January 3, 1975

To the Graduate Council:

I am submitting herewith a thesis written by Edward Burk McWilliams entitled "Paleoenvironmental Analysis of the Chapman Ridge Sandstone (Middle Ordovician) in the Area of Knoxville, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

Kenneth R. Walker

Kenneth R. Walker, Major Professor

We have read this thesis
and recommend its acceptance:

Garnett Bigg

Harry J. Klepser

Accepted for the Council:

Hilton A. Smith

Vice Chancellor
Graduate Studies and Research

# PALEOENVIRONMENTAL ANALYSIS OF THE CHAPMAN RIDGE SANDSTONE (MIDDLE ORDOVICIAN) IN THE AREA OF KNOXVILLE, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

Edward Burk McWilliams

March 1975

ACKNOWLEDGMENTS

The writer wishes to thank Dr. Kenneth R. Walker who suggested this problem and provided guidance throughout the study. He is also very grateful to Dr. Garrett Briggs and Dr. Harry Klepser for their helpful criticism in the preparation of this paper. Dr. R. E. McLaughlin was most helpful in field work and resulting discussion. Finally, the writer extends great appreciation to his wife, Cheryl, who typed the first two drafts of this thesis. The project was partially funded by a grant from the National Science Foundation.



1197669

## ABSTRACT

The Middle Ordovician Chapman Ridge Sandstone in the Knoxville, Tennessee area consists of nine distinct lithologies from the study of four outcrop sections. These lithic types are considered to reflect the shifting and accumulation of eight different, shallow water environments. The resultant vertical sequence of rocks exhibits a complex intertonguing of lithologies.

Prior to Chapman Ridge deposition, the underlying Holston reef complex was partially exposed to subaerial erosion as a result of a slight lowering of sea level. A carbonate bank-lagoon complex, which is represented by lower Chapman Ridge deposits, was established in this area following resubmergence. As the adjacent shale basin to the southeast became filled with terrigenous grains, coarser clastic sediments began to spill over into the study area and "drown" this early carbonate sequence. An increased terrigenous sediment influx allowed for the development of an extensive sand flat-barrier island-lagoon complex which is now represented by the main body of the Chapman Ridge Formation. These sands may have been introduced into this area by longshore transport from the southwest.

The origin of the hematite associated with these rocks is discussed briefly in this report. It is felt that the iron was deposited during or shortly after the accumulation of Chapman Ridge sediments.

TABLE OF CONTENTS


| CHAPTER | | PAGE |
|---|---|---|
| I. | INTRODUCTION | 1 |
| | Purpose of Investigation | 1 |
| | Description of Study Area | 2 |
| | Previous Investigations | 2 |
| | Procedure | 10 |
| II. | DESCRIPTIONS OF LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS | 12 |
| | General Considerations | 12 |
| | Calcareous Quartz Sandstone | 15 |
| | Sandy Biosparite | 24 |
| | Trilobite-Rich Sandy Biosparite | 30 |
| | Biosparite | 32 |
| | Oosparite | 36 |
| | Biomicrite | 38 |
| | Calcareous Shale | 47 |
| | Calcareous Mudstone | 49 |
| | Interbedded Calcareous Shale and Sandy Biosparite | 53 |
| | Hematite-Coated Grains | 60 |
| III. | STRATIGRAPHY OF DEPOSITIONAL ENVIRONMENTS | 67 |
| | General Setting | 67 |
| | Disconformity (?) at Top of Holston Limestone | 70 |
| | Stage I: Carbonate Bank-Lagoon | 74 |

LIST OF TABLES


| TABLE | | PAGE |
|---|---|---|
| I. | Stratigraphic Section Localities . . . . . | 5 |
| II. | Summary of Lithologies, Characteristics, and Postulated Environments of the Chapman Ridge Sandstone . . . . . | 13 |
| III. | Volume Percent Analysis of Samples 1-T-1 Through 1-F-4 . . | 89 |
| IV. | Volume Percent Analysis of Samples 1-G-1 Through 2-C-1 . . | 90 |
| V. | Volume Percent Analysis of Samples 2-D-1 Through 3-C-2 . . | 91 |
| VI. | Volume Percent Analysis of Samples 3-D-1 Through 5-1 . . . | 92 |

# LIST OF FIGURES


| FIGURE | | PAGE |
|---|---|---|
| 1. | The Chapman Ridge Sandstone of East Tennessee . . . . . | 3 |
| 2. | Outcrop of the Chapman Ridge Sandstone in the Knoxville Area and Localities of Sections Studied . . . . . | 4 |
| 3. | Various Classifications of Middle Ordovician Rocks of East Tennessee . . . . . | 9 |
| 4. | Outcrop Photograph of Trough Cross-Bedding in Calcareous Quartz Sandstone Along Alcoa Highway . . . . . | 16 |
| 5. | Outcrop Photograph of Thick-Bedded Sandstone in the Upper Units of the Formation at Alcoa Highway . . . . . | 17 |
| 6. | Photomicrograph of Calcareous Quartz Sandstone . . . . . | 18 |
| 7. | Hand Sample Photograph of Ripple Drift Cross-Laminae in Calcareous Quartz Sandstone . . . . . | 19 |
| 8. | Allochemical Percentage Composition of Calcareous Quartz Sandstones (Q), Biosparites (B), Sandy Biosparites (S), and Trilobite-Rich Sandy Biosparite (T) . . . . . | 20 |
| 9. | Outcrop Photograph of Thin Beds and Laminae of Calcareous Sandstone . . . . . | 21 |
| 10. | Outcrop Photograph of Calcareous Sandstone which Shows Interference Ripple Marks and Horizontal Burrows . . . . | 22 |
| 11. | Outcrop Photograph of Low Angle, Planar Cross-Beds which Overlie Ripple Drift Cross-Laminae in Calcareous Quartz Sandstones . . . . . | 25 |

FIGURE PAGE

12. Hand Sample Photograph of Channel Lag Deposits (Shale Clasts) in Postulated Tidal Channel Sandstone . . . . . 25

13. Outcrop Photograph of Ripple Drift Cross-Laminated Sandy Biosparite . . . . . 27

14. Hand Sample Photograph of Ripple Drift Cross-Bedding in Sandy Biosparite . . . . . 27

15. Hand Sample Photograph of Sandy Biosparite Lithology which Contains Highly Abraded, 0.2-0.5 cm Size Skeletal Fragments . . . . . 28

16. Photomicrograph of Sandy Biosparite Lithology . . . . . 29

17. Photomicrograph of Trilobite-Rich, Sandy Biosparite . . . . 31

18. Outcrop Photograph of Low Angle, Planar Cross-Bedded, Biosparite Lithology . . . . . 33

19. Photomicrograph of Biosparite Containing Abundant Pelmatozoan Grains (P) and Trilobites (T) . . . . . 34

20. Photomicrograph of Oosparite Lithology Showing the Various Nuclei for the Ooids . . . . . 37

21. Hand Sample Photograph of Biomicrite Lithology with Abundant Algally Coated Fossil Grains (A), Ooids (O), and White Fossil Debris (D) . . . . . 40

22. Photomicrograph of Extensively Bored Pelmatozoan Remains (P) and Abraded Ramose Bryozoan (B) in Micrite Matrix . . 40

23. Outcrop Photograph of Chapman Ridge Biomicrite Lithology Overlying Holston Calcarenite . . . . . 41

FIGURE PAGE

24. Hand Sample Photograph of Flattened, Hematitic Oncolite (O) in Biomicrite . . . . . 43

25. Hand Sample Photograph of Oncolites (O) and Ooids (X) in Biomicrite Lithology . . . . . 43

26. Photomicrograph of Recurring Laminae of Glauconite (Green), Limonite (Yellow), and Calcite (White) in Oncolite . . . . 44

27. Photomicrograph of "Quiet Water" Ooid Showing Alternating Laminae of Glauconite (Green) and Calcite (Stained Red) . . 45

28. Photomicrograph of Randomly Oriented Ooids in Biomicrite Lithology . . . . . 46

29. Photomicrograph of a Horizontal Burrow, Filled with Black Fecal Pellets in Calcareous Shale Lithology . . . . . 48

30. Outcrop Photograph of Folded Calcareous Shales . . . . . 50

31. Hand Sample Photograph of Clasts of Mud (M) and Algae (A) which are Included in Calcareous Mudstone Lithology . . . . 51

32. Photomicrograph of Algal Clast and Surrounding Mudstone Matrix . . . . . 51

33. Outcrop Photograph of Calcareous Mudstones Showing Numerous, Rounded Clasts of Algal Origin . . . . . 52

34. Hand Sample Photograph of Interlaminated Calcareous Shale and Biosparite Lithology . . . . . 55

35. Hand Sample Photograph of Mottled Interlaminated Calcareous Shale and Biosparite Lithology . . . . . 55

36. Photomicrograph of Lensoid-Bedding in Inferred Tidal Delta Deposits . . . . . 57

FIGURE PAGE

37. Hand Sample Photograph of Flasure-Bedded, Tidal Delta Deposits . . . . . 57

38. Hand Sample Photograph Showing Tidal Channel or Gully Deposits Cutting Through Adjacent Finer Grained Units . . . 58

39. Outcrop Photograph of Tidal Channel Deposits (Arrows) and Surrounding Tidal Flat Sediments . . . . . 58

40. Outcrop Photograph of Small, Discontinuous, Tidal Gully Sands in Tidal Flat Deposits . . . . . 59

41. Photomicrograph of Hematite-Coated Grains of Ramose Bryozoan (B) and Pelmatozoan (P) in Biosparite Lithology . . . . . 61

42. Photomicrograph of Hematite-Coated Quartz Grains in Calcareous Sandstone . . . . . 62

43. Photomicrograph of Syntaxial Overgrowth of Iron-Coated, Algally-Bored, Pelmatozoan Grain . . . . . 63

44. Photomicrograph of Syntaxial Overgrowths of Pelmatozoan Grains . . . . . 64

45. Cross Sectional Diagram of Middle Ordovician Environments of East Tennessee, Prior to Chapman Ridge Time . . . . . 68

46. Map View of Regional Environmental Pattern During a Part of the Middle Ordovician in East Tennessee . . . . . 68

47. Complex Facies Pattern in the Middle Ordovician Rocks of Tennessee . . . . . 69

48. Contact of Holston Limestone and Chapman Ridge Sandstone at Locality B . . . . . 71

FIGURE PAGE

49. Contact of Holston Limestone and Chapman Ridge Sandstone at Locality A . . . . . 72

50. Proposed Depositional Models for the Chapman Ridge Sandstone . . . . . 75

51. Barrier Island-Lagoon-Tidal Flat Model of Stage II During Chapman Ridge Deposition . . . . . 77

# CHAPTER I

# INTRODUCTION

## I. PURPOSE OF INVESTIGATION

It has long been recognized that the first, thick sequence of Ordovician terrigenous clastic sediments in the Knoxville area is now recorded in the sandstones of the Chapman Ridge Sandstone. Although numerous disputes have repeatedly arisen over the correlation of these rocks with similar strata in other strike belts of east Tennessee, this formation, together with the underlying Holston "marble," has been mapped in this area by different workers over the years. But there has been little work done on the stratigraphic relationships between the Holston and the Chapman Ridge, and few people have examined the latter formation with emphasis on its environment of deposition. (Ferrigno, 1973, and Ferrigno and Walker, 1973, have studied the origin of the Holston.) The present project was undertaken to: (1) analyze the lithologic and facies character of the Chapman Ridge Sandstone based upon outcrop descriptions and thin-section studies; (2) use this information to formulate hypotheses on its environment of deposition; and (3) describe the stratigraphic relationships of the Chapman Ridge and Holston formations in light of recently proposed, paleoenvironmental models for the Middle Ordovician of east Tennessee.

## II. DESCRIPTION OF STUDY AREA

The area of study is located in southern Knox County in east Tennessee where the Chapman Ridge Formation crops out in a series of northeast-trending strike belts. This area was chosen because the type locality of the Chapman Ridge is included within this region, and outcrops are reasonably accessible and thus suitable for detailed, lithologic analysis. Topographically the Chapman Ridge caps the highest ridges in this region and commonly outcrops in near vertical bluffs. The bed rock is covered by thick, red soils, except where exposed along bluffs and road cuts.

As presently mapped, the Chapman Ridge Sandstone is limited to strike belts between the Dumplin Valley fault on the southeast and the Saltville fault on the northwest. A single strike belt south of the Knoxville fault which includes the type section of the Chapman Ridge at locality B was selected for study (Figures 1 and 2). Detailed section localities are provided in Table I. This area includes portions of the John Sevier (G.Q. 514), Knoxville (G.Q. 115), Shooks Gap (G.Q. 76), and Bearden (G.Q. 126) U. S. Geological Survey 7.5 minute geologic quadrangles.

## III. PREVIOUS INVESTIGATIONS

The first writer to report on these rocks was Safford who in 1869 termed them the "Iron Limestones" due to their ferruginous, sandy limestone lithology. Included in his description of the formation are interbeds of blue, calcareous shale (Safford, 1869). He felt that

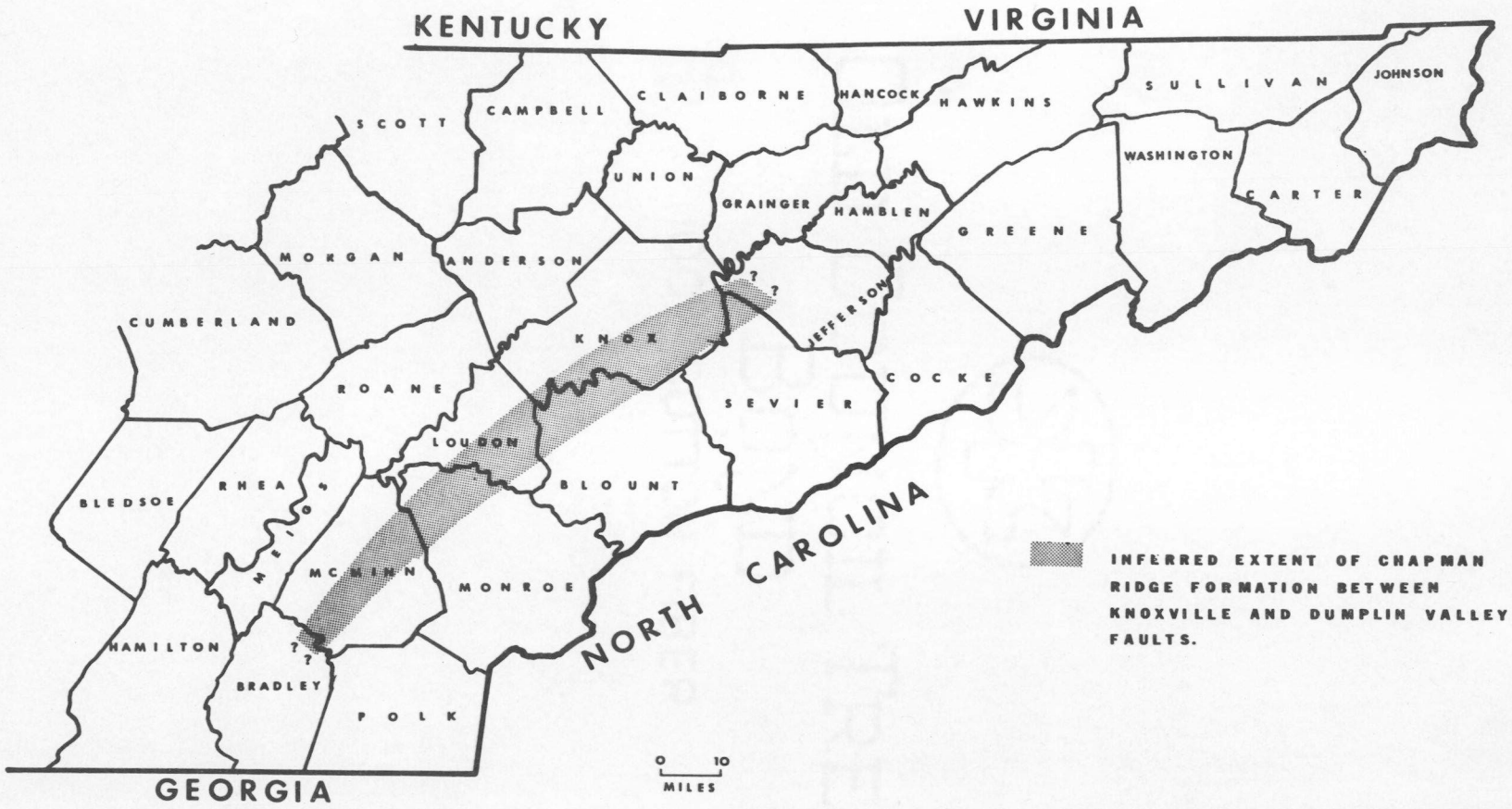



FIGURE 1. The Chapman Ridge Sandstone of east Tennessee.

