thickly laminated to thinly bedded (3-50mm, 20mm average), with flat to uneven bases and wave-rippled to burrowed upper surfaces. Beds commonly pinch-and-swell and contain fossil lags composed of fragmented fossil debris and quartz granules. Lenticular ironstones are present, which are extremely fossiliferous. The shale is gray to red-brown, very silty, massive, and may be bioturbated(?). Overall the amount of bioturbation is

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				moderate, the storm-bed frequency is low to moderate and the percentage of wave ripples is low. Some of the ironstones exhibited wave-rippled upper surfaces. The last 2.0m of the interval is a fault zone with extensive deformation.
Hm	1E-16	9.0m	181.4m	This zone is extensively fractured and contains silty to very fine-grained, gray sandstone interbedded with gray shale, all of which is extensively burrowed.
Hm	1E-17	20.0m	172.4m	The sandstone/shale ratio varies from 1:2 to 1:3 in this interval. The sandstone is light gray, very fine to silty, and massive to rarely horizontally laminated. The sandstone layers are thickly laminated to thinly bedded (10-40mm, 10-15mm average), with burrowed tops and rare wave ripples. The bases of beds are gradational to flat and uneven. Higher up in the interval the amount of burrowing decreases slightly, and internal stratification becomes more evident. The following sedimentary structures are common: Hummocky cross-stratification (also micro-hummocky); horizontal laminations; and asymmetrical ripple cross-laminations. No ironstones are present in this interval. Intercalated with the sandstone are light gray to light-green silty shales, that are sandy in part, and may be non-bioturbated(?). Overall the amount of biogenic reworking is moderate, the storm-bed frequency is moderate and the percentage of wave ripples is low.
Hm	1E-18	31.5m	152.4m	The sandstone/shale ratio varies from 1:1 to 1:2. The sandstone is gray, silty to very fine-grained, massive to hori-

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				zonally laminated and hummocky cross-stratified. The sandstone layers are very thinly bedded to medium-bedded (10-30mm, 20-30mm average), with burrowed to wave-rippled tops (with asymmetrical cross-laminations) and flat to slightly uneven bases. The wave ripples exhibit both an interference and parallel pattern, with typical height/length ratios of 4mm/80mm. First ironstone detected 15.0m up into the interval, and it is richly fossiliferous with crinoids, brachiopods, and other fragmented skeletal material. Gutter casts and load casts are present on the undersides of several beds. Scattered limonite-replaced fossils are common in some sands and the amount of fossil debris starts to increase higher up in the interval. Sandstone and ironstone beds pinch-and-swell laterally. Graded beds occur infrequently and commonly contain a fossiliferous lag at the base. The top of the interval is capped by a 130mm maroon-fossiliferous hummocky cross-stratified bed. The shale is gray, silty in part, and may be bioturbated(?). Overall the amount of bioturbation is moderate to moderately low, the storm-bed frequency is moderate and the percentage of wave ripples is moderately low.
Hs? FC?	1E-19	17.0m	120.9m	The sandstone/shale ratio varies from 5:1 to 10:1. The sandstone is maroon to green, very fine to fine-grained, hummocky cross-stratified and amalgamated in part. The sandstone layers are very thinly bedded to thickly bedded (20mm-0.6m, 150mm average), with flat bases and burrowed tops. Laminations are defined by fossil debris and a few beds contain red mud chips. Several of the beds are iron-

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				rich and many contain iron-rich fossil lags at the base of layers. Towards the top of the interval is a 3 meter zone of green, very fine- to fine-grained sandstone that is capped by a burrowed conglomeratic bed. The shales are gray to brown-red, silty to rarely sandy, horizontally laminated and non-bioturbated. The last 2 meters are composed of bioturbated gray shale with red, fine- to medium-grained sandstone beds with red mud chips. (There may be a fault between the last 2 meters and the rest of the interval.)
FC	1E-20	16.0m	103.9m	The sandstone/shale ratio is 20:1. The sandstone is grey-green to red, fine- to coarse-grained, with maroon mud chips extremely common. The sandstone layers are thinly bedded to thickly bedded (30mm-0.5m, 80-100mm average) and commonly are trough cross-stratified. Several of the layers are wave-rippled and some are amalgamated. The shale is gray, discontinuous and non-bioturbated(?). The interval is capped by a green, trough cross-laminated bed, which is in turn capped by an iron-rich conglomeratic bed. Some of the pebbles are up to 40mm (very coarse-pebble gravel) in length.
Hm	1E-21	8.0m	87.9m	The sandstone/shale ratio is 1:3 to 1:4. The sandstone is gray, silty to very fine-grained, and massive to horizontally laminated. The sandstone layers are thinly laminated to thinly bedded (2-50mm, 15-20mm average), with wave-rippled tops, flat bases, gutter casts and flute casts. Ironstones are present and pinch-and-swell dramatically. The shale is gray to brown, silty, and is non-bioturbated.

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
Hm	1E-22	28.0m	79.9m	The sandstone/shale ratio for this interval varies from 1:3 to 1:4. The sandstone is gray, silty to very fine-grained, massive, horizontally laminated and micro-hummocky cross-stratified. Ironstones are red to yellowish orange, pinch-and-swell laterally, and contain maroon mud chips. The sandstone layers are very thinly bedded to medium-bedded (10-150mm, 20-25mm average), with flat to uneven bases (gutter casts) and burrowed to wave-rippled upper surfaces. Graded beds are present and are characterized by an iron-rich fossil lag at the base. Wave ripples occasionally exhibit asymmetrical cross-laminations and exhibit height/length ratios of 9mm/115mm. The intercalated shale is gray to rarely red-brown, silty in part, and non- to partially bioturbated. Overall the bioturbation is low, the frequency of storm beds is moderate, and the percentage of wave ripples is low.
Hs	1E-23	19.9m	71.9m	The sandstone/shale ratio for this interval varies from 1:1 to 2:1. The sandstone is gray, silty to very fine-grained, horizontally laminated, and hummocky cross-stratified. The sandstone layers are very thinly bedded to medium-bedded (20mm-0.15m, 30-50mm average), with wave-rippled to burrowed tops and flat to uneven bases. Some beds are abundantly fossiliferous (ironstones?) with gastropods, crinoids, and brachiopods as common constituents. Graded beds are common with fossil (gastropods, crinoids) - rich lags at the base of the layers. The interbedded shale is gray and non-bioturbated. Overall the amount of bioturbation is low, the