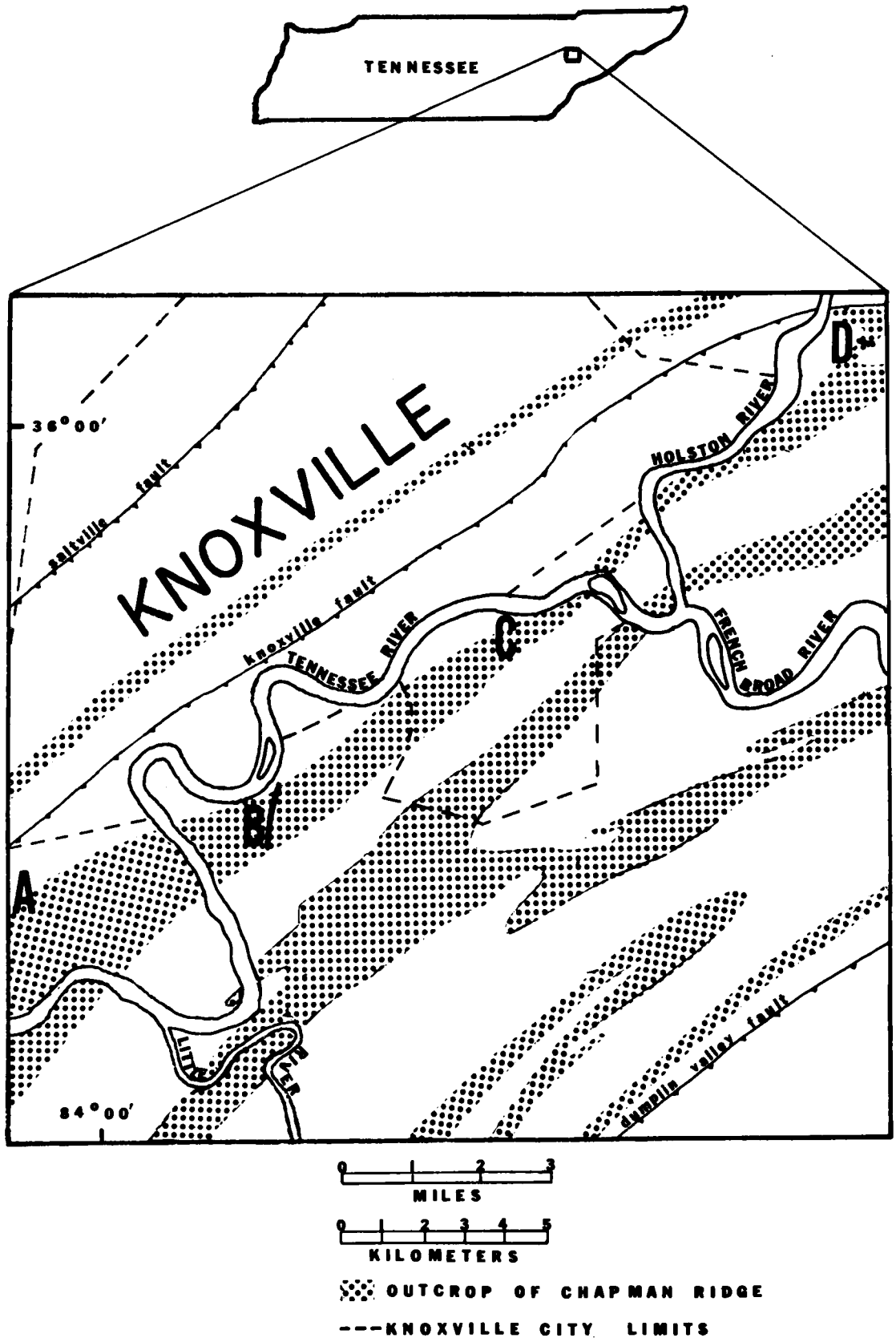



FIGURE 2. Outcrop of the Chapman Ridge Sandstone in the Knoxville area and localities of sections studied.

TABLE I. Stratigraphic Section Localities.

| Section | Location |
|---|---|
| A | Southeast quarter of Bearden Quadrangle. Road cut along east side of Dogwood Road, 20 yards north of intersection with Wrights Ferry Rd. |
| B | West central part of Knoxville Quadrangle. Type locality of Chapman Ridge Sandstone. Road cut along Alcoa Highway, 1/5 mile south of Looney Island; 50 yards north of intersection with Woodson Drive to intersection with Mt. Vernon Drive. |
| C | East central part of Knoxville Quadrangle. Hillside exposure approximately 50 yards south of Island Home Drive and 50 yards northeast of end of Ford Street. |
| D | South central part of John Sevier Quadrangle. Road cut along north side of I-40, one mile east of Armstrong Island and at intersection with Oglesby Road. |

these rocks extend southeast from Knoxville to Chilhowee Mountain and southwest to Bradley County near Cleveland, Tennessee. He first proposed the term, "Red Belt," for this series of rocks.

Keith (1895) described rocks of similar lithologic character and proposed the name, Tellico Sandstone, for outcrops along the Tellico River in Monroe County. He also believed that these limey, red sandstones were correlative with similar looking rocks in the Knoxville area. The earliest, detailed description of thin hematite seams within these "Tellico" sandstones is found in Burchard's report in 1913. Unlike the previous studies, his work was confined to strike belts between the Saltville and Dumplin Valley faults. He mentioned that iron ore had been mined from these rocks since the early 1900's from three separate localities in east Tennessee: (1) at Riceville in Bradley County; (2) from the Tuckahoe District in Knox and Jefferson Counties; and (3) near the town of Sweetwater in Monroe County. At each locality the seams are found immediately above the underlying Holston "marble." The thick, overlying residuum contains concentrated ore at numerous localities which Burchard (1913) considered economically important.

Stose and Schrader (1923) described the mining of manganese along with iron ore in the Sweetwater vicinity. They were presumably the earliest workers to refer to the base of the "Tellico" as resting unconformably on the Holston. Providing detailed maps and photographs of this sharp, undulating contact, they suggested that subaerial exposure of the Holston allowed weathering and subsequent accumulation of these manganese and iron deposits. Sources for these sediments were not discussed. Gordon (1924) mapped the "Tellico" sands in this

belt in the Friendsville district of Loudon County in his study of the marbles of east Tennessee. Within the sands, he found discontinuous, carbonate mounds, approximately 200 feet thick, which he termed the "Meadow Marble." Gordon also concluded that a disconformity marks the "Tellico"-Holston contact. In mapping the Mascot-Jefferson City zinc mining district, Bridge (1945) included these sandstones within the Ottosee shales. He did not refer to the thickness or character of these rocks in this area.

Rodgers (1953) mapped these sandstones in this belt in the Niota and Athens district of McMinn County. Apparently uncertain of the correlation of these belts with strike belts to the southeast where Keith had studied the Tellico, Rodgers did not refer to these rocks as Tellico but instead included them as an upper unit within the Holston Formation. He noticed the apparent unconformable surface within the sequence but concluded that the higher quartz content of the sands caused them to weather differently from the underlying limestone. He also found "considerable" thicknesses of shale separating the sands from the marbles in places. Rodgers concluded that in this area the "Tellico" is merely a quartzose phase of the Holston.

In mapping the Knoxville area, Cattermole (1955) agreed with Rodgers that the "Tellico" of these strike belts is not correlative with the type Tellico, which he concluded was stratigraphically lower than the Holston. Cattermole renamed this formation the Chapman Ridge Sandstone for outcrops along Alcoa Highway in Knox County, south of Looney Island (locality B of Figure 2, page 4). Noting that a 9 to 30 meters thick "tongue" of gray, calcareous shale commonly separates

this formation from the Holston, he defined the Chapman Ridge as including all strata between this lower shale tongue (or the top of the Holston where the shale is missing) through to the upper contact with shales and limestones of the overlying Ottosee Formation. Various stratigraphic classifications of these rocks are summarized in Figure 3. A total thickness varying between 210 and 275 meters was measured for this unit by Cattermole (1955) in the Knox County area. Further mapping of the Chapman Ridge in this area has been conducted by Swingle (1967) and by Cattermole (1958, 1960, 1966). In describing rocks south of Knoxville, Cattermole (1960) mapped several "marble" units near the top of the Chapman Ridge. These carbonate buildups are neither continuous nor confined to any one stratigraphic horizon as they are also found in the Ottosee shales. Steve LaFollette (1974) studied the Vestal "marble" Member of the Ottosee, and Preston Sitterly is currently investigating the Meadow "marble" within the Chapman Ridge (Master's thesis, in preparation).

Several workers have mapped Chapman Ridge strata in portions of Blount and Loudon counties (Miller, 1953; Gibbs, 1965; and Moehl, 1965). All of these reports refer to the presence of pebbles of chert and quartz in the sandstones. To the southwest, near Cleveland, Tennessee, in Bradley County, Swingle (1959) stated that the Chapman Ridge is missing due to erosion in the strike belt southeast of the Knoxville fault. However, in the belt between the Knoxville and Saltville faults he mapped the Holston, like Rodgers (1953), with an upper sandy phase which may represent Chapman Ridge sediments. Mel Smith (Doctoral dissertation, in preparation at The University of Tennessee) is mapping

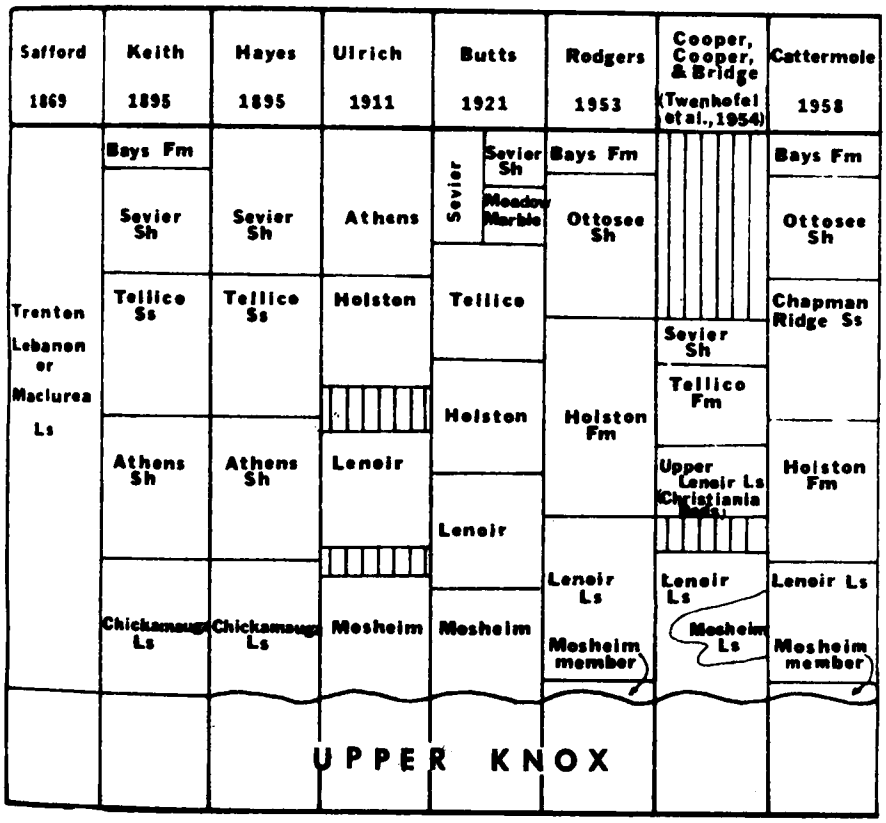



FIGURE 3. Various classifications of Middle Ordovician rocks of east Tennessee.

SOURCE: R. E. McLaughlin. 1973. Observations on the biostratigraphy and stratigraphy of Knox County, Tennessee, and vicinity. In Geology of Knox County, Tennessee. Tennessee Division of Geology, Bull. 70, p. 25-62.

the strike belt south of the Knoxville fault in McMinn County in an attempt to relate Rodger's work with Swingle's. Approximately 70 meters of Chapman Ridge Sandstones are present in this locality (Smith, personal communication).

## IV. PROCEDURE

Following a general reconnaissance of the Chapman Ridge Sandstone in Knox County, the strike belt immediately to the southeast of the Knoxville fault was selected for study. Four outcrop localities, A, B, C, D, were examined in the field and are located on Figure 2, page 4, and Table I, page 5. At all of these localities the contact between the Holston and the Chapman Ridge is exposed. Two localities, B and D, offer fairly complete exposures throughout the entire formation. Most of the Chapman Ridge is covered at sections A and C.

Outcrops were described based on lithologic and bedding characteristics. Samples were collected at intervals ranging from 15 centimeters to 9 meters and averaging about 1.5 meters. Each unique lithology encountered was sampled. A total of 135 samples collected from all four localities were sliced and examined on polished surfaces. Color descriptions of samples were made according to the U. S. Geological Survey Rock Color Chart. Thin-sections were prepared from 101 of these samples (34 samples were not thin-sectioned because they are very similar in lithology to sectioned samples). These thin-sections were mounted on 5 by 7.6 cm glass slides and stained with Alizarine Red-S solution as an aid in identifying dolomite (Friedman, 1959).

Each slide was described based on its composition (allochemical and orthochemical) and sedimentary structures. All thin-sections were examined under the petrographic microscope, and from these a total of 37 slides were chosen as representative lithologies. These samples were then point counted with an average of 550 counts per slide. (Point-count procedures are outlined by Chayes, 1954.) The point-count analyses are given in Appendix A.

# CHAPTER II

## DESCRIPTIONS OF LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS

### I. GENERAL CONSIDERATIONS

Nine distinct lithologies are recognized within the Chapman Ridge Sandstone in this area. Typically these lithologies are vertically gradational into one another, and thus admixing of two or more lithologies is common. Horizontal control in the study of these units here is lacking due to the relative steep angles of dip associated with these beds (generally between 20 degrees and 30 degrees to the southeast) and because of the absence of continuous outcrops along strike. For this reason, the writer has applied principles from Walther's Law to gain some perspective on the horizontal distribution of Chapman Ridge facies.

Complete outcrop and sample descriptions with point count data are provided in the Appendixes. Rock classification in this report follows Folk (1959). The grain size terminology used here is based on the Udden-Wentworth grade scale, and classification of bedding thickness is in accordance with Ingram (1954). The various lithologies discussed in this chapter with accompanying depositional environments are summarized in Table II.

TABLE II. Summary of Lithologies, Characteristics, and Postulated Environments of the Chapman Ridge Sandstone.

| Lithology | Characteristic Features | Postulated Environment | References |
|---|---|---|---|
| Calcareous quartz sandstone; sandy biosparite | Ripple drift cross laminae; ripple marks; abraded fossils; absence of indigenous fauna; excellent sorting of sediments. | Subtidal sand flats | Ball (1967); Purdy (1964); Geblein (1969) |
| Calcareous quartz sandstone; sandy biosparite; trilobite-rich biosparite | Low angle, planar cross-beds; well sorted sediments; nested shells and highly abraded fossils; rounded shale clasts. | Beach | Folk and Robles (1964); Blatt, et al. (1972); McKee (1964) |
| Calcareous quartz sandstone; biosparite; sandy biosparite | Trough cross-beds; channel lag deposits. | Tidal channel | McKee (1964) |
| Biosparite | Absence of mud matrix; lack of extreme abrasion of fauna; trough cross-bedding; high angle planar cross-beds; mud clasts; absence of detrital quartz. | Carbonate bank | Ball (1967) |
| Oosparite | Well sorted grains; abraded fossils; absence of indigenous fauna, ripple marks; low angle, planar cross-beds. | Oolite shoal | Ball (1967); Purdy (1961); Purdy (1964) |

TABLE II. (continued)

| Lithology | Characteristic Features | Postulated Environment | References |
|---|---|---|---|
| Biomicrite; calcareous mudstone | Algally bored ramose bryozoa and pelmatozoa, unabraded trilobites and cephalopods; oncolites and "quiet water" ooids; unsorted deposits of clasts of algae and terrigenous mud; thin, undulating mud laminae in biomicrites; mottled outcrop appearance. | Carbonate lagoon | Stephenson (1973); Bathurst (1967); Ginsburg (1960); Geblein (1969); Freeman (1962); Knox (1970); Hessland (1949) |
| Calcareous shale | Absence of faunal elements; abundant horizontal burrows; fecal pellets. | Lagoon | Rhoads (1967) |
| Interlaminated shales and sandy biosparites | Thin horizontal laminae; cut and fill structures; vertical burrows; dolomite rhombs; mud cracks; few, scattered skeletal remains. | Tidal flat | Van Stratten (1957); Walker and Ferrigno (1973); Murray and Pray (1965); Rhoads (1967) |
| Interlaminated shales and sandy biosparites | Lensoid, flasure, and rippled bedding; few horizontal burrows; absence of fauna. | Tidal delta | Reineck and Wunderlich (1968); Purdy (1964) |

# II. CALCAREOUS QUARTZ SANDSTONE

## Lithologic Description

The thin to thick bedded calcareous quartz sandstones (Figures 4, 5, 6, and 7) are characterized by their high content of well sorted, fine-grained quartz which constitutes approximately 40 percent of the total rock composition. Highly abraded fossil debris (primarily pelmatozoan grains and ramose bryozoa) average 15 percent in amount and generally are confined to laminae and lenses which weather out white. Fine sand size, rounded clasts of micrite (referred to as "peloids" by Bathurst, 1967, and thought to have formed by the micritization of fossil debris) usually represent 10 to 15 percent of the lithology. Rounded clasts of terrigenous mud frequently containing dolomite rhombs are minor (less than 4 percent). Allochems are cemented together by sparite and in a few cases by microspar. Figure 8 provides the allochemical percentage composition for these calcareous quartz sandstones, assuming a 100 percent allochem content (i.e., all matrix and cement are excluded from calculations). Both terrigenous and fossil grains are often enveloped in thin rims of iron oxide.

Units of these sandstones may exhibit high (greater than 10 degrees) and/or low (less than 10 degrees) angle planar cross-bedding, trough cross-bedding, and ripple-drift cross lamination. Numerous bedding surfaces display interference ripple marks, trilobite tracks, and orthocone cephalopod shells (Figures 9 and 10). Cross beds show no apparent preferred orientation.