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				frequency of storm beds is moderately low, and the percentage of wave ripples is low.
Hs	1E-24	10.0m	52.0m	The sandstone/shale ratio is 3:1. The sandstone is light-green to gray, very fine-grained and hummocky cross-stratified. The sandstone layers are very thinly bedded to thickly bedded (10mm-0.5m, 50mm average), with flat bases and bioturbated tops. Sands are discontinuous in part and heavily burrowed. Fossil debris is common and defines the laminations in the hummocky cross-stratified beds. The mudstone is maroon to green silty, in part, and heavily burrowed.
MB	1E-25	10.0m	42.0m	The sandstone/shale ratio for this interval is 1:3. The sandstone is gray, silty to very fine-grained, and completely burrowed. The mudstone is maroon to green, extensively burrowed, and contains brachiopods, crinoids, and gastropods.
MB	1E-26	7.0m	32.0m	The sandstone/shale ratio for this interval is 5:1 to 7:1. The sandstone is gray, very fine-grained to silty, horizontally laminated, hummocky cross-stratified, and burrowed in part. The sandstone layers are thinly bedded (30mm-0.3m, 0.1m average), amalgamated in part, with flat bases and tops. The mudstone is gray to maroon, silty and bioturbated.
MB	1E-27	8.5m	25.0m	The sandstone/shale ratio is 1:5. The sandstone is gray, very fine-grained, and bioturbated. The mudstone is maroon

Section 2 (continued)

Facies	Unit No.	Unit Thickness (m)	Cumulative Thickness (m)	Description
				to slightly green, bioturbated, and contains abundant brachiopods.
MB	1E-28	16.5m	16.5m	The sandstone/shale ratio for this interval is 5:1 to 7:1. The sandstone is gray, very fine-grained, horizontally laminated, hummocky cross-laminated, and burrowed in part. The sandstone layers are thinly bedded to medium-bedded (30-200mm, 50mm average), with flat bases and flat to burrowed tops. Several of the sandstone beds are amalgamated in part. The mudstone is maroon-gray, silty and bioturbated.

APPENDIX
(Section 3)
HAND SAMPLE THIN SECTION DESCRIPTIONS

Sample No: 1A-7
Formation: Rockwood
Location: Base of Formation

HAND SAMPLE DESCRIPTION

Color: Fresh-light brown
Weathered-light brown to orange brown
Structures: Coarsening-upwards sample
Grain Size: Maximum - 8.0mm
Minimum - 0.05mm
Mode - 0.1-0.5mm
Sorting: Poor
Roundness: Angular to well-rounded
Sphericity: Moderate
Composition: Quartz, rock fragments, phosphatic grains, fossils, hematite and carbonate cement.

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 10.0mm
Minimum - 0.05mm
Mode - 0.5-0.1mm

Roundness: Well-rounded to angular

Sorting: Poorly Sorted

Sphericity: Moderate to high

Composition:

Monocrystalline (unstrained) quartz	35%
Monocrystalline (strained) quartz	25%
Plagioclase feldspar	2%
Polycrystalline (2-5 crystallites/grain) quartz	trace
Siltstone/mudstone fragments	2%
Sandstone fragments	5-10%
Polycrystalline (>5 crystallites/grain) quartz	trace
Phosphatic (?) and chamosite ooids	trace

Composition:	Percent:
Phosphatic fossil fragments and granules	1%
Microcline feldspar	trace
Glaucinite pellets	trace
Hematite-replaced fossil fragments	trace
Phyllosilicates	1%

Cement:

Hematite	2-3%
Sparry Calcite, siderite?	10-15%
Dolomite	5%

Recalculated percent for Folk et al (1970).
Classification:

Q = 80%
F = 16%
R = 4%

Other features: Hematite was detected replacing skeletal debris and coating grains. Many of the sedimentary rock fragments contained phosphatic and chamosite oolites. Chamosite oolites were disc-shaped.

Rock Name: Calcareous sublitharenite

APPENDIX
Section 3 (continued)

Sample No: 1A-10
Formation: Rockwood
Location: 3.3m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-tan to gray
Structures: Horizontal to low-angle laminations, completely disrupted by burrowing in the upper part of the sample.

Grain size: < 0.0625mm

Sorting: Well sorted

Roundness: ?

Sphericity: ?

Composition: Quartz, carbonate cement

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.01mm
Mode - 0.05mm

Roundness: Sub-angular

Sorting: Well-sorted

Sphericity: Moderate/high

Composition:

Monocrystalline (unstrained) quartz	30%
Monocrystalline (strained) quartz	20%
Plagioclase feldspar	1%
Phyllosilicates	1%
Opalines	5%
Phosphate grains	trace
Glaucinite pellets	trace
Tourmaline	trace

Cements:	Percent:
Sparry Calcite	40%
Silica	2-3%

Recalculated percent for Folk et al (1970).
Classification:

Q = 98%
F = 2%
R = 0%

Rock Name: Calcareous quartz arenite

APPENDIX
Section 3 (continued)

Sample No: 1A-1
Formation: Rockwood
Location: 13.68m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-gray to orange-brown

Structures: Horizontal laminations

Grain Size: Maximum - 0.1mm
Minimum - < 0.0625mm
Mode - 0.05 to 0.01mm?

Sorting: Well-sorted

Roundness: Sub-rounded

Sphericity: Moderate

Composition: Quartz, heavy minerals, carbonate cement.

Composition:	Percent:
Opaque grains	2-3%
Jourmaline	trace
Epidote (?)	trace
Peloids (?)	trace

Cement:	Percent:
Sparry calcite	20-25%
Silica	trace

Recalculated percent for Folk et al (1970).
Classification:

Q = 99%
F = 1%
R = 0%

Other features: Laminations defined by opaques, phosphatic fragments and grains, and glauconite pellets. Absence of hematite cement.