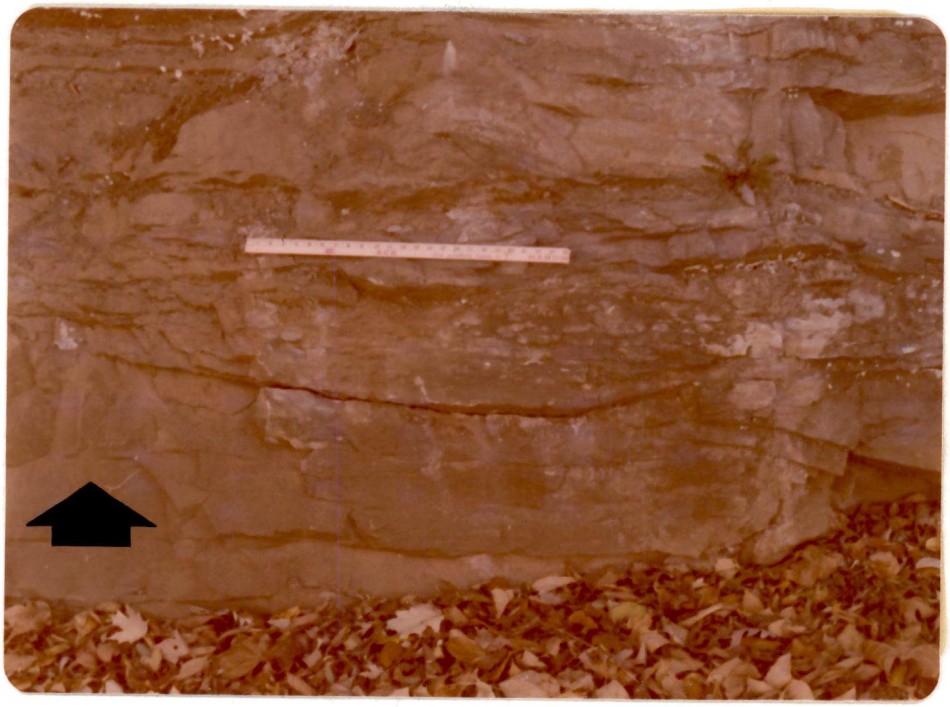


FIGURE 4. Outcrop photograph of trough cross-bedding in calcareous quartz sandstone along Alcoa Highway. Ruler is 0.7 meter long and up arrow is shown.



FIGURE 5. Outcrop photograph of thick-bedded sandstone in the upper units of the formation at Alcoa Highway. Note planar cross-beds in right central portion of the photograph. Ruler is 0.7 meter long and stratigraphic up direction is given by arrow.

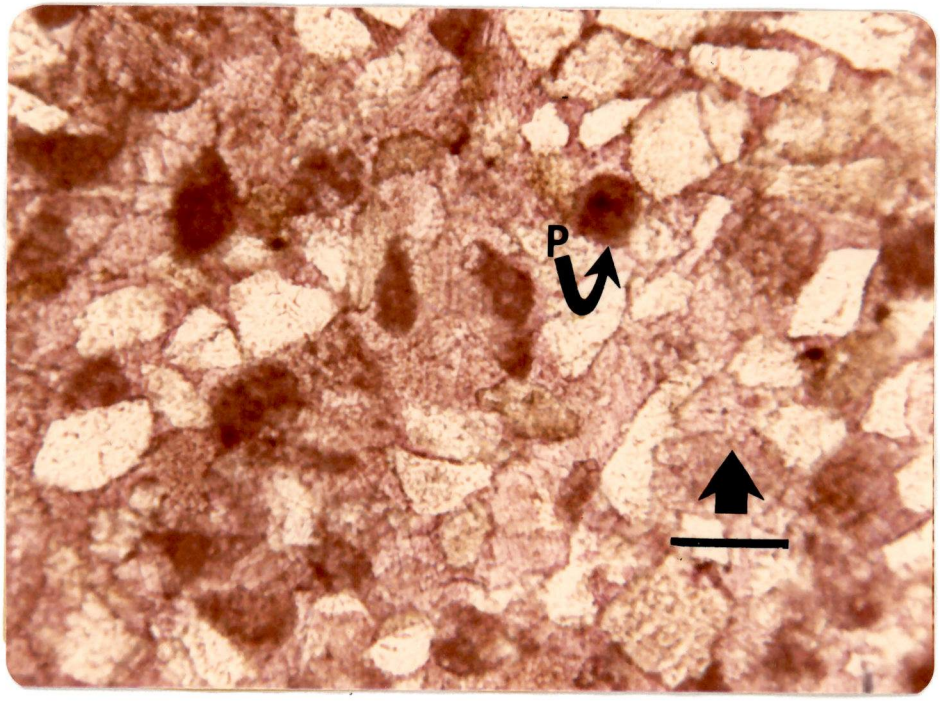



FIGURE 6. Photomicrograph of calcareous quartz sandstone. Note abundance of subangular, white quartz grains and rounded peloids (P). Spar cement is stained red. Bar scale is 0.2 mm long and up direction is shown by arrow.

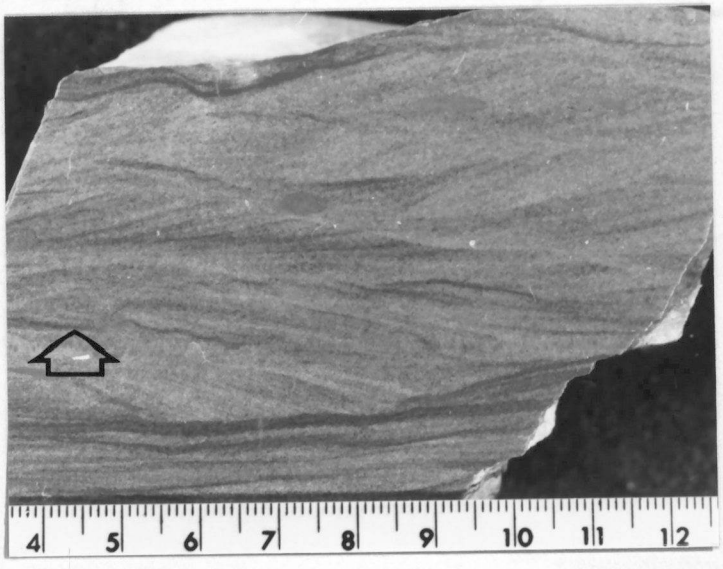



FIGURE 7. Hand sample photograph of ripple drift cross-laminae in calcareous quartz sandstone. Scale is in cm and arrow provides up direction.

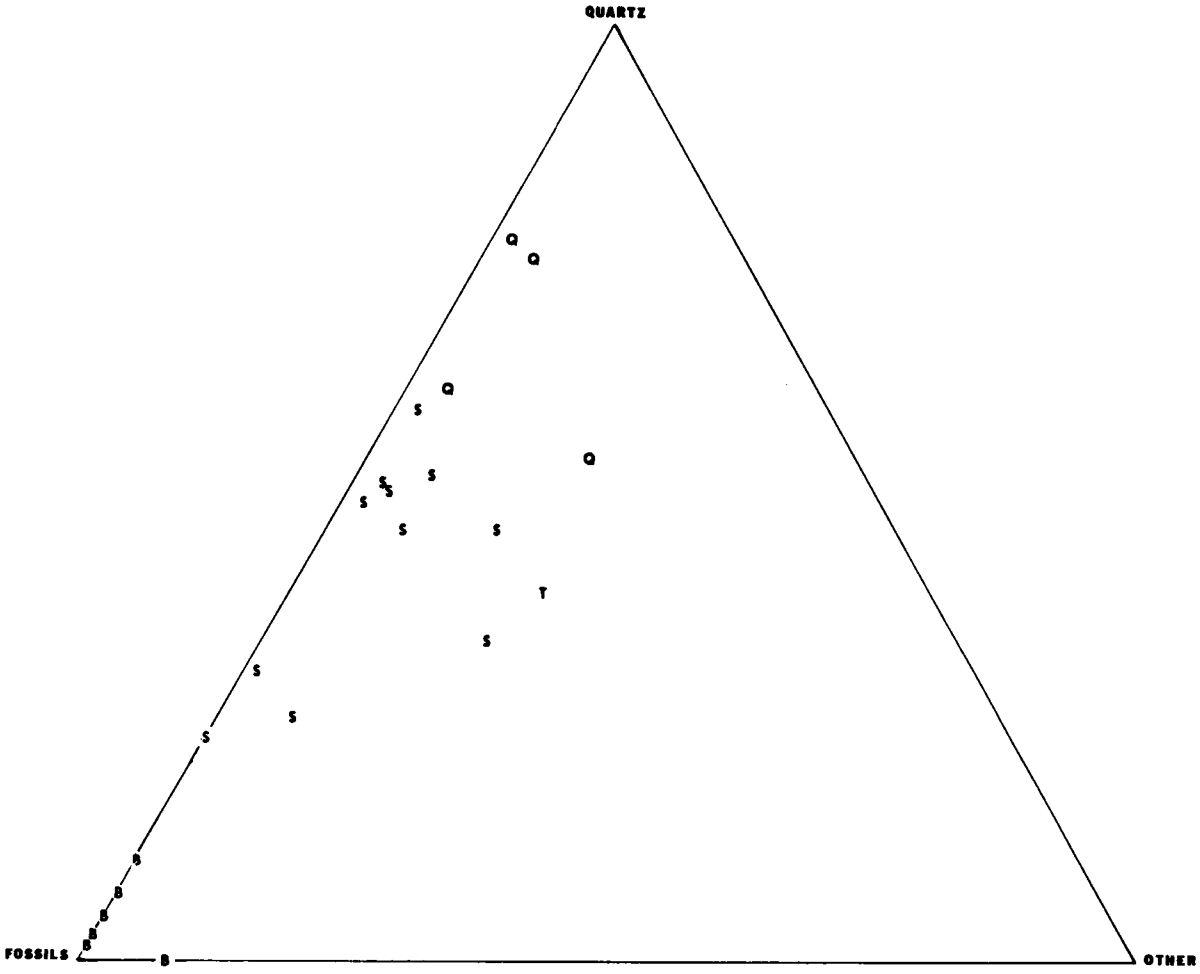



FIGURE 8. Allochemical percentage composition of calcareous quartz sandstones (Q), biosparites (B), sandy biosparites (S), and trilobite-rich sandy biosparite (T). This is a 100 percent diagram of the allochems--all cement is excluded from calculations. "Other" category includes noncalcareous mud clasts, metamorphic rock fragments, glauconite, and plagioclase.



FIGURE 9. Outcrop photograph of thin beds and laminae of calcareous sandstone. Note that all bed surfaces are rippled. Pencil is 15.2 cm long and points in up direction.

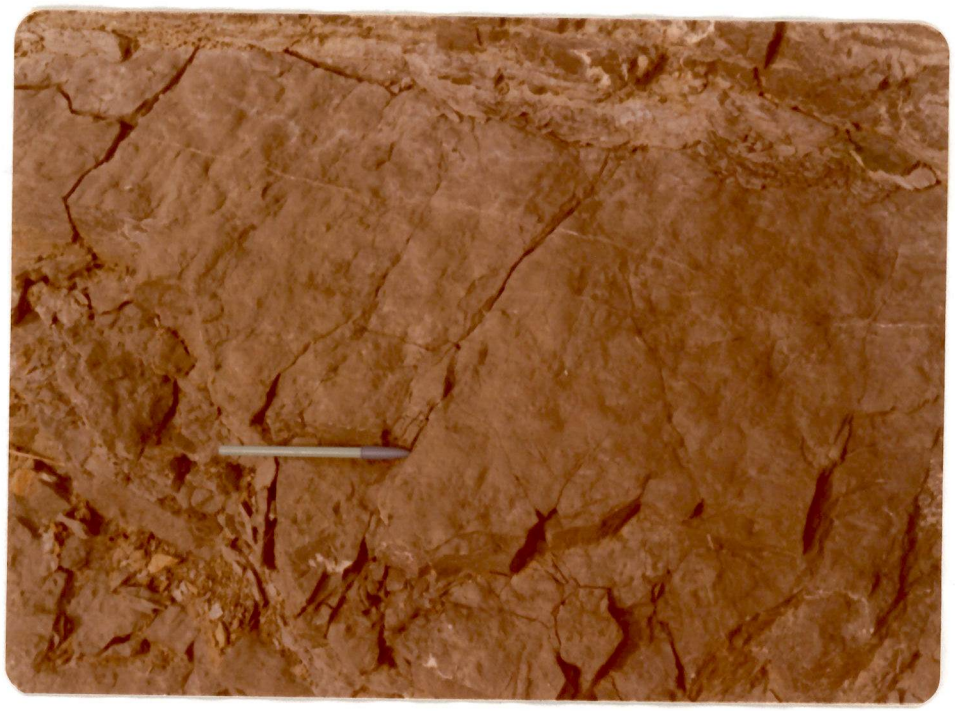


FIGURE 10. Outcrop photograph of calcareous sandstone which shows interference ripple marks and horizontal burrows. Pen is 15.2 cm long and is positioned on top of bed.

Commonly this lithology grades vertically and imperceptibly into the sandy biosparites. Thin interbeds of calcareous shale and interlaminated sandy biosparites and shale are particularly abundant at the base and also towards the top of these sandstone units.

Environmental Interpretations

These calareous quartz sandstones are inferred to represent deposits from barrier islands and shallow subtidal, marine sand flats. Evidence for the extensive, shallow sand flats is provided by the preponderance of ripple marks and ripple drift cross laminae associated with these rocks. This environment was marked by constantly shifting sands in response to wave and tidal action. As a result, sands are well sorted and contain few fossils, all of which are abraded. This rapidly moving substrate would have been unsuitable for most benthonic organisms and would thus account for the scarcity of fossils found in these units (Purdy, 1964). A modern analogy to the proposed environment is described by Ball (1967) in his discussion of sand bodies of the Bahamas. Although this analogue is set in a non-terrigenous, wholly carbonate complex, the hydraulogic parmaters (i.e., physical sedimentary structures) are applicable to these quartz sandstones of the Chapman Ridge. Geblein (1969) provides a comparable "rippled sand facies" in the shallow waters (0.7 to 1.2 meters deep ) around Bermuda. Here he found that sand size sediment is constantly kept in motion by waves and tides and that during flood tide approximately 108 grams of sediment per hour move over one square foot of bottom surface. This repeated movement of grains results in extremely well sorted sands in which benthonic fauna are virtually absent.

The proposed barrier island-beach environment is suggested by the low angle (2 degrees to 10 degrees), planar cross-beds (Figure 11), associated high angle, planar cross-beds and trough cross-beds. Low angle cross-bedding may reflect foreshore accretion deposits which formed by the lateral growth seaward of the beach sequence. The barrier island-beach complex was destroyed by tidal channels which cut through the barriers and swept sediment into an inferred lagoon (discussed later in Section VII of this chapter). High angle, planar cross-beds and trough cross-bedding are here interpreted as reflecting lateral migration of a confined flow of water (McKee, 1964). These channel sandstones characteristically contain pebble-size, shale clasts (Figure 12) and abraded fossil debris which are interpreted to be channel lag deposits.

## III. SANDY BIOSPARITE

### Lithologic Description

The sandy biosparite lithology is primarily distinguished from the calcareous quartz sandstones by the lower percentages of terrigenous grains (less than 50 percent and averaging approximately 30 percent) in the sandy biosparites, with an accompanying increase in carbonate material (allochemical and orthochemical). (See the analyses shown on Figure 8, page 20.)

The grain content of the sandy biosparites is quite variable. All samples of this lithology contain well-sorted, fine quartz grains which vary from 15 percent to 43 percent and average about 25 percent. Numerous examples were found in which rounded peloids constitute 20

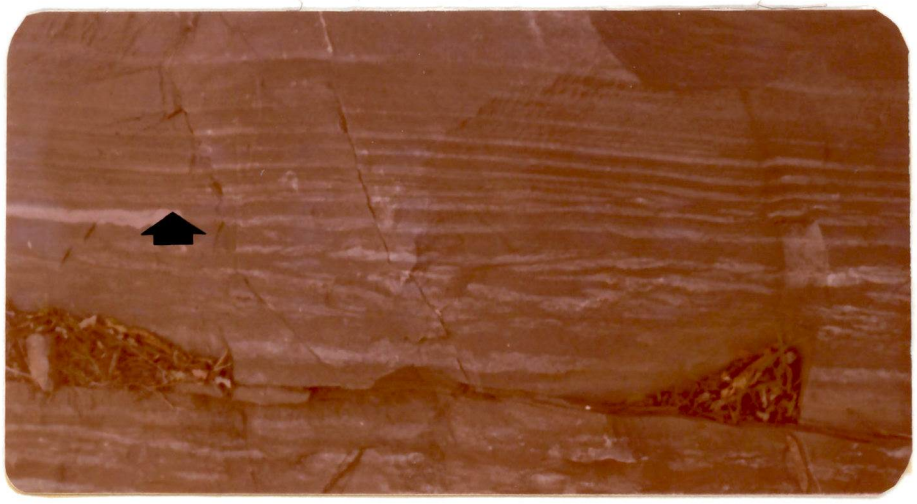


FIGURE 11. Outcrop photograph of low angle, planar cross-beds which overlie ripple drift cross-laminae in calcareous quartz sandstones. Up arrow represents 5 cm.

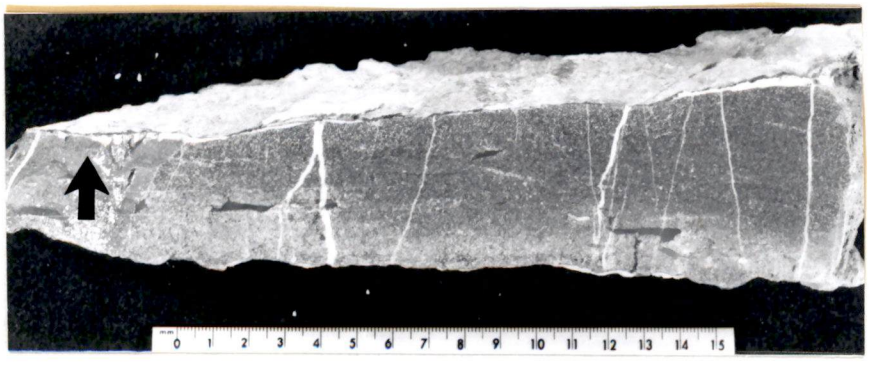



FIGURE 12. Hand sample photograph of channel lag deposits (shale clasts) in postulated tidal channel sandstone. Scale is in cm and up is indicated by arrow.

percent of the rock while other samples are lacking in peloids. Recognizable fossils in this lithology are abraded and dominated by pelmatozoa, trilobites, and ramose bryozoan which together compose 15 to 20 percent of the rock. Fine sand size grains of plagioclase, metamorphic rock fragments, and glauconite are present in trace amounts (less than 1 percent). Allochemical composition is given in Figure 8, page 20 (calculations are based on 100 percent allochems). Note from the graph that the more sandy biosparites grade into the calcareous quartz sandstones and that four sandy biosparite samples contain between 50 and 59 percent quartz. These four samples are composed of relatively high carbonate cement percentages (30 percent) and thus have a total rock composition of less than 50 percent terrigenous grains.

Sedimentary structures associated with the sandy biosparites appear identical to those found in the calcareous quartz sandstones (Figures 13, 14, 15, and 16). In fact in many cases these two lithologies may be distinguished only through detailed petrographic analysis.

Environmental Interpretations

Due to the presence of similar bedding characteristics and only subtle lithologic variations, the sandy biosparites are inferred to represent comparable depositional environments to the calcareous quartz sandstones: barrier island--tidal channel--sand flat complex. The slightly higher percentage of abraded fossils in this lithology is not considered to be a reflection of differing environmental conditions.



FIGURE 13. Outcrop photograph of ripple drift cross-laminated sandy biosparite. More fossiliferous units weather out white. Pencil is 15.2 cm long and points in up direction.

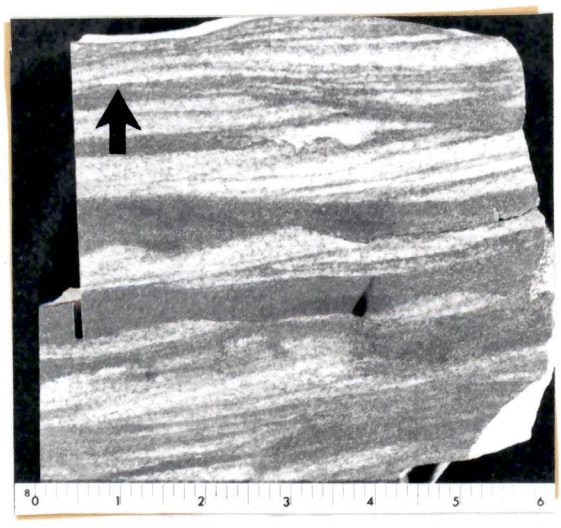



FIGURE 14. Hand sample photograph of ripple drift cross-bedding in sandy biosparite. Scale is in inches and arrow points up.

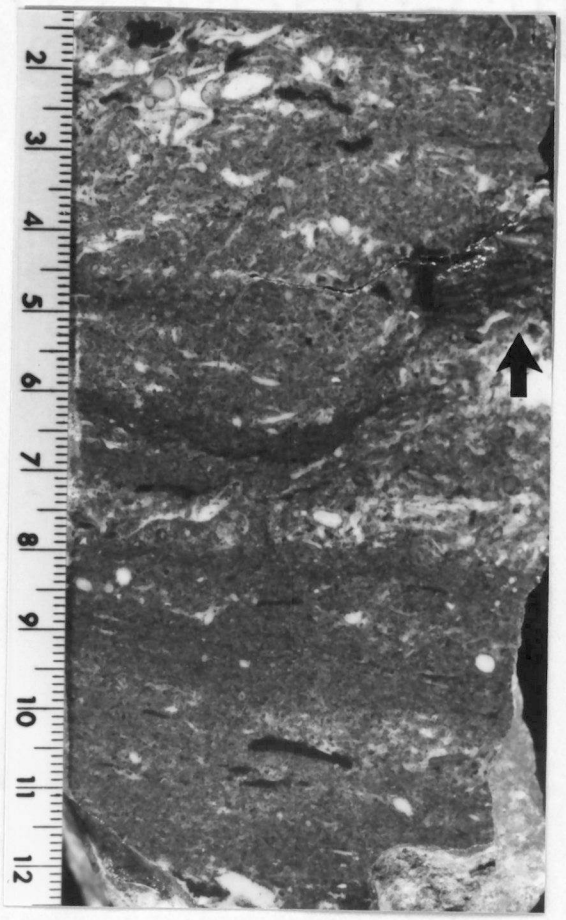



FIGURE 15. Hand sample photograph of sandy biosparite lithology which contains highly abraded, 0.2-0.5 cm size skeletal fragments. Scale is in cm and up direction is shown by arrow.

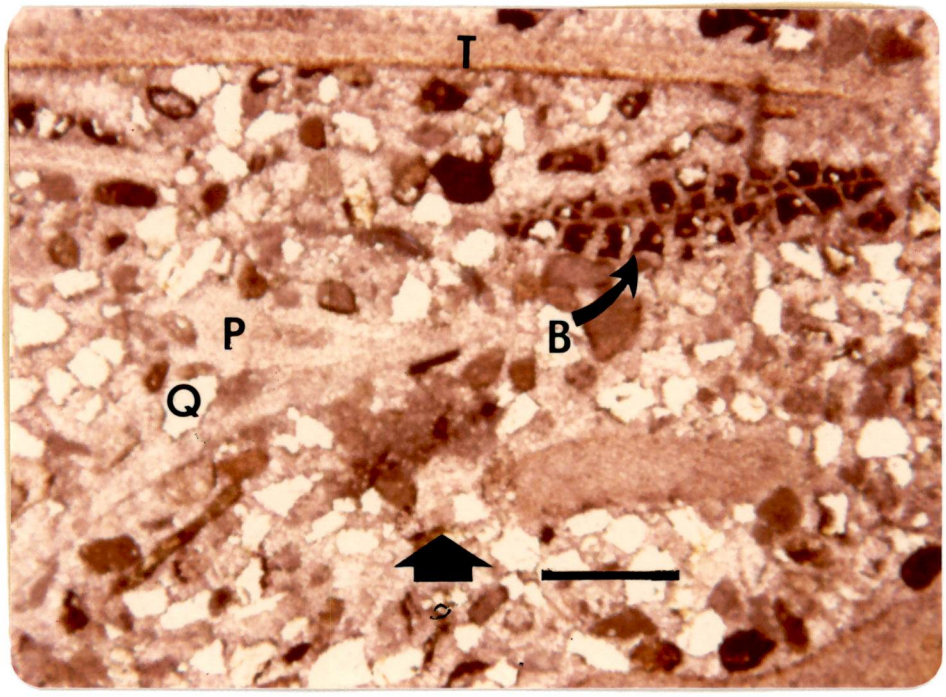



FIGURE 16. Photomicrograph of sandy biosparite lithology. Ramose bryozoan grains (B) are filled with hematite; trilobite fragments (T); pelmatozoan (P); subangular-subround quartz grains (Q). Bar scale is 0.5 mm long and adjacent arrow shows up direction.

# IV. TRILOBITE-RICH SANDY BIOSPARITE

## Lithologic Description

This rock type is considered here as a separate and distinct lithology from the other sandy biosparites due to the preponderance of trilobite carapaces. These trilobites are commonly nested and constitute approximately 10 percent of the total lithology (Figure 17). Fine, well sorted, quartz grains may comprise as much as 25 percent of this rock (Figure 8, page 20). Pelmatozoan grains and peloids together average 20 to 25 percent and appear abraded. Typically rounded, pebble-size clasts of terrigenous mud are found here but constitute only about 10 percent of the rock. Broken fragments of brachiopods and fine grains of glauconite are noted in trace amounts. These allochems are cemented by sparry calcite.

Units of the trilobite-rich sandy biosparite are thin- to medium-bedded and generally characterized by low angle, planar cross-beds. This lithology vertically is bounded by beds of quartz sandstone and sandy biosparite.

## Environmental Interpretations

Based upon evidence from the above descriptions, it is suggested that the trilobite-rich sandy biosparite sequences represent former beach deposits. The abraded condition of all fossils and the presence of well sorted, fine quartz grains are indicative of relatively high energy currents. Nested shells have been found associated with beach deposits by Folk and Robles (1964) in a study of modern beaches of the Alacran reef complex. Here again, the gently dipping planar cross-beds probably

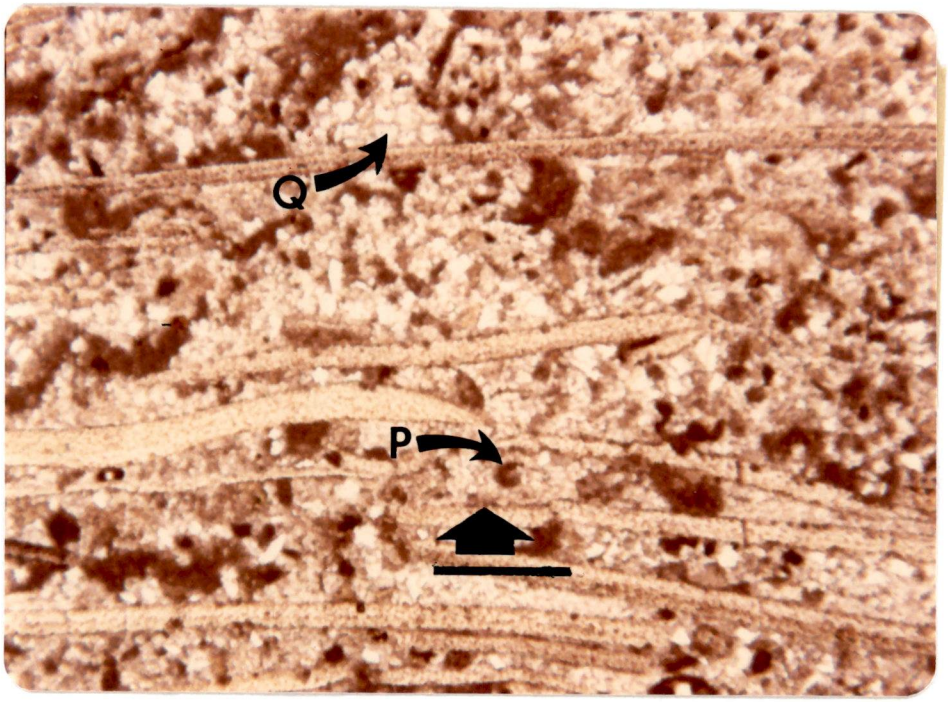



FIGURE 17. Photomicrograph of trilobite-rich, sandy biosparite. The trilobite carapaces are nested and show lack of abrasion. Quartz grains (Q) and peloids (P) are indicated. Bar scale is 0.5 mm and adjacent up arrow is given.

resulted from foreshore beach progradation. The shale pebbles in these rocks could represent beach step deposits, accumulating at the base of the beach face because of the incompetence of tidal flood to transport these grains higher onto the beach or ebb currents to remove them (Blatt et al., 1972).

## V. BIOSPARITE

### Lithologic Description

The biosparites constitute a very significant and extensive lithology in the lower portions of the Chapman Ridge Sandstone. This lithic type is composed almost exclusively of abraded fossil debris in sparry calcite cement (Figures 18 and 19). Fine grains of detrital quartz constitute only about 3 to 4 percent of the total rock, and it is this criteria which distinguishes these biosparites from the more quartz-rich, sandy biosparites (Figure 8, page 20). Pelmatozoan grains and trilobite carapaces together comprise 40 to 60 percent of the lithology. (Generally pelmatozoan grains are the more dominant faunal element.) The remainder of the fossils are ramose bryozoan (average 10 percent) and trace amounts (less than 1 percent) of incrusting bryozoan, mollusk, and brachiopod fragments. In some samples there are minor amounts of subrounded, terrigenous mud clasts which average 1 cm in length.

Units which contain this lithology exhibit a variety of sedimentary structures. Most of these sequences are thin- to medium-bedded and marked by the presence of low angle, large scale, planar cross-beds. Occasional high angle and trough cross-bedding is also present. These



FIGURE 18. Outcrop photograph of low angle, planar cross-bedded, biosparite lithology. Pencil is 15.2 cm long and shows up direction.

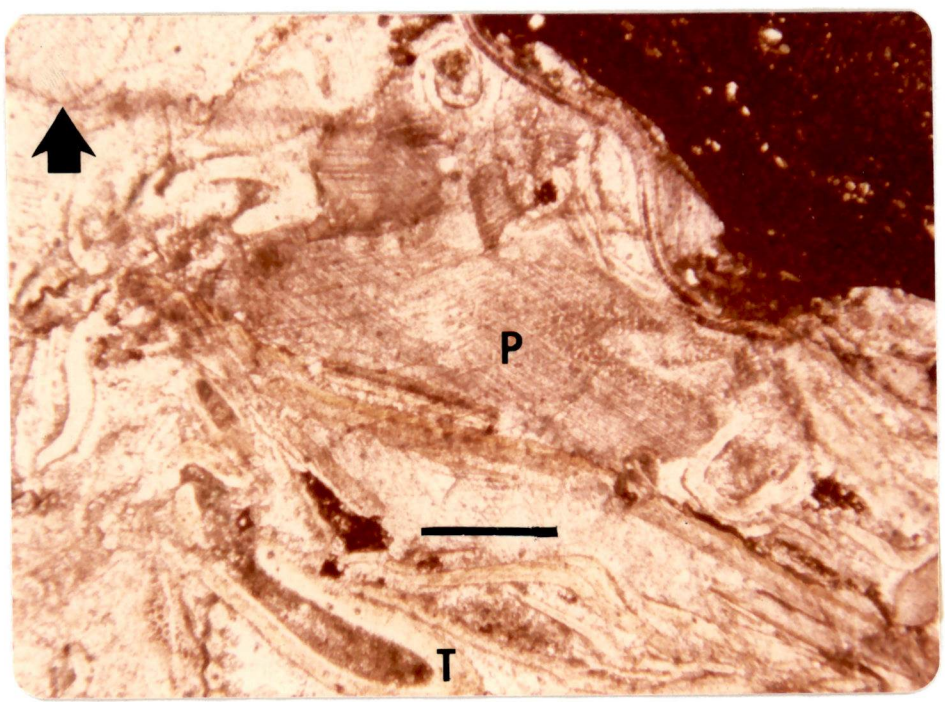



FIGURE 19. Photomicrograph of biosparite containing abundant pelmatozoan grains (P) and trilobites (T). Bar scale is 0.5 mm long and up arrow is shown. Notice the absence of quartz grains in this lithology.

units are underlain by beds of biomicrite and in places by calcareous mudstone sequences. Locally common in the biosparites are interbeds of calcareous shale which appear identical to the clasts noted in this lithology. The shales are more abundant higher in the biosparite sequences.

Environmental Interpretations

The writer interprets the biosparites as reflecting deposits from a shallow subtidal, carbonate bank complex. This bank supported a fauna composed primarily of pelmatozoa, trilobites, and ramose bryozoan which upon death contributed to the buildup of the bank. The absence of mud matrix in these rocks indicates that currents were effectively sorting the sediments; yet, faunal elements were probably not transported great distances from life site as evidenced by their lack of extreme abrasion. Thus it is believed that current activity while persistent, for the most part was not of a torrential nature. In fact the disarticulation of pelmatozoan structures could have been caused by relatively gentle currents, following death of the organism.

Trough cross-bedding and high angle cross-beds are inferred to have formed in tidal channels which bisected the bank complex and allowed fossil debris to be swept lagoonward with tidal flood. Lagoonal muds were incorporated as clasts in these bank deposits as they were transported by tidal ebb currents.

# VI. OOSPARITE

## Lithologic Description

The oosparites are characterized by their high content of well sorted, fine ooids and fossil debris which are cemented in sparry calcite. Constituting between 22 and 54 percent of the total lithology, the ooids have formed around nuclei of various grains (fossils, pellets, quartz grains) (Figure 20). Typically their lamellae boundaries are outlined by iron oxide rims. Uncoated fossils in these rocks are dominated by pelmatozoans (vary between 5 and 25 percent) and to a lesser extent by ramose bryozoan (1 to 11 percent). All fossil grains are extensively abraded. Fine quartz grains are present in all beds, but do not exceed 3 percent.

Units of oosparite are rare in the Chapman Ridge Sandstone (note in the section descriptions in Appendix B that this lithology is found only at Section C) although scattered traces of ooids are occasionally found in some of the biosparite and quartz sandstone samples. Oosparite beds occur in the lower portions of the formation as medium-bedded units which grade vertically into biosparites. These sequences are marked by the presence of low angle (3 to 5 degrees), planar cross-beds and rippled bed boundaries.