Rock Name: Calcareous quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.2mm
Minimum - 0.05mm
Mode - 0.05-0.1mm

Roundness: Sub-angular to sub-rounded

Sorting: Well-sorted

Sphericity: Moderately high

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	30%
Plagioclase (An 12-14) feldspar	1%
Phosphatic fossil fragments and grains	1%
Glauconite pellets	trace

APPENDIX
Section 3 (continued)

Sample No: 1A-1a
Formation: Rockwood
Location: 15.78m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-orange/brown to white
Weathered-tan to brown

Structures: Low-angle laminations

Grain Size: Maximum - 0.1mm
Minimum - < 0.0625mm
Mode - ?

Sorting: Well-sorted

Roundness: Sub-rounded

Sphericity: Moderate

Composition: Quartz, phyllosilicates, hematite (limonite) cement.

Cements:	Percent:
Hematite	5-10%

Recalculated percent for Folk et al (1970).
Classification:

Q = 99%
F = 1%
R = 0%

Other features: Extreme abundance of porosity; Grains commonly coated by hematite.

Rock Name: Iron-rich quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.01mm
Mode - 0.05-0.1mm

Sorting: Well-sorted

Roundness: Sub-rounded to sub-angular

Sphericity: Moderate to high

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	28%
Phyllosilicates	2-5%
Plagioclase feldspar	trace
Peloids (?)	2%
Opauques	trace
Porosity	10-15%

APPENDIX
Section 3 (continued)

Sample No: 1A*-2a
Formation: Rockwood
Location : 41.43m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-light brown to orange/brown

Structures: Horizontal to wavy laminations

Grain Size: Maximum - 0.1mm
Minimum - < 0.0625mm
Mode - ?

Sorting: Well-sorted

Roundness: Sub-angular

Sphericity: Moderate

Composition: Quartz, heavy minerals, carbonate cement, fossils.

Cements: Percent:

Hematite	1%
Silica	trace
Sparry Calcite	10-20%
Dolomite	1-2%

Recalculated percent for Folk et al (1970).
Classification:

Q = 97%
F = 3%
R = 0%

Other features: The majority of the hematite occurred as thin seams, resembling stylolites.

Rock Name: Calcareous quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.05mm
Mode - 0.05-0.075mm

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderately high

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	30%
Plagioclase (An 0-10) feldspar	1-2%
Phyllosilicates	2-3%
Glauconite pellets	trace
Opauques	1%
Peloids (?)	trace

APPENDIX
Section 3 (continued)

Sample No: 1A*-3
Formation: Rockwood
Location : 65.93m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-gray to slightly orange/brown

Structures: Horizontal to low-angle laminations that are slightly disrupted by burrowing.

Grain Size: Maximum - 0.1mm
Minimum - < 0.0625mm
Mode - ?

Sorting: Well-sorted

Roundness: Sub-rounded

Sphericity: Moderate

Composition: Quartz, heavy minerals, phyllosilicates, carbonate cement.

Cements: Percent:

Sparry Calcite	10-20%
Silica	trace
Hematite	1%

Recalculated percent for Folk et al (1970).
Classification:

Q = 100%
F = trace
R = 0%

Other features: Both phyllosilicates and opaques define bedding; Horizontal and vertical burrows were detected.

Rock Name: Calcareous quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.025mm
Mode - 0.05mm

Sorting: Well-sorted

Roundness: Sub-rounded

Sphericity: Moderate to high

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	27%
Plagioclase feldspar	trace
Phyllosilicates	5-7%
Opauques	3-5%

APPENDIX
Section 3 (continued)

Sample No: 2A-1
Formation: Rockwood
Location : 80.05m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-orange/brown
Weathered-gray/brown
Structures: Horizontal laminations
Grain Size: Maximum - 0.1mm
Minimum - < 0.0625mm
Mode - ?
Sorting: Well-sorted
Sphericity: Moderate
Composition: Quartz, phyllosilicates, fossils,
hematite, and/or limonite cement.

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.15mm
Minimum - 0.025mm
Mode - 0.05 to 0.075mm

Sorting: Well-sorted
Roundness: Sub-rounded to angular
Sphericity: Moderate to high

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	23%
Phyllosilicates	2-3%
Opaques	trace
Epidote (?)	trace
Jourmaline	1%
Glauconite pellets	trace

Composition:	Percent:
Fossil fragments	2-3%
Chert fragments	trace
Porosity	10-20%
Altered feldspars (?)	?

Cements:	Percent:
Hematite	10%
Silica	trace

Recalculated percent for Folk et al (1970).
Classification:

Q = 100%
F = 0%
R = 0%

Other features: Extremely high porosity;
Crude horizontal laminations; Hematite
concentrated along horizontal laminations;
Fossils replaced by hematite.

Rock Name: Iron-rich quartz arenite

APPENDIX
Section 3 (continued)

Sample No: 2A-5
Formation: Rockwood
Location : 85.85m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-maroon/gray
Weathered-maroon/gray
Structures: Horizontal laminations; Base of sample
composed of a (15mm) fossil lag.
Grain Size: Maximum - 1.0mm (rare)
Minimum - < 0.0625mm
Mode - ?
Sorting: Moderate
Roundness: Angular to sub-rounded
Sphericity: Moderate
Composition: Quartz, fossils, rock fragments, hematite
cement, carbonate cement.

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 2.0mm
Minimum - 0.025mm
Mode - 0.05-0.1mm

Sorting: Moderate
Roundness: Angular to sub-rounded
Sphericity: Moderate

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	27%
Plagioclase (An 10-14) feldspar	trace
Fossils (echinoderms, bryozoans)	5-10%
Sedimentary rock fragments	trace
Phyllosilicates	trace
Mudstone/siltstone fragments	trace

Composition:	Percent:
Glauconite pellets	1-2%
Jourmaline	trace
Chert fragments	trace
Opaques	1%

Cements:	Percent:
Sparry Calcite	5%
Hematite	15%
Opaques	trace

Recalculated percent for Folk et al (1970).
Classification:

Q = 99%
F = 0%
R = 1%

Other features: Pores of fossil fragments
filled with hematite; Glauconite pellets
partially altered to limonite; Some fossil
fragments unaltered by hematite; Carbonate
rock fragments present containing dolomite
in part; Carbonate cement concentrated at
base of sample.