## Environmental Interpretation

These isolated oosparites are inferred to have formed in narrow discontinuous oolite shoals. In discussing the formation of ooids today on the Great Bahama Bank, Purdy (1961) notes that optimum conditions occur in shallow, warm, agitated waters (average six feet deep)

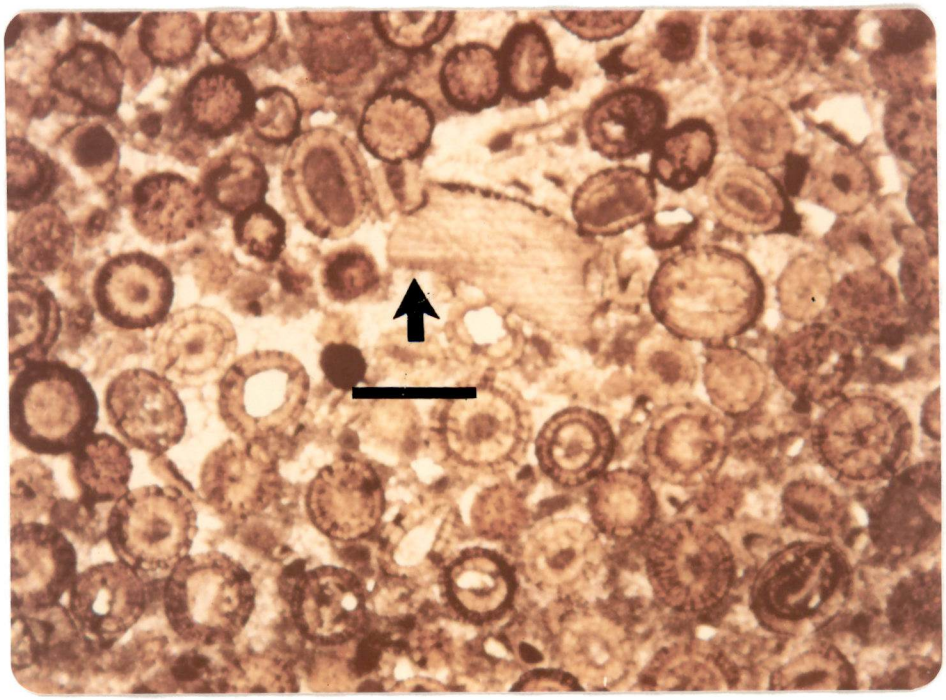


FIGURE 20. Photomicrograph of oosparite lithology showing the various nuclei for the ooids. Note the hematite coatings between laminae in the ooids. Bar scale is 0.5 mm long and up direction is indicated by arrow.

which are supersaturated with calcium carbonate. The well sorted grains and ripple marks of Chapman Ridge oosparites suggest that these deposits probably formed in a comparable, shifting environment that was constantly subjected to current movement. Ball (1967) discovered that Bahamian oolite shoals are marked by low angle, planar cross-beds which dip predominantly bankward. Cross-beds are formed by the lateral migration of the shoal environment. The Chapman Ridge cross-beds appear comparable to those described by Ball although the writer was unable to detect a general trend in their orientation.

The abraded condition of the fossils in the oosparites and the gradational relationship between these units and biosparite sequences indicate that the fauna were probably transported in to the shoals from adjacent bank complexes. The absence of indigenous fossils to this environment was probably a result of the constantly shifting substrate (Purdy, 1964).

## VII. BIOMICRITE

### Lithologic Description

Dispersed throughout biomicrite units are high percentages of bored fossils (primarily ramose bryozoan and pelmatozoan grains) which together constitute between 15 and 40 percent of the total rock. Other fossils which may attain an abundance of 10 percent but generally limited to amounts less than 4 percent are divided among trilobites, brachiopods, cephalopods, and unidentified mollusk fragments. Incrusting bryozoan are present in trace amounts and show extensive abrasion. In many samples the fossils have been algally bored to the extent

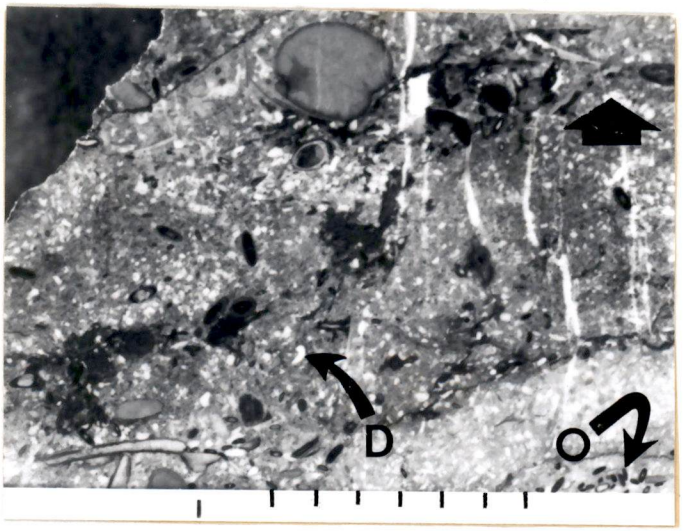



FIGURE 21. Hand sample photograph of biomicrite lithology with abundant algally coated fossil grains (A), ooids (O), and white fossil debris (D). Scale is in cm, and up arrow is shown at upper right.

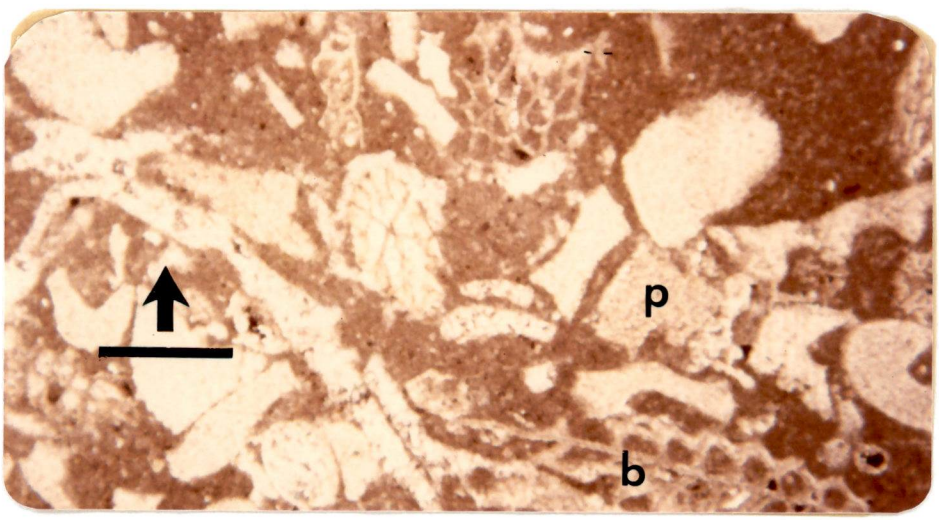



FIGURE 22. Photomicrograph of extensively bored pelmatozoan remains (P) and abraded ramose bryozoan (B) in micrite matrix. Bar scale is 0.5 mm long, and up direction is shown by the arrow.



FIGURE 23. Outcrop photograph of Chapman Ridge biomicrite lithology overlying Holston calcarenite. Ruler is positioned on contact and is 2.0 feet (0.7 m) long. Up direction is provided by the arrow at left.

fossil grains by algae, a process termed micritization (Bathurst, 1967). There is evidence that this hypothesis is applicable here as (1) most fossil grains in lagoonal sediments are bored and (2) many grains serve as nuclei for algal oncolites (Figures 24, 25 and 26). Oncolites grow where sticky, algal material covers a grain, and successive layers of sediment are trapped and bound to this gelatinous mass. The thickness of the oncolite is increased by the ability of the algae to penetrate through this newly attached sediment and expose another sticky, algal layer (Ginsburg, 1960). After the grain is rolled over, additional material is deposited on the previously protected side, and thus a subround, roughly concentric, laminated structure is formed. Geblein (1969) has discovered that these oncolites are restricted to protected, shallow waters where bottom sediment movement is within the range of 8 to 40 grams per hour per foot.

Associated with the oncolites in Chapman Ridge lagoonal sediments are ooids which the writer interprets as having formed within these relatively quiet waters (Figures 27 and 28). Freeman (1962) described the occurrence of ooids in the muds of Laguna Madre, Texas, and suggests that they are not forming in the "classical" manner of a high energy, shoal environment as outlined by Purdy (1961). Freeman proposed that the Laguna Madre ooids are <u>in situ</u> deposits, possibly forming due to some organic influence, such as algae. The Chapman Ridge ooids found in biomicrite units are elliptical and composed of successive laminae of glauconite and/or hematite and calcite. Knox (1970) reported similar chamosite ooids from the Winter Gill ironstones (Jurassic) of England and felt that they formed in protected areas. Hessland (1949)

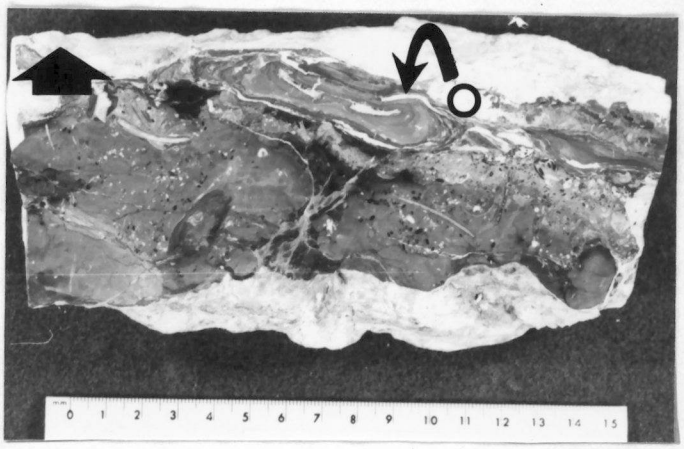



FIGURE 24. Hand sample photograph of flattened, hematitic oncolite (O) in biomicrite. Notice the numerous small ooids lower in the sample. Scale is in cm. Arrow at upper left points up.

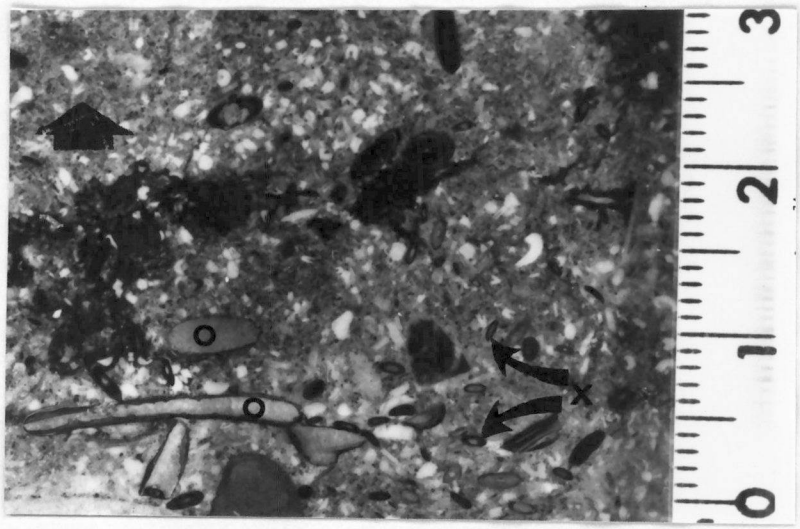



FIGURE 25. Hand sample photograph of oncolites (O) and ooids (X) in biomicrite lithology. Scale is in cm and up direction is indicated by arrow at upper left.

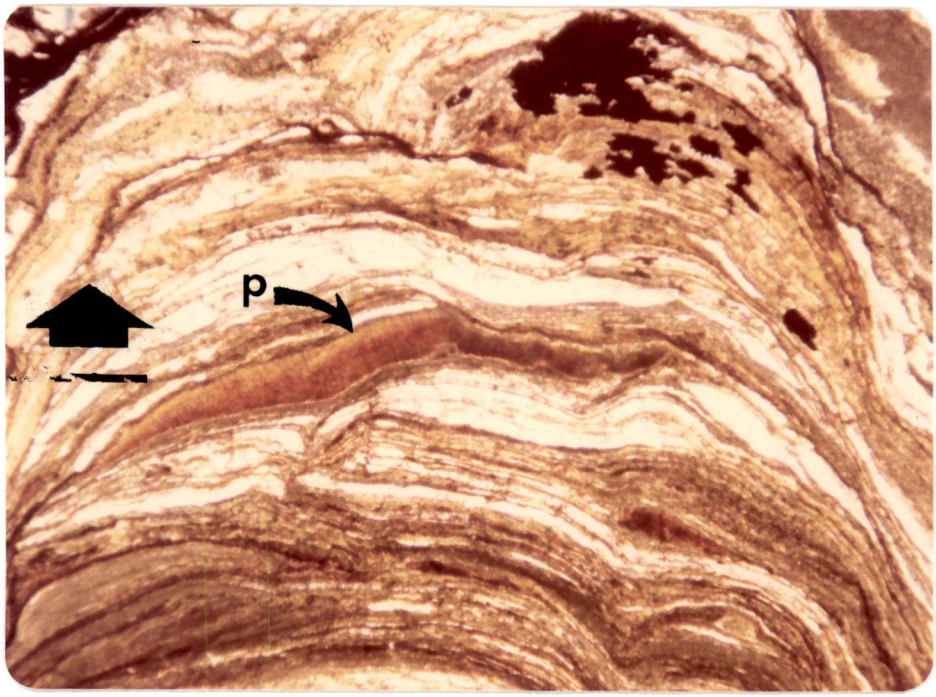



FIGURE 26. Photomicrograph of recurring laminae of glauconite (green), limonite (yellow), and calcite (white) in oncolite. (P) is a hematite-coated pelmatozoan grain which has been incorporated in the oncolite. Bar scale is 0.5 mm long. Arrow at left points up.

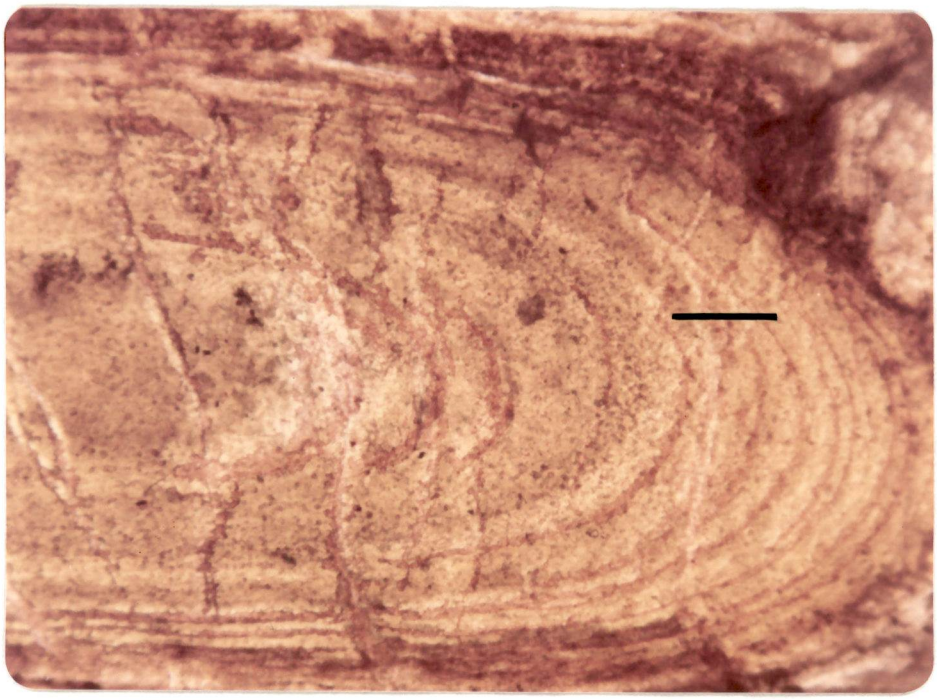


FIGURE 27. Photomicrograph of "quiet water" ooid showing alternating laminae of glauconite (green) and calcite (stained red). Bar scale is 0.2 mm long.



FIGURE 28. Photomicrograph of randomly oriented ooids in biomicrite lithology. Note the alternation of hematite (reddish brown) and glauconite (green). Grain (O) at right is an oncolite with its long axis oriented nearly vertically. Nuclei are mostly pelmatozoan fragments. Bar scale is 0.5 mm long and up direction is shown.

observed presumably the same type of structures in Lower Ordovician strata of Sweden. He also related algal activity to their formation.

Chapman Ridge quiet water ooids and oncolites frequently show an alternation of glauconite and hematite laminae. The writer interprets these structures as resulting from periodic, stronger currents, possibly generated by storms, which carried more oxygenated water into this otherwise quiet water environment. This slight turbulence would have rolled these grains around while oxidizing their outermost glauconite layer. Although questions still remain concerning the origin of glauconite, it is thought that this glauconite probably formed within these lagoons because the oncolites and ooids are unabraded, showing no evidence of extensive transportation. Furthermore, as suggested by Knox (1970), this glauconite may have formed as an alteration of terrigenous clays which were repeatedly washed into the lagoon.

## VIII. CALCAREOUS SHALE

### Lithologic Description

The calcareous shales are characterized by a general absence of faunal elements although many of the samples contain minor percentages (less than 4 percent) of silt size fragments of trilobites, bryozoa, and pelmatozoa. These shales are typically burrowed horizontally and filled with fecal pellets (Figure 29). Occasional, very thin lenses and laminae of very fine quartz grains are present within this lithology.