Rock Name: Hematitic quartz arenite

APPENDIX
Section 3 (continued)

Sample No: 2B-3
Formation: Rockwood
Location : 96.8m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray/green
Weathered-orange/brown to dark gray

Structures: Massive to poorly defined low-angle laminations defined by granules.

Grain Size: Maximum - 1.0mm
Minimum - 0.1mm
Mode - 0.6 to 1.0mm

Sorting: Poor

Roundness: Angular to well-rounded

Sphericity: Low to high

Composition: Quartz, rock fragments, fossil fragments, carbonate, hematite cement.

Composition:	Percent:
Very fine-grained sandstone fragments	5-10%
Mudstone/siltstone fragments	5%
Chamosite ooids	5%
Fossil fragments (bryozoans, echinoderms, Phosphatic brachiopods)	2-5%
Glauconite pellets	5%
K-feldspar	1-3%

Cements:	Percent:
Micrite	30%
Hematite	6%
Chamosite	4%

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 10.0mm
Minimum - 0.05mm
Mode - 1.0mm

Sorting: Poor

Roundness: Angular to well-rounded

Sphericity: Low to high

Composition:	Percent:
Monocrystalline (unstrained) quartz	5%
Monocrystalline (strained) quartz	10%
Polycrystalline (> 5 crystallites/grain) quartz	5%
Polycrystalline (2-5 crystallites/grain) quartz	1-2%

Recalculated percent for Folk et al (1970).
Classification:

Q = 49%
F = 7%
R = 44%

Other features: Sedimentary rock fragments stained by hematite in part; Some of the mudstone fragments may be siderite nodules (?); All chamosite ooids are disc-shaped, nuclei hard to determine; Skeletal fragments replaced by hematite (chamosite?) in part.

Rock Name: Ferruginous calcareous litharenite

APPENDIX
Section 3 (continued)

Sample No: 2B-4
Formation: Rockwood
Location : 97.75m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-green to maroon
Weathered-greenish/gray to maroon/brown

Structures: Coarser grains defining high-angle laminations.

Grain Size: Maximum - 2.0mm
Minimum - 0.25mm
Mode - 0.5mm

Sorting: Moderately poor

Roundness: Sub-angular

Composition: Quartz, rock fragments, fossil fragments, hematite and chamosite (?) cement.

Composition:	Percent:
Phosphatic brachiopod fragments	1%
K-feldspar (?)	0-5%
Porosity	10%

Cements:	Percent:
Hematite	1-2%
Chamosite	1%
Silica	1%

Recalculated percent for Folk et al (1970).
Classification:

Q = 87%
F = 6%
R = 7%

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 2.0mm
Minimum - 0.1mm
Mode - 0.3 to 0.6mm

Sorting: Moderate to moderately-poor

Roundness: Sub-angular to sub-rounded

Sphericity: Moderate

Composition:	Percent:
Monocrystalline (unstrained) quartz	10-15%
Monocrystalline (strained) quartz	60%
Polycrystalline (> 5 crystallites/grain) quartz	1%
Polycrystalline (2-5 crystallites/grain) quartz	trace
Fine sandstone-siltstone fragments	trace
Mudstone fragments	5%

Other features: Grains commonly coated by hematite, chamosite; Phosphatic brachiopods commonly fractured; Authigenic quartz overgrowths are common.

Rock Name: Sublitharenite

APPENDIX
Section 3 (continued)

Sample No: 28-5
Formation: Rockwood
Location : 100.15m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray/green
Weathered-gray/green to slightly brown

Structures: Crude parallel alignment of mudstone clasts

Grain Size: Maximum - 7mm
Minimum - 0.1 to 0.2mm
Mode - 0.5mm?

Sorting: Moderately well-sorted

Roundness: Sub-angular to sub-rounded

Sphericity: Moderate

Composition: Quartz, rock fragments, hematite and chamosite (?) present.

Cements:	Percent:
Hematite	5-7%
Chamosite	2-5%
Silica	1-5%

Recalculated percent for Folk et al (1970).
Classification:

Q = 89%
F = 1.5%
R = 9.5%

Other features: Both hematite and chamosite were detected coating grains; Fossil fragments replaced by hematite.

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 14mm
Minimum - 0.1mm
Mode - 0.4 to 0.6mm

Sorting: Moderately well-sorted

Roundness: Sub-angular to well-rounded

Composition:	Percent:
Monocrystalline (unstrained) quartz	30%
Monocrystalline (strained) quartz	40%
Polycrystalline (> 5 crystallites/grain) quartz	5%
Mudstone-siltstone fragments	5-8%
Glaucinite Pellets	trace
K-feldspar (?)	1%
Echinoderm fragments	trace

Rock Name: Iron-rich sublitharenite

APPENDIX
Section 3 (continued)

Sample No: 28-7a
Formation: Rockwood
Location : 106.95m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-white to very light-gray rarely maroon
Weathered-gray to faintly red

Structures: High angle cross-laminations defined by coarse grains and granules.

Grain Size: Maximum - 12.0mm
Minimum - 0.25mm
Mode - 1.0mm

Sorting: Moderately low

Roundness: Sub-angular

Sphericity: Moderate

Composition: Quartz, rock fragments, fossil fragments, carbonate and silica cement.

Composition:	Percent:
Chert fragments	2-3%
Mudstone-siltstone fragments	3-4%
Siltstone-V.F. Sandstone fragments	1%
Glaucinite Pellets	trace
Feldspar (plagioclase?)	1%
Tourmaline	trace
Fossil fragments	1-2%

Cements:	Percent:
Sparry Calcite	10-20%
Silica	5%
Siderite	trace
Hematite	trace

Recalculated percent for Folk et al (1970).
Classification:

Q = 88%
F = 1%
R = 11%

Other features: Fossil fragments composed of echinoderm plates and phosphatic brachiopods; Echinoderm plates are generally replaced by hematite; Silica cement occurs as overgrowths.