Shale units are particularly common in the lowermost sections of the Chapman Ridge Sandstone. They typically occur overlying

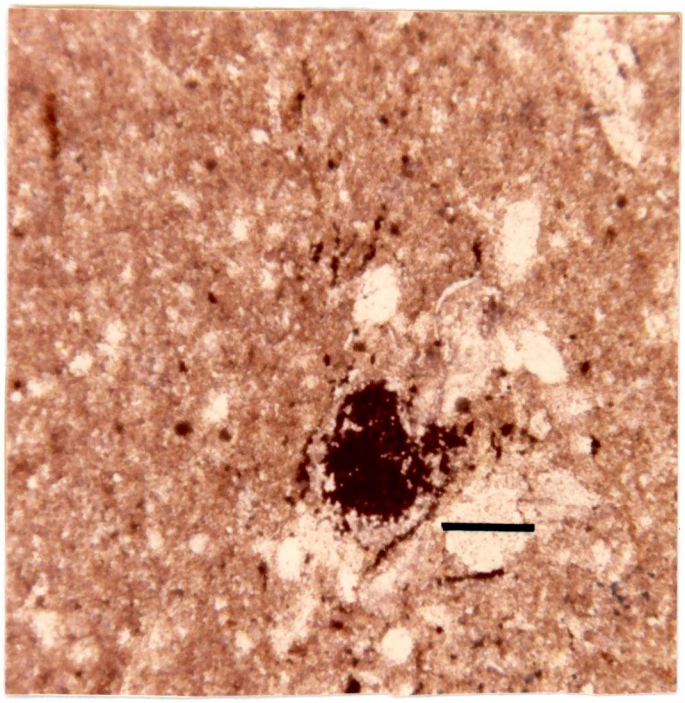


FIGURE 29. Photomicrograph of a horizontal burrow, filled with black fecal pellets in calcareous shale lithology. Bar scale is 0.2 mm long.

biosparite sequences and are transitional into the interlaminated shale and sandy biosparite lithology (Figure 30). Although thin interbeds of shale are found associated with the coarser, more quartzose lithologies, they are the more dominant lithic type higher in the section as the Chapman Ridge grades into the overlying Ottosee Shale.

Environmental Interpretations

These relatively sand-free, calcareous shales are interpreted as lagoonal deposits which vertically are transitional into tidal delta, and barrier island sequences. As Rhoads (1967) has shown, burrowers in relatively constant, subtidal environments move laterally through the sediment, feeding on its organic content and producing horizontal burrows. The paucity of allochemical components of these rocks suggests a restricted environment. These monotonous, thinly laminated shales exhibit little evidence that currents were operative in this setting.

## IX. CALCAREOUS MUDSTONE

Lithologic Description

The limonite-stained, calcareous mudstones are poorly sorted and heterogeneous in their allochemical composition (Figures 31, 32 and 33). Rounded Girvanella lumps 2 to 10 cm in diameter are common in some units though absent in others. All samples of mudstone contain minor amounts of bored pelmatozoan and bryozoan which together average about 8 percent of the total lithic type. Rounded, pebble size clasts of terrigenous mud are also found in all samples, though they generally



FIGURE 30. Outcrop photograph of folded calcareous shales. These shales overlie beds of biosparite lithology (B) which can be seen at lower left. Ruler is 0.7 m long, and up direction is shown by arrow.

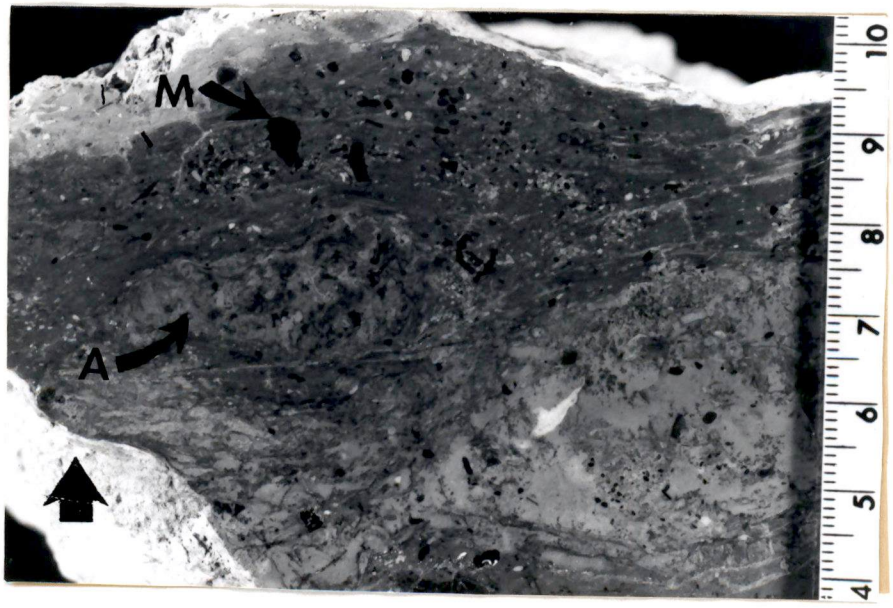



FIGURE 31. Hand sample photograph of clasts of mud (M) and algae (A) which are included in calcareous mudstone lithology. Scale is in cm. Bold arrow points up direction.

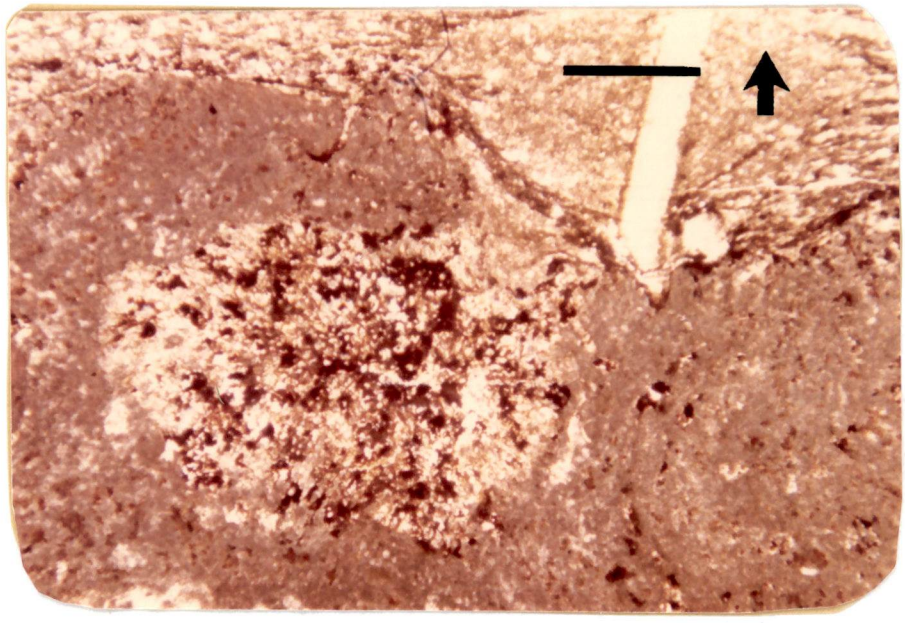


FIGURE 32. Photomicrograph of algal clast and surrounding mudstone matrix. Bar scale is 0.5 mm long, and up direction is indicated by arrow.

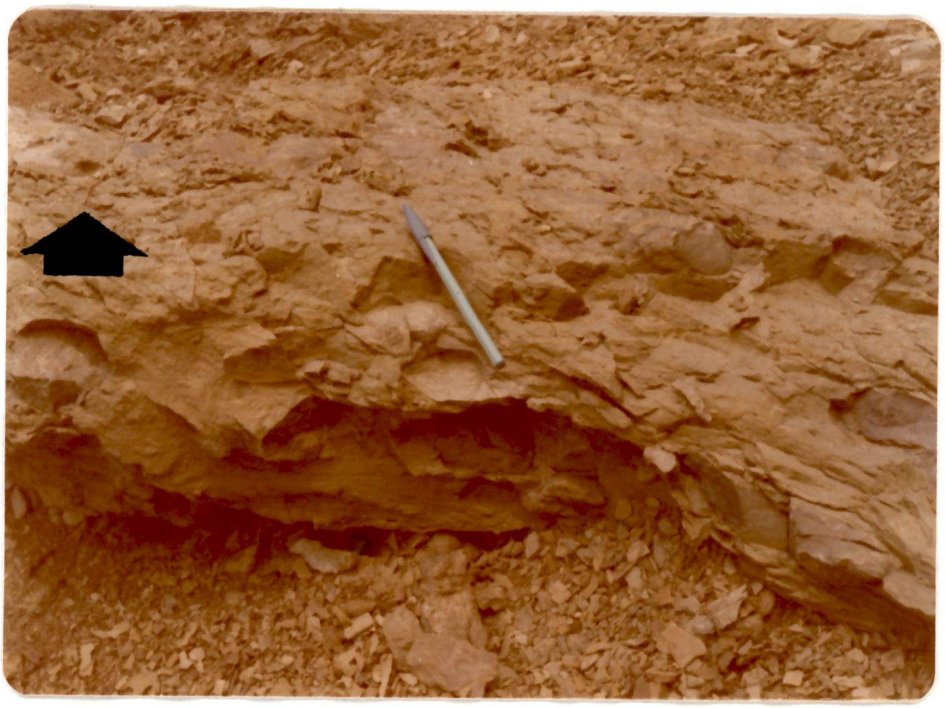


FIGURE 33. Outcrop photograph of calcareous mudstones showing numerous, rounded clasts of algal origin. Pen is 15.2 cm long, and arrow at left points up.

do not exceed 5 percent. These units further contain whole, orthocone cephalopods and silt size, quartz grains, but neither component totals more than 3 percent of the lithology.

The calcareous mudstones are generally thin-bedded but lack any internal stratification. Within these units the coarser mud clasts are not confined to specific bedding horizons, and indeed many have their long axes oriented vertically. These sequences are interbedded with biomicrite units in the lowermost portions of the Chapman Ridge Sandstone. Many of the biomicrite samples contain discontinuous, thin clay laminae which appear identical to the finer mud units of these calcareous mudstones.

Environmental Interpretations

The writer suggests that the calcareous mudstones represent washover or storm deposits which accumulated in the carbonate lagoonal sequences. The heterogenous character and lack of sorting in these rocks is an indication of very rapid deposition. Abraded fossils were probably derived from an adjacent carbonate bank and transported in along with these muds. The clasts of Girvanella may represent lagoonal fauna that became dislodged from the sediment surface and incorporated into the storm deposits.

## X. INTERBEDDED CALCAREOUS SHALE AND SANDY BIOSPARITE

Lithologic Description

This lithology is quite variable in allochemical composition and in the sedimentary and biogenic structures which it exhibits. In

some samples shale is the predominant lithology with abundant thin lenses and laminae of very fine grained, sandy biosparite. Other examples show the sandy biosparites as the major lithic type with numerous thin interbeds of shale. In all cases, however, units are very thinly bedded. Most samples are heavily burrowed (vertically and/or horizontally), occasionally to the extent that a mottled lithology results (Figures 34 and 35).

The more shaly units of these sequences are marked by the presence of thin, horizontal laminae of sandy biosparite with occasional 2 to 20 cm thick lenses of more fossiliferous sandy biosparites. Cut and fill structures are common here. These units contain vertical burrows, but fossil debris is generally lacking. A few of these samples include dolomite rhombs. Many of the shale bedding surfaces exhibit mud cracks (Walker and Ferrigno, 1973).

Those predominantly coarse grained units of the interlaminated shales and sandy biosparite lithology are characterized by flasure, lensoid, and rippled bedding structures. A general absence of fauna is associated with these units; yet most samples are horizontally burrowed.

Sequences of this lithology grade vertically into the relatively sand-free calcareous shales and the sandy biosparites. These transitions are generally very subtle and difficult to detect in outcrop.

## Environmental Interpretations

The interlaminated shales and sandy biosparites are considered to reflect several different, co-existing environments. First, the

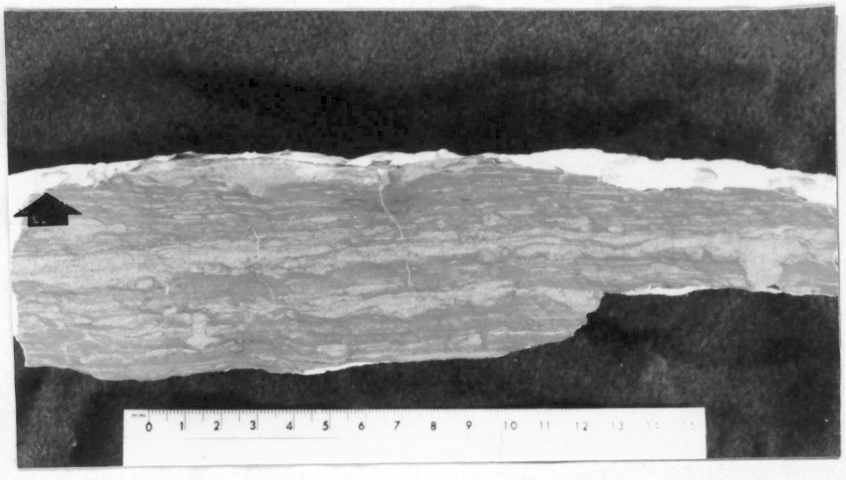


FIGURE 34. Hand sample photograph of interlaminated calcareous shale and biosparite lithology. Lensoid-bedding and vertical burrows are present. Scale is in cm, and arrow points up.

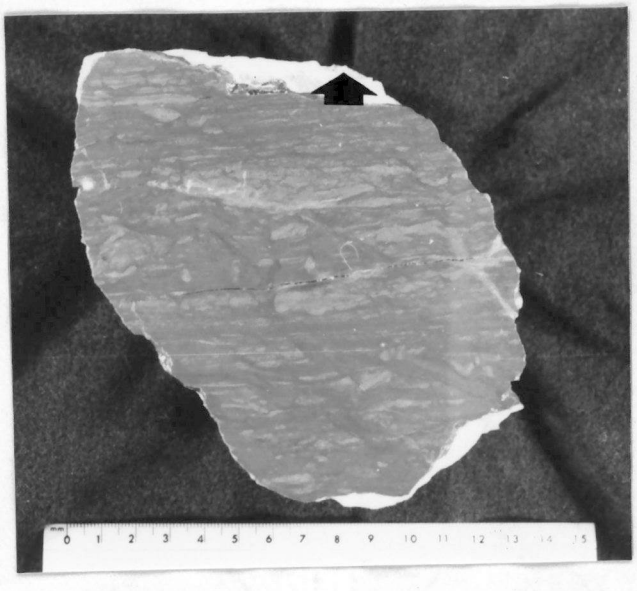


FIGURE 35. Hand sample photograph of mottled interlaminated calcareous shale and biosparite lithology. Mottling was produced by extensive burrowing. Scale is in cm, and arrow points up.

shale-poor units are thought to be indicative of shallow tidal fans or delta deposits. The lenticular bedding inherent in all of these units (Figures 36 and 37) was probably related to the alternation of tidal currents and slack water at high or low tide (Reineck and Wunderlich, 1968). Sand ripples were developed during tidal movement (flood or ebb) and muds accumulated during tidal inactivity. The lack of fossils here was probably due to frequently shifting sediments (Purdy, 1964). The numerous horizontal burrows in the rocks are perhaps a reflection of subtidal conditions (discussed in section VIII of this chapter).

Secondly, the sand-poor sequences of this lithology are interpreted to represent tidal flat deposits. The thin, horizontal laminae in these rocks probably have recorded successive flooding by unusually high tides (either storm or spring tides). Further documentation for this inference is provided by the abundant vertical burrows which Rhoads (1967) suggested as being indicative of high intertidal or supratidal conditions. The dolomite rhombs found in these units could reflect early dolomite formation which Murray and Pray (1965) related to conditions on supratidal flats. Also, the mud cracked shales here suggest a period of subaerial exposure. The few scattered skeletal remains noted earlier could have been washed onto these flats during excessively high tides. Finally, the presence of cut and fill structures containing sandy biosparite units (Figures 38, 39, and 40) are interpreted to be small intertidal creeks or gullies within the flat, similar to those described on the Wadden Sea flats by Van Stratten (1957).

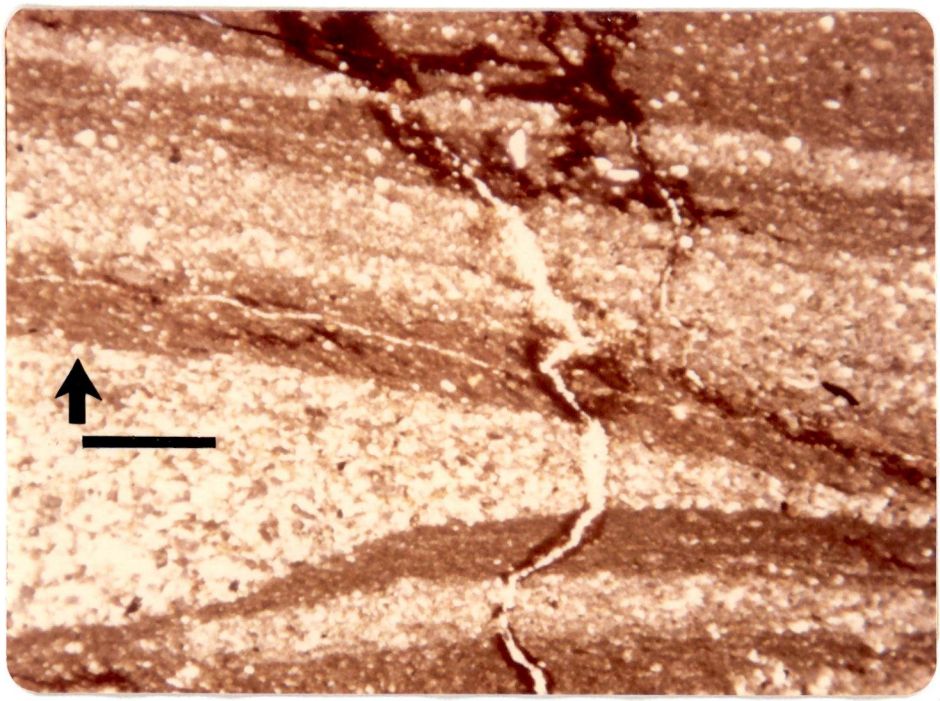


FIGURE 36. Photomicrograph of lensoid-bedding in inferred tidal delta deposits. Bar scale is 0.5 mm long, and arrow points up.