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 2.5mm
Minimum - 0.1mm
Mode - 0.8 to 1.0mm

Sorting: Moderate

Roundness: Sub-angular to sub-rounded

Sphericity: Moderately high

Composition:	Percent:
Monocrystalline (unstrained) quartz	23%
Monocrystalline (strained) quartz	40%
Polycrystalline (> 5 crystallites/grain) quartz	1%
Polycrystalline (2-5 crystallites/grain) quartz	trace

Rock Name: Calcareous sublitharenite

APPENDIX
Section 3 (continued)

Sample No: 2B-8
Formation: Rockwood
Location: 110.15m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray to rarely yellow
Weathered-gray to maroon/gray

Structures: High-angle cross-laminations

Grain Size: Maximum - 50mm
Minimum - 0.1mm
Mode - 1.0mm

Sorting: Poor

Roundness: Sub-angular to well-rounded

Sphericity: Moderate

Composition: Quartz, rock fragments, fossils, hematite and carbonate cement.

Composition:	Percent:
Carbonate rock fragments	2%
Fossils	5%

Cements:	Percent:
Hematite	5%
Limonite	1-2%
Sparry Calcite	33%

Recalculated percent for Folk et al (1970).
Classification:

Q = 82 %
F = 0 %
R = 18 %

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 3.5mm
Minimum - 0.1mm
Mode - 0.5 to 2.0mm

Sorting: Poor

Roundness: Sub-angular to well-rounded

Sphericity: Moderate

Composition:	Percent:
Monocrystalline (unstrained) quartz	15%
Monocrystalline (strained) quartz	30%
Polycrystalline (> 5 crystallites/grain) quartz	1%
Mudstone fragments	4%
Siltstone-sandstone fragments	4%

Other features: Hematite was detected replacing fossils and coating grains; Evidence (abrasion) for quartz grains being coated by hematite before deposition; Some of the sparite cement may be siderite; Limonite found in matrix and as a replacement in fossils; Fossils composed of bryozoans, echinoderms, and phosphatic brachiopods; Carbonate rock fragments contain echinoderms, ostracodes and bryozoans.

Rock Name: Calcareous sublitharenite

APPENDIX
Section 3 (continued)

Sample No: 2B-9
Formation: Rockwood
Location: 111.30m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray/green to yellow/brown
Weathered-yellow/brown to maroon

Structures: Parallel alignment of pebbles and fossils.

Grain Size: Maximum - 34.0mm
Minimum - < 0.0625mm
Mode - 1.0mm

Sorting: Poor

Roundness: Well-rounded to angular

Sphericity: Low to high

Composition: Bottom 45mm of sample-quartz, rock fragments, fossils, hematite and carbonate cement; Top 70mm of sample-fossils, quartz, carbonate cement.

Composition:	Percent:
Polycrystalline (> 5 crystallites/grain) quartz	1%
Polycrystalline (2-5 crystallites/grain) quartz	trace
Sandstone fragments	10%
Siltstone/mudstone fragments	5%
Fossils	10-15%
Glauconite pellets	1%
Phyllosilicates	1%
Phosphate pebbles	trace
Chamosite ooids	trace

Cements:	Percent:
Sparry Calcite	20%
Micrite	10-15%
Hematite	3-5%

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 34.0mm
Minimum - 0.1mm
Mode - 1.0 to 2.0mm

Sorting: Very poorly sorted

Roundness: Angular to very well-rounded

Sphericity: Low to very high sphericity

Composition:	Percent:
Monocrystalline (unstrained) quartz	10%
Monocrystalline (strained) quartz	17%

Recalculated percent for Folk et al (1970).
Classification:

Q = 64 %
F = 0 %
R = 36 %

Other features: Bottom 50m of thin section is a mixed carbonate/clastic conglomerate; Top 25mm of thin section is a trilobite-rich limestone; Fossils included phosphatic brachiopods, echinoderms, molluscs, gastropods, and trilobites; Most of the fossils replaced by hematite or limonite; Phosphate pebbles partially replaced

APPENDIX

Section 3 (continued)

Other features continued: by calcite; Sandstone rock fragments contained quartz sand, phosphatic brachiopod fragments, glauconite pellets, peloids, chamosite ooids, bryozoans, molluscs, echinoderms, siltstone and mudstone fragments; Superficially coated ooids; Abundant carbonate cement, hematite and possibly limonite cement.

Rock Name: Bottom 50mm - Iron-rich litharenite
 Top 25mm - Dunham's Classification: Iron-rich, trilobite wackestone-packstone
 Folk's Classification: Iron-rich, unsorted biosparite

APPENDIX

Section 3 (continued)

Sample No: 2B-10
 Formation: Rockwood
 Location: 109.85m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-light green
 Weathered-dark green to gray
 Structures: Faint horizontal to low-angle laminations;
 Maroon mud chips concentrated at top of the sample.
 Grain Size: Maximum - 18mm (rare)
 Minimum - 0.2mm
 Mode - 0.25mm
 Sorting: Moderately well-sorted
 Roundness: Sub-angular
 Sphericity: Low to moderate
 Composition: Quartz, rock fragments, fossil fragments,
 hematite and chamosite (?) cement.

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 1.0 to 2.0mm
 Minimum - 0.05mm
 Mode - 0.1mm

Sorting: Moderately well-sorted
 Roundness: Sub-angular
 Sphericity: Moderately-low

Composition:	Percent:
Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	40%
Plagioclase (An 30-50) feldspar	1-2%
Fossil fragments	1%

Composition:	Percent:
Mudstone fragments	1-3%
Glauconite	trace
Opauques	trace
Epidote (?)	trace

Cements:	Percent:
Hematite	2-5%
Chamosite (?)	5-8%
Siderite	1%
Silica	1%

Recalculated percent for Folk et al (1970).
 Classification:

Q = 94%
 F = 2.5%
 R = 3.5%

Other features: Carbonate cement rimmed with brown discoloration indicating the presence of siderite; Fossils include bryozoans, echinoderms, and molluscs, all of which are replaced by hematite; Phosphatic brachiopods also present; Mudstone fragments appear stretched.

Rock Name: Iron-rich sublitharenite

APPENDIX
Section 3 (continued)

Sample No: 2B-11
Formation: Rockwood
Location: 112.35m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-brownish orange
Weathered-gray to orange/brown

Structures: Crude parallel alignment of fossils

Grain Size: Maximum - 1.5mm
Minimum - 0.1mm
Mode - 0.5mm

Folk's Texture: Unsorted biosparite

Dunham's Texture: Wackestone-packestone

Composition: Bioclasts, quartz, hematite, sparite.

Other features: Fossils replaced by hematite; Not all echinoderms and bryozoans are replaced by hematite; Quartz is moderately well-rounded and highly spherical.

Classification:

Dunham - Iron-rich, trilobite-echinoderm wackestone
Folk - Iron-rich, unsorted biosparite

THIN SECTION DESCRIPTION

GRAINS	VARIETY	SIZE	PERCENT
Allochems:			
Bioclasts-	echinoderms	0.2-1.0mm	20%
	trilobites	0.1-1.5mm	20%
	bryozoans	0.3-0.7mm	5%
	gastropods	0.3mm	1%
Ooids-	superficial	0.2mm	trace

Detritals:	monocrystal-line quartz	0.1-0.4mm	4%
------------	-------------------------	-----------	----

Non-carbonate cement: Hematite (replaced all of the fossils).

Sparry Calcite (siderite?): 50%

APPENDIX
Section 3 (continued)

Sample No: 2B-13
Formation: Rockwood
Location: 115.75m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-maroon to gray
Weathered-gray

Structures: Crude parallel alignment of grains burrowed in part.

Grain Size: Maximum - 2.0mm
Minimum - 0.2mm
Mode - 0.6mm

Classification:

Dunham - Iron rich, trilobite-echinoderm packstone
Folk - Iron-rich, unsorted biosparite

Folk's Texture: Unsorted biosparite

Dunham's Texture: Packstone

Composition: Bioclasts, rock fragments, quartz, hematite cement, sparite.

THIN SECTION DESCRIPTION

GRAINS	VARIETY	SIZE	PERCENT
Allochems:			
Bioclasts-	echinoderms	0.2-1.2mm	15%
	trilobites	0.1-2.0mm	15%
	gastropods	0.8-2.0mm	2%
	bryozoans	0.2-0.5mm	1%
Ooids (?)	superficial	0.3-0.45mm	trace
Intraclasts-	mixed carbonate and clastic fragment	1.0mm	1%
Detritals:	mudstone fragment	2.0mm	trace
	glauconite	0.3mm	trace
	monocrystalline quartz	0.2-0.5mm	1%

APPENDIX
Section 3 (continued)

Sample No: 2B-14a
Formation: Rockwood
Location : 116.75m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray to yellow/orange
Weathered-gray to maroon

Structures: Parallel alignment of skeletal debris

Grain Size: Maximum - 4.0mm
Minimum - 0.2mm
Mode - 0.5 to 1.0mm

Folk's Texture: Unsorted to sorted biosparite

Dunham's Texture: Wackestone-packestone

Composition: Trilobites, ooids (?), quartz, gastropods, hematite sparite cement.

THIN SECTION DESCRIPTION

GRAINS	VARIETY	SIZE	PERCENT
Allochems:			
Bioclasts-	trilobites	0.5-2.8mm	10-15%
	gastropods	0.3-1.0mm	10%
Ooids-	superficial	0.5-0.6mm	trace
Pellets-	peloid	0.4mm	trace
Detritals:	monocrystalline quartz	0.05-1.0mm	3-5%
	mudstone fragments	0.5-2.0mm	trace
	microcline feldspar	0.15mm	trace

Non-Carbonate Cement: Hematite 8%, limonite 2%, chamosite (?) 1%.

Carbonate Cement: Sparry Calcite 60%, Dolomite?

Sorting: Moderate to poorly sorted

Other features: Parallel alignment of trilobite fragments; Hematite and limonite have replaced the trilobite fragments; Some of the gastropods are partially hematitic; Hematite coats quartz grains and occurs in discontinuous veins; Some of the gastropods may be partially replaced by chamosite (?); Nuclei of ooids include skeletal fragments and quartz grains.

Classification:

Dunham - Iron-rich, gastropod-trilobite wackestone

Folk - Iron-rich, unsorted biosparite

APPENDIX
Section 3 (continued)

Sample No: 2B-15
Formation: Rockwood
Location : 121.81m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-maroon/orange to gray
Weathered-predominantly gray to slightly maroon/gray

Grain Size: Crude horizontal laminations; Burrow-disrupted for the most part

Folk's Texture: Unsorted biosparite

Dunham's Texture: Wackestone to packstone

Composition: Bioclasts, quartz, hematite and sparite cement.

Other features: extremely iron-rich

THIN SECTION DESCRIPTION

GRAINS	VARIETY	SIZE	PERCENT
Allochems:			
Bioclasts-	trilobites	0.2-7.0mm	20-30%
	echinoderms	0.2-0.3mm	<1%
	bryozoans	0.2-0.3mm	<1%
Ooids-	superficial	0.2-0.4mm	1-2%
Detritals:	monocrystalline quartz	0.1-0.4mm	1%

Non-Carbonate Cement: Hematite 10%

Micrite: 0%

Microsparite: 0%

Sparry Calcite: 57%

Sorting: Moderate to poor

Other features: Crude parallel alignment to trilobite fragments. Trilobite fragments commonly fractured. Hematite has replaced many of the fossil fragments.

Classification:

Dunham - Iron-rich trilobite wackestone-packstone

Folk - Iron-rich, unsorted biosparite

APPENDIX
Section 3 (continued)

Sample No: 28-18
Formation: Rockwood
Location: 149.85m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray to maroon
Weathered-gray/brown to maroon

Structures: Horizontal laminations; Fossil/granule lag at base of bed.

Grain Size: Maximum - 5.0mm
Minimum - < 0.0625mm?
Mode - ?

Sorting: Poor

Roundness: Sub-angular

Sphericity: Moderate

Composition: Quartz, rock fragments, fossils, carbonate cement, iron cement.