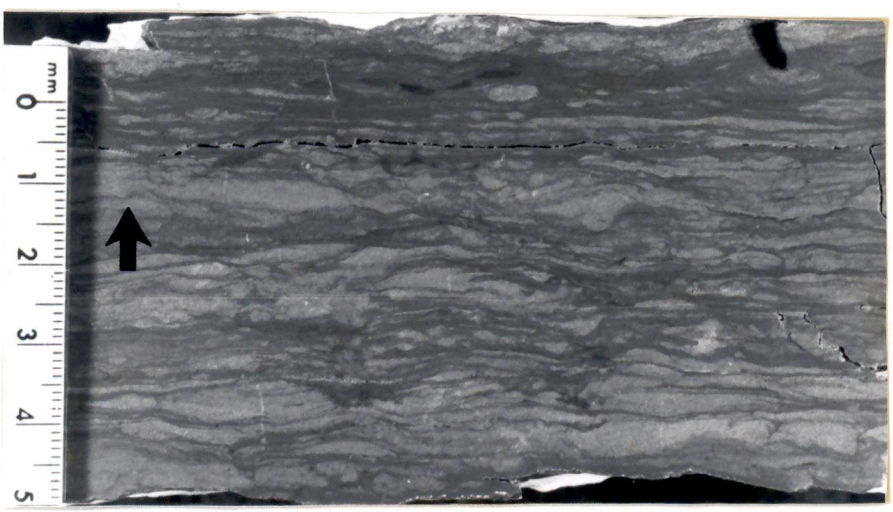



FIGURE 37. Hand sample photograph of flasure-bedded, tidal delta deposits. Scale in cm. Arrow indicates up direction.

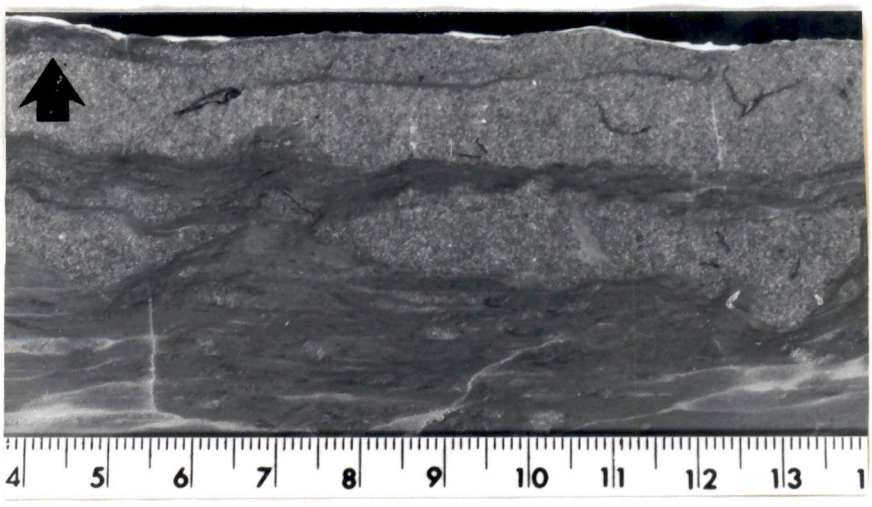



FIGURE 38. Hand sample photograph showing tidal channel or gully deposits cutting through adjacent finer grained units. Notice trilobite carapaces in these channels. Scale in cm; up arrow is shown.

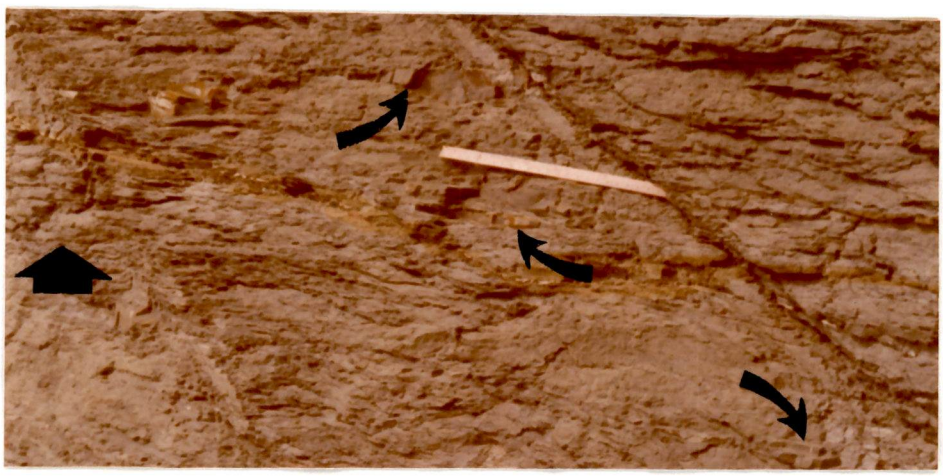


FIGURE 39. Outcrop photograph of tidal channel deposits (arrows) and surrounding tidal flat sediments. Ruler is 0.7 m long. Bold arrow at left shows up direction.

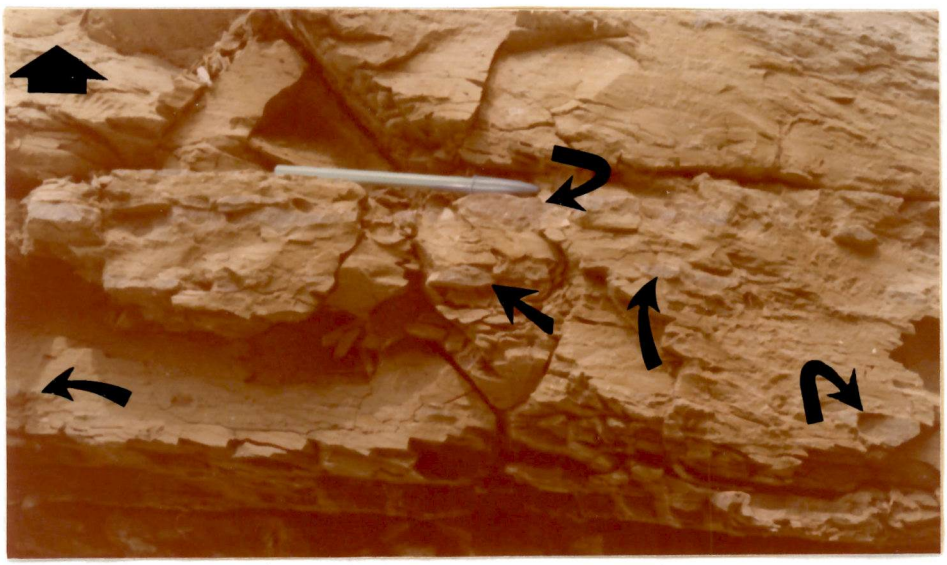


FIGURE 40. Outcrop photograph of small, discontinuous, tidal gully sands in tidal flat deposits. Pencil is 15.2 cm long and arrow at upper left points up.

# XI. HEMATITE-COATED GRAINS

Although a detailed analysis of the occurrence and origin of the numerous hematite-coated grains in the Chapman Ridge sands would constitute a study by itself, certain observations can be made from this work. Coatings of hematite rim various grains in these rocks and fill pores and openings within fossils (Figures 41 and 42). Iron is also noted between laminae in many of the ooids. Boundaries between these grains and the surrounding hematite appear very sharp. Although stylolites contain the greatest concentrations of this iron, the thickest grain coatings are found on those fossils which have been extensively bored by algae.

Surrounding most pelmatozoan grains in Chapman Ridge sands are syntaxial overgrowths of sparry calcite (Figure 43). From studies of modern reefs it has been shown that the growth of this spar occurs very early following deposition (Bathurst, 1971, p. 326). Along grain boundaries which mark the growth of this intergranular spar into voids, this hematite is absent (Figure 44). These observations indicate that the hematite was deposited prior to the development of the syntaxial overgrowths. There does not appear to be any evidence to indicate a late diagenetic origin (excluding iron found along stylolites) for this hematite.

Numerous studies have been conducted on the origin of iron-rich sedimentary rocks (see Garrels and Christ, 1965; and James, 1966, for experimental work); however, questions still remain particularly in the areas of mode of iron transportation and precipitation. The

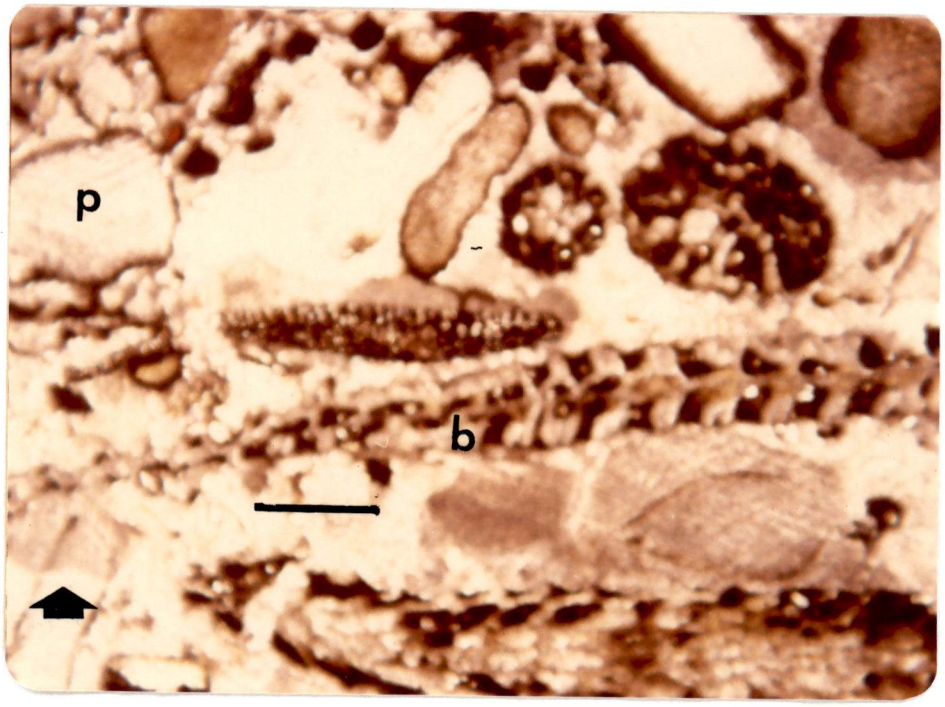



FIGURE 41. Photomicrograph of hematite-coated grains of ramose bryozoan (B) and pelmatozoan (P) in biosparite lithology. Bar scale is 0.5 mm long. Hematite appears black. Up arrow is at lower left.

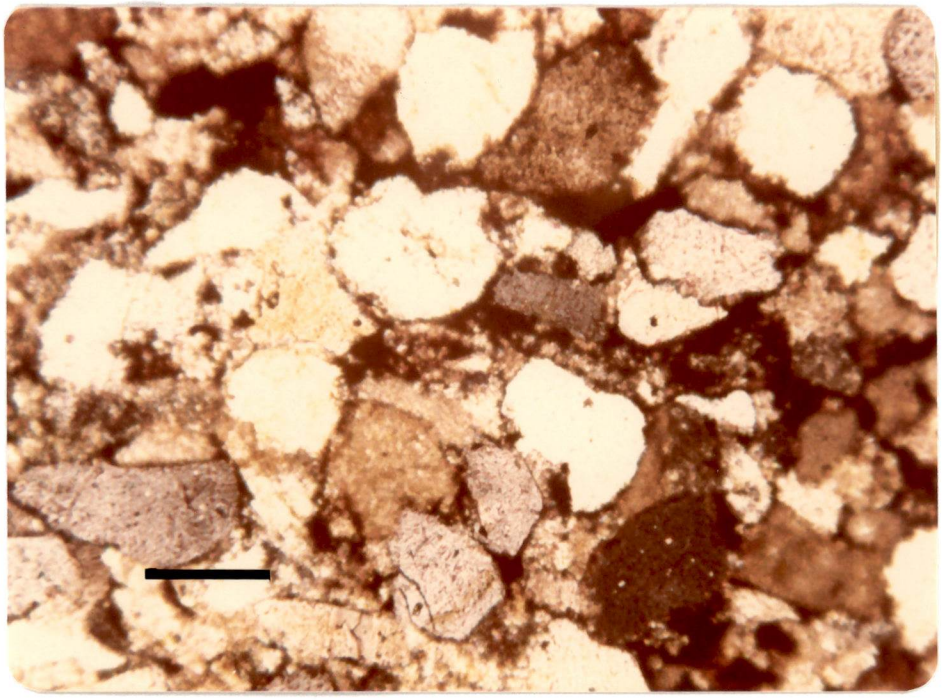


FIGURE 42. Photomicrograph of hematite-coated quartz grains in calcareous sandstone. Bar scale is 0.2 mm long. Stratigraphic up-direction is toward top of photograph.

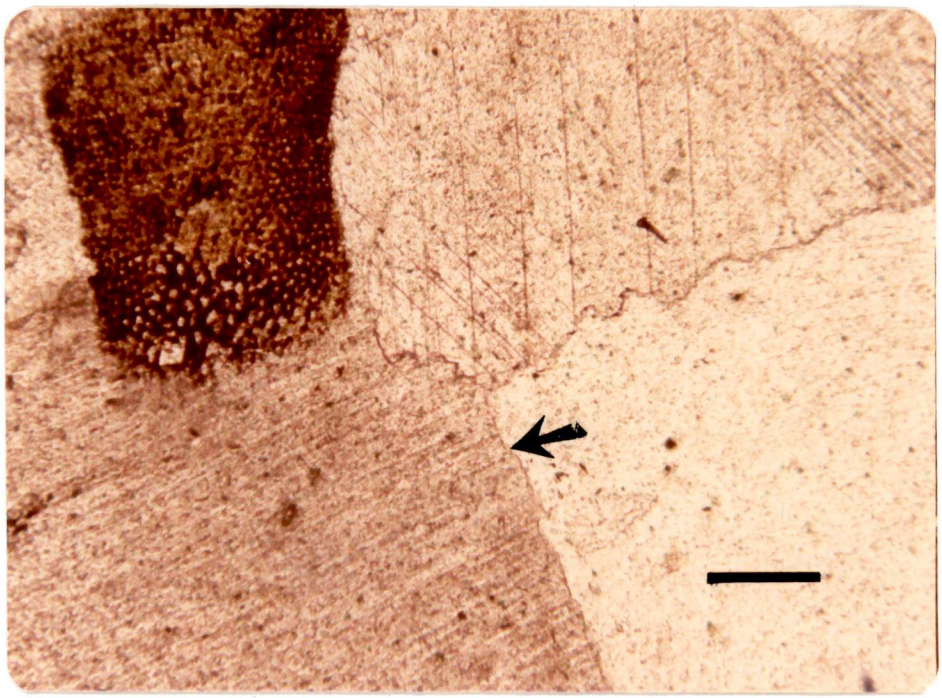


FIGURE 43. Photomicrograph of syntaxial overgrowth of iron-coated, algally-bored, pelmatozoan grain. Bar scale is 0.2 mm long.

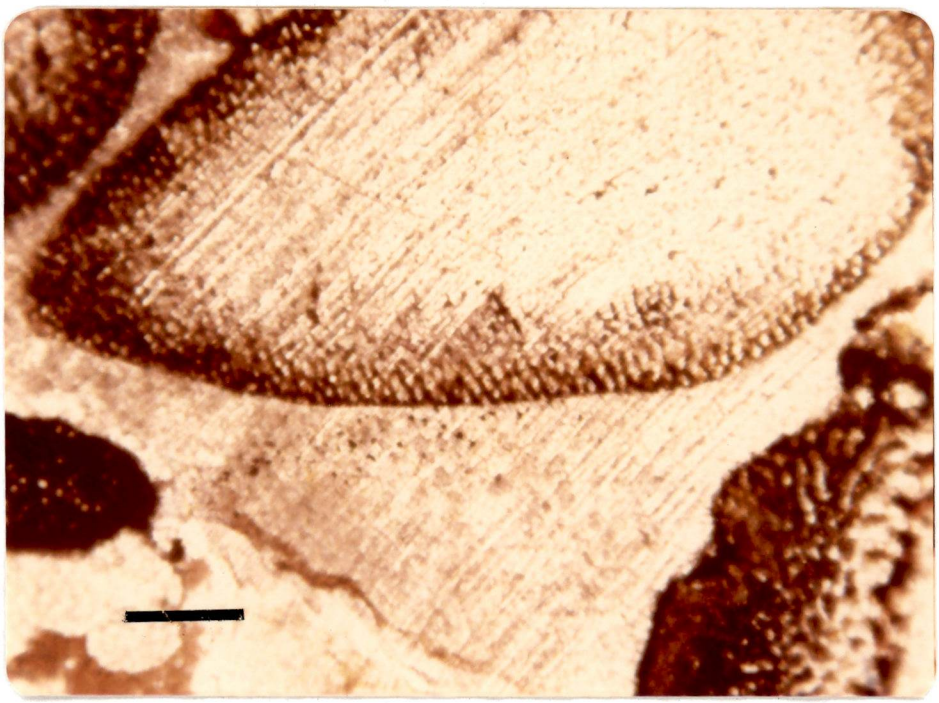


FIGURE 44. Photomicrograph of syntaxial overgrowths of pelmatozoan grains. Note the absence of iron along this grain boundary (denoted by arrow). Bar scale is 0.2 mm long.

writer has reviewed many of these works with the hope that previous findings might suggest an environment in which this Chapman Ridge hematite could have formed. Most studies on this subject conclude that the iron is deposited in the form of glauconite, chamosite, or siderite in shallow, restricted basins where reducing conditions exist (Sheldon, 1970; Hunter, 1970; and Castano and Garrels, 1950). Sheldon (1964) interpreted the Silurian iron ores in the Birmingham, Alabama, vicinity as having formed on the lagoonward side of a barrier island system. These Silurian lagoonal deposits consist of chamosite muds which grade islandward into an inferred oxidizing zone near the island shore where hematite was formed by the oxidation of chamosite. Bioclastic debris was washed lagoonward across the islands during storms into this facies where it was coated with hematite. The iron was derived from streams which emptied directly into lagoons and precipitated in these restricted, reducing environments. Hunter (1970) suggested a similar origin for the Clinton ores of the Central Appalachian Basin.

The writer does not believe these explanations apply to the hematite in the Chapman Ridge sands for several reasons. First, there is no evidence to suggest that there were nearby streams debouching iron-rich sediments into this area; on the contrary, the hematite is found in well sorted, mature sandstones and calcarenites and is virtually absent in the intervening shales. Also the lack of the less stable terrigenous grains (i.e., feldspars and lithic fragments) in these rocks probably is due to considerable transportation and accompanying winnowing of the sediments. Therefore, it is felt that no firm conclusion can be reached on the origin of this hematite from this study.

However, due to (1) the occurrence of iron between laminae in ooids and as sharp coatings of allochems and (2) the absence of iron along grain boundaries which mark intergranular growth of spar into voids, it is thought that this iron was deposited contemporaneously with or shortly following the accumulation of Chapman Ridge sediments.

# CHAPTER III

## STRATIGRAPHY OF DEPOSITIONAL ENVIRONMENTS

### I. GENERAL SETTING

Prior to Chapman Ridge time, this area of east Tennessee during the Middle Ordovician had been the site for the accumulation of shallow-water carbonate sediments. Walker (1974) has proposed an environmental array to explain the distribution of these deposits (Figures 45, 46, and 47). His model consists of a shalf edge reef tract which was bordered on the southeast by a deeper-water, shale basin. The quiet, shallow waters of the back reef area provided a setting in which carbonate and, to a lesser degree, terrigenous muds accumulated. These environmental conditions are now reflected in the rocks of the Holston Limestone (reef), the Sevier Shale (basin), and the Lenoir Formation (lagoon). Most workers have assumed that the Chapman Ridge sediments were derived from source rocks to the southeast of the area (now covered by the Blue Ridge and Piedmont provinces), and that this influx smothered and eventually destroyed the Holston reef complex. Although Ferrigno and Walker (1973) suggested a shallow water origin for these sands, little work has been done on the facies relationships between the Chapman Ridge and the underlying Holston Formation.

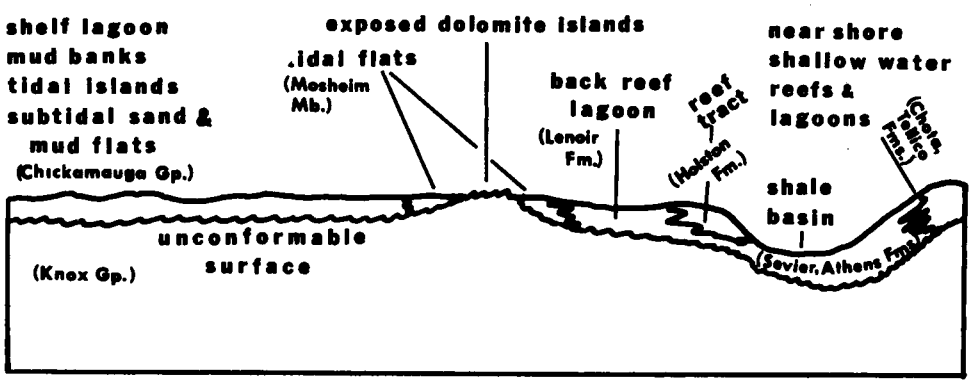



FIGURE 45. Cross sectional diagram of Middle Ordovician environments of east Tennessee, prior to Chapman Ridge time.

SOURCE: K. R. Walker. 1974. Community patterns: Middle Ordovician of Tennessee, Chapter 9 of Principles of benthic community analysis (notes for a short course) by Zeigler, A. M., and others. Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmosphere Science, University of Miami, p. 9.1-9.9.

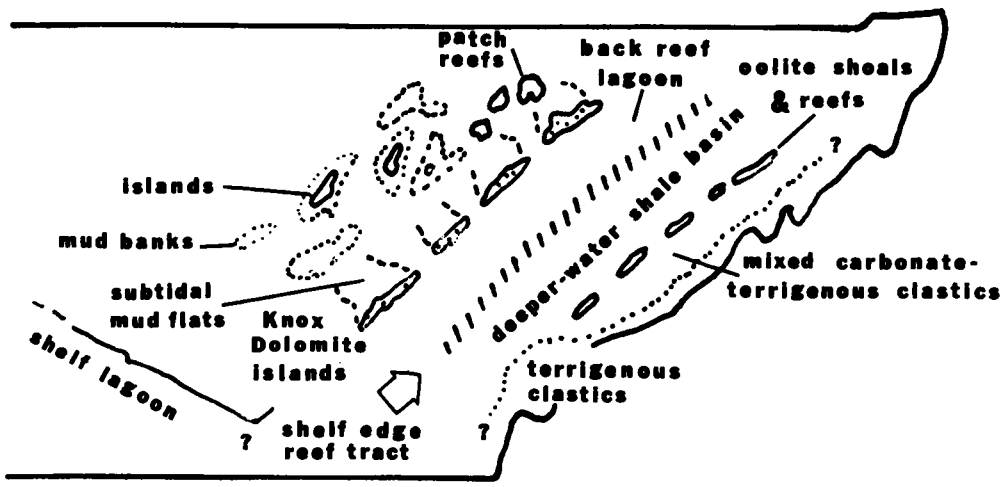



FIGURE 46. Map view of regional environmental pattern during a part of the Middle Ordovician in east Tennessee.

SOURCE: K. R. Walker. 1974. Community patterns: Middle Ordovician of Tennessee, Chapter 9 of Principles of benthic community analysis (notes for a short course) by Zeigler, A. M., and others. Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmosphere Science, University of Miami, p. 9.1-9.9.

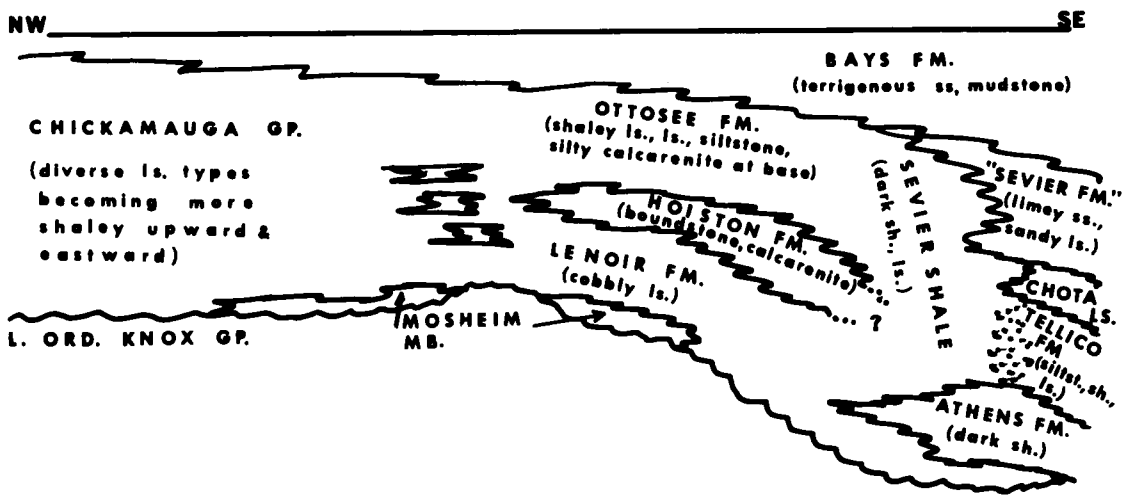



FIGURE 47. Complex facies pattern in the Middle Ordovician rocks of Tennessee. Chapman Ridge is included in Ottosee Fm.

SOURCE: K. R. Walker. 1974. Community patterns: Middle Ordovician of Tennessee, Chapter 9 of Principles of benthic community analysis (notes for a short course) by Zeigler, A. M., and others. Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmosphere Science, University of Miami, p. 9.1-9.9.

## II. DISCONFORMITY (?) AT TOP OF HOLSTON LIMESTONE

As mentioned in Chapter I several early workers suggested that the Chapman Ridge Sandstone disconformably overlies the Holston Limestone. Their reasoning was based primarily on the sharpness and undulating nature of this contact. Nevertheless, Rodgers (1953) and other recent workers have rejected this hypothesis under the assumptions that (1) the contact marked a facies boundary and (2) the contrasting field appearances of the two formations were caused by slightly different weathering characteristics (a product of a gradual increase in detrital quartz in the limestones). Perhaps the strongest case for a conformable contact can be seen at the Deane Quarry in southwestern Knox County where Ferrigno (1973) found Holston reef core masses projecting into and laterally contiguous with Chapman Ridge sands, clearly proving the contemporaneity of the two. The writer has visited this locality and finds no disagreement with Ferrigno's conclusions.

However, at each of the four section localities described in this report (Figure 2, page 4) the contact is sharp, exhibits up to 0.6 meter of relief, and is not characterized by the presence of laterally equivalent reef core masses with flanking Chapman Ridge sands (Figures 48 and 49). Also, the writer, in sampling across the contact, did not discover a general admixture of quartz to Holston sediments as Rodgers (1953) proposed. Instead, the upper part of the Holston is virtually quartz-free, in contrast to the higher quartz percentages in the Chapman Ridge sands. Furthermore, there is no gradual increase in terrigenous grain percentages higher in the Chapman Ridge Sandstone.



FIGURE 48. Contact of Holston Limestone and Chapman Ridge Sandstone at Locality B. Ruler is 0.7 m long and its lower end is at the contact.



FIGURE 49. Contact of Holston Limestone and Chapman Ridge Sandstone at Locality A. Contact marked by red paint line. Pen is 12.7 cm long.

If virtually continuous deposition occurred across this contact and the sharp, undulating nature of the boundary is a result of local scour and fill sedimentation, one would expect to find lithologic evidence of these contemporaneous facies (i.e., Holston rock types in Chapman Ridge sediments and vice versa). But the findings of this report provide no such evidence. In addition, the lowest Chapman Ridge units in contact with the Holston are typically biomicrites. The underlying scoured surface in the Holston was probably not formed as these muds were deposited. A more reasonable hypothesis is that the top of the Holston was subjected to subaerial exposure which allowed erosion of its surface, and later, following resubmergence, the Chapman Ridge muds accumulated.

Thus, there seems to be valid evidence both for and against an unconformity existing on top of the Holston Limestone. In studying the units immediately above this contact, the writer paid particular attention to the presence of hematite at this interval (page 39), thinking that this mineral might be related to an extended period of subaerial exposure. But similar-looking lithologies are present at the contact in Deane Quarry where relatively continuous deposition appears certain. Therefore, the writer concludes that the end of Holston deposition in this area was probably marked by a discontinuous, uneven, subaerial exposure for a relatively short time. This uneven disconformity may have been produced because throughout Holston deposition there existed considerable relief on reef core masses (Ferrigno, 1973), and a slight lowering of sea level would have exposed the higher reef structures while keeping the intervening areas submerged.

## III. STAGE I: CARBONATE BANK-LAGOON

A combination of partial subaerial exposure and increased terrigenous influx effectively destroyed the Holston reefs. Presumably, the first set of environments to become established in this area following complete resubmergence was a carbonate bank sequence in the shallow subtidal waters which covered the formerly active reef complex (Stage 1 of Figure 50). There is evidence to suggest that, basinward of this bank, narrow oolite shoals may have existed as these bank deposits contain interbeds of and locally grade vertically into oosparites. The edge of this carbonate platform, adjacent to a shale basin which existed to the southeast (Walker, 1974), would have provided a suitable setting for ooids to have formed (Purdy, 1961). Occasional storms and high tides transported finer grained, terrigenous sediments from the basin across this bank into an inferred lagoon. Lagoonal muds which include interbeds of storm debris also contain fossil fragments from the bank that could have been supplied regularly through tidal channels.

## IV. STAGE II: LAGOON-BARRIER ISLAND COMPLEX

Overlying the predominantly carbonate units of the lower Chapman Ridge are sequences of calcareous shales and interbedded sandy biosparites and shales. It is thought by Walker (1974) that an increased sediment supply from the southeast filled the shale basin which had previously acted as a catchment area in preventing terrigenous sediments from reaching this area during the Middle Ordovician

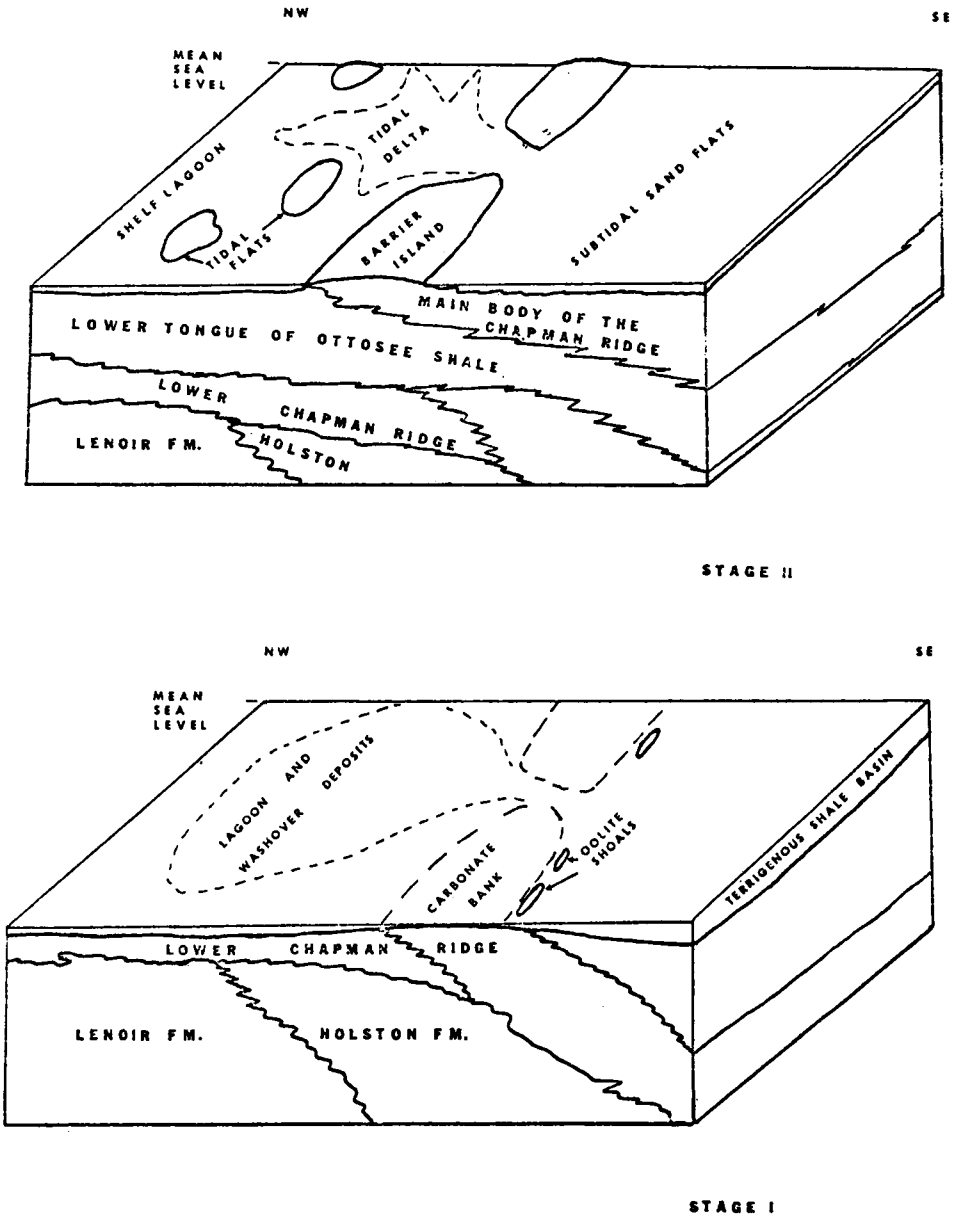



FIGURE 50. Proposed depositional models for the Chapman Ridge Sandstone.

(Figure 45, page 68). As the distal products of this sediment influx first covered this region, the lower, finer-grained units (mapped as the lower tongue of the Ottosee Shale by Cattermole, 1955, because of their resemblance to the shales of the overlying Ottosee Formation) were deposited as interbedded tidal flat, tidal delta, and lagoonal deposits (Figure 51). By this time the predominant skeletal fraction accumulating in these sediments consisted of (1) reworked fossil debris from the earlier bank environment and (2) orthocone cephalopods and graptolites which floated into lagoons.

More shaly units grade vertically into the coarser, calcareous quartz sandstones and sandy biosparites which represent the main body of the Chapman Ridge (Stage 2 of Figure 50). These deposits, interpreted as barrier island-sand flat sequences, contain occasional interbeds of tidal delta and tidal flat units, as facies boundaries fluctuated back and forth.

## V. SOURCE AREA FOR CHAPMAN RIDGE SEDIMENTS

This treatment of the environmental stratigraphy of Chapman Ridge deposition is in general accord with Walker's model of the Middle Ordovician of east Tennessee. However, the subject of a source area for these terrigenous sediments remains a lingering