Composition:	Percent:
Sedimentary rock fragments	trace
Glaucinite-replaced fossil fragments	8%
Hematite-replaced fossil fragments	7%
Plagioclase feldspar	2%

Cements:	Percent:
Sparry Calcite	15%
Dolomite	5-7%

Recalculated percent for Folk et al (1970).
Classification:

Q = 94%
F = 3%
R = 3%

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.8mm
Minimum - 0.01mm
Mode - 0.05mm

Sorting: Moderately sorted

Roundness: Angular to well-rounded

Sphericity: Moderate

Composition:	Percent:
Monocrystalline (unstrained) quartz	35%
Monocrystalline (strained) quartz	25%
Opalines	1%
Phyllosilicates	trace

Other features: Excellent mm-thick fossil/granule lag composed of abraded hematite-and glauconite-replaced skeletal debris and well-rounded quartz grains that were cemented by calcite and dolomite; Above the fossil/granule lag were siliciclastic silt-sized grains, lacking in any carbonate or ferruginous content.

Rock Name: Calcareous quartz arenite

APPENDIX
Section 3 (continued)

Sample No: 28-19
Formation: Rockwood
Location: 155.75m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-gray

Structures: Horizontal laminations; Partially burrowed.

Grain Size: Maximum - 0.4mm
Minimum - ?
Mode - ?

Cements:	Percent:
Dolomite	20-25%
Hematite	1%

Folk's Texture: Micrite

Dunham's Texture: Mudstone

Classification:

Folk's Texture: Quartz-rich, dolomitic micrite

Dunham's Texture: Quartz-rich, dolomitic mudstone

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.4mm
Minimum - 0.01mm
Mode - 0.075mm

Other Features: Sample appears crudely graded (fining-upwards); Dolomite concentrated in lower part of sample.

Sorting: Well-sorted

Roundness: Sub-angular to sub-rounded

Sphericity: Moderately high

Composition:	Percent:
Monocrystalline (unstrained) quartz	20%
Monocrystalline (strained) quartz	15%
Opalines	5%
Phyllosilicates	trace
Tourmaline	trace

Cements:	Percent:
Neomorphosed Micrite	40%

APPENDIX
Section 3 (continued)

Sample No: 2C-1a
Formation: Rockwood
Location : 163.65m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-gray/brown

Structures: Massive with rare horizontal laminations;
heavily bioturbated.

Grain Size: Maximum - ?
Minimum - ?
Mode - ?

Sorting: ?

Roundness: ?

Sphericity: ?

Composition: ?

Composition: Percent:
Opakes 2-3%

Cement: Percent:
Sperry Calcite 20-25%
Silica Overgrowths 3%

Recalculated percent for Folk et al (1970).
Classification.

Q = 100%
F = 0%
R = 0%

Other features: Horizontal burrowing
disrupting laminations.

Rock Name: Calcareous quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.01mm
Mode - 0.05mm

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderately-high

Composition:

Monocrystalline (unstrained) quartz
Monocrystalline (strained) quartz
Phyllosilicates
Glauconite

Percent:

30%
30%
5-7%
1-2%

APPENDIX
Section 3 (continued)

Sample No: 3A-2
Formation: Rockwood
Location : 216.05m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-gray
Weathered-gray

Structures: Faint horizontal to low-angle laminations;
Burrow-disrupted in part.

Grain Size: Maximum - ?
Minimum - ?
Mode - ?

Sorting: ?

Roundness: ?

Sphericity: ?

Composition: ?

Composition: Percent:
Clay matrix 5%

Cements: Percent:
Sperry Calcite 1%
Silica overgrowths 2-3%

Recalculated percent for Folk et al (1970).
Classification:

Q = 100%
F = 0%
R = 0%

Other features: Low-angle laminations
defined by phyllosilicates and heavy
minerals; Horizontal burrowing detected.

Rock Name: Quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.05mm
Minimum - 0.01mm
Mode - 0.03mm

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderate

Composition:

Monocrystalline (unstrained) quartz
Monocrystalline (strained) quartz
Phyllosilicates
Opaque grains
Altered glauconite pellets

Percent:

40%
29%
10%
10%
1-2%

APPENDIX
Section 3 (continued)

Sample No: 3A-5
Formation: Rockwood
Location : 237.35m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-green/gray
Weathered-gray/brown to slightly green/gray

Structures: Horizontal to low-angle laminations.
Fifteen to twenty millimeter fossil lag zone at base.

Grain Size: Maximum - 0.1mm
Minimum - ?
Mode - ?

Sorting: Well-sorted

Roundness: Sub-angular

Sphericity: Moderate

Composition: Quartz, fossils, rock fragments, hematite and carbonate cement.

Composition: Percent:

Plagioclase feldspar	1%
Altered glauconite pellets	1-2%
Hematite-replaced fossil fragments	1%
Phyllosilicates	1%
Opales	5%

Cement: Percent:

Sparry Calcite	5-10%
Hematite	1%
Silica overgrowths	2-3%

Recalculated percent for Folk et al (1970).

Classification:

Q = 99%
F = 1%
R = 0%

Other features: This sample is faintly graded, with fossils concentrated at the base; Horizontally burrowed in part.

Rock Name: Calcareous quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.12mm
Minimum - 0.01mm
Mode - 0.075mm

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderately high

Composition: Percent:

Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	26%

APPENDIX
Section 3 (continued)

Sample No: 3A-8
Formation: Rockwood
Location : 239.35m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-green/gray
Weathered-gray/brown to orange/red

Structures: Massive to crudely horizontally laminated;
Burrowed in part.

Grain Size: Maximum - ?
Minimum - ?
Mode - ?

Sorting: ?

Roundness: ?

Sphericity: ?

Composition: ?

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.01mm
Mode - 0.05 to 0.075mm

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderately-high

Composition: Percent:

Monocrystalline (unstrained) quartz	40%
Monocrystalline (strained) quartz	31%
Glauconite pellets	2%
Opales	2-5%

Composition: Percent:

Peloids	1-2%
Hematite-replaced fossils	1%
Phyllosilicates	5-7%
Clay matrix	0-5%

Cement: Percent:

Sparry Calcite	1%
Hematite	1%
Silica overgrowths	3-5%

Recalculated percent for Folk et al (1970).

Classification:

Q = 100%
F = 0%
R = 0%

Other features: Hematite-replaced fossils included echinoderms and gastropods; Glauconite pellets partially altered to limonite.

Rock Name: Quartz arenite

APPENDIX
Section 3 (continued)

Sample No: 4A-5
Formation: Rockwood
Location : 261.75m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-light to dark gray
Weathered-Light to medium gray

Structures: Horizontal to slightly wavy laminations.

Grain Size: Maximum - 0.1mm
Minimum - ?
Mode - ?

Sorting: ?

Roundness: ?

Sphericity: ?

Composition: ?

Composition:	Percent:
Tourmaline	trace
Glaucanite	1-2%
Clay matrix	8-10%

Cement:	Percent:
Hematite	trace

Recalculated percent for Folk et al (1970).
Classification:

Q = 99%
F = 1%
R = 0%

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.05mm
Mode - 0.075mm

Other features: Low-angle cross-laminations defined by heavy minerals.

Rock Name: Quartz arenite

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderately-high

Composition:	Percent:
Monocrystalline (unstrained) quartz	45%
Monocrystalline (strained) quartz	35%
Phyllosilicates	1-2%
Opakes	5%
Plagioclase (An 2-10) feldspar	1%

APPENDIX
Section 3 (continued)

Sample No: 4A-6
Formation: Rockwood
Location : 257.05m above base

HAND SAMPLE DESCRIPTION

Color: Fresh-very dark gray
Weathered-dark gray to yellow

Structures: Horizontally laminated

Grain Size: Maximum - ?
Minimum - ?
Mode - ?

Sorting: ?

Roundness: ?

Sphericity: ?

Composition: ?

Cement:	Percent:
Hematite	7-10%
Silica overgrowths	1%

Recalculated percent for Folk et al (1970).
Classification:

Q = 100%
F = 0%
R = 0%

Other features: Hematite coated grains common.

Rock Name: Quartz arenite

THIN SECTION DESCRIPTION

Apparent Grain Size: Maximum - 0.1mm
Minimum - 0.01mm
Mode - 0.075mm

Sorting: Well-sorted

Roundness: Angular to sub-rounded

Sphericity: Moderately-high

Composition:	Percent:
Monocrystalline (unstrained) quartz	44%
Monocrystalline (strained) quartz	33%
Glaucanite pellets	1-2%
Hematite grains	1-2%
Phyllosilicates	5%
Opakes	2-3%
Clay Matrix	trace

Section 3

PALEOCURRENT DATA (WEST LIMB)

Note: Paleocurrent data have been corrected for structural dip.

WAVE RIPPLE DATA
WEST LIMB

#	Azimuth	#	Azimuth	#	Azimuth	#	Azimuth
1	29°	26	1°	51	70°	76	30°
2	13°	27	110°	52	155°	77	65°
3	106°	28	47°	53	33°	78	140°
4	15°	29	50°	54	45°	79	70°
5	61°	30	40°	55	135°	80	110°
6	21°	31	135°	56	143°	81	60°
7	177°	32	155°	57	50°	82	122°
8	158°	33	155°	58	165°	83	116°
9	30°	34	140°	59	130°	84	110°
10	176°	35	22°	60	145°	85	20°
11	63°	36	45°	61	177°	86	110°
12	140°	37	108°	62	170°	87	140°
13	48°	38	50°	63	50°	88	165°
14	45°	39	63°	64	143°	89	115°
15	75°	40	57°	65	13°	90	37.5°
16	50°	41	30°	66	35°	91	140°
17	26°	42	55°	67	35°	92	148°
18	60°	43	42°	68	177°	93	115°
19	57°	44	60°	69	55°	94	2°
20	20°	45	70°	70	36°	95	10°
21	60°	46	47°	71	164°	96	5°
22	30°	47	15°	72	23°	97	45°
23	5°	48	55°	73	10°	98	170°
24	33°	49	65°	74	130°		
25	151°	50	10°	75	30°		

Section 3 (continued)
PALEOCURRENT DATA (WEST LIMB)

(I). Trough Cross-Strata

#	Azimuth
1	86°
2	89°
3	180°
4	330°

(II). Asymmetrical Ripple Cross-Laminations

#	Azimuth
1	302°
2	25°
3	338°
4	290°
5	32°
6	60°
7	63°
8	35°

(III). Gutter Casts

#	Azimuth
1	22°
2	38°
3	46°
4	65°
5	34°
6	41°
7	85°
8	61°
9	135°
10	30°

(IV). Flute Casts

#	Azimuth
1	225°
2	230°
3	242°

Section 3
PALEOCURRENT DATA (EAST LIMB)

Note: Paleocurrent data have been corrected for structural dip.

WAVE RIPPLE DATA
EAST LIMB

#	Azimuth	#	Azimuth
1	165°	21	10°
2	178°	22	100°
3	130°	23	25°
4	160°	24	25°
5	170°	25	135°
6	45°	26	65°
7	176°	27	35°
8	135°	28	30°
9	44°	29	135°
10	160°	30	20°
11	138°	31	11°
12	127°	32	60°
13	22°	33	130°
14	20°	34	10°
15	23°	35	10°
16	176°	36	6°
17	18°	37	125°
18	65°	38	20°
19	175°		
20	10°		

Section 3 (continued)

PALEOCURRENT DATA (EAST LIMB)

Note: Paleocurrent data have been corrected for structural dip.

GUTTER CASTS

EAST LIMB

#	Azimuth
1	15°
2	25°
3	175°
4	169°
5	4°
6	25°

FLUTE CAST

EAST LIMB

#	Azimuth
1	185°

VITA

Kurt Allen Easthouse was born on January 23, 1959 in Berkeley, California. In June of 1977, the author graduated from Del Valle High School in Walnut Creek, California.

The following fall, he began his first year of college at the University of California at Berkeley. The next year he transferred to the University of California at Davis. During the fall of 1980, the author took a planned educational leave and travelled to the South Pacific. Three months were spent touring Hawaii, Fiji, Tahiti, New Zealand, and Australia. Upon his return to Davis, the author completed his education and received a Bachelor of Science Degree in Geology in June of 1982.

After graduation from College, time was spent touring Europe for three months. The author backpacked through 14 countries on the Continent. When the author returned to the States, he obtained a position working on offshore and onshore oil rigs as a well-site Geologist. During the fall of 1984, the author enrolled at the University of Tennessee at Knoxville and began working towards a Master of Science in Geology. On September 7, 1985, the author was married to Kimberly Rosen in Carmel-by-the-Sea, California. The author completed his Master of Science in Geology during the winter of 1987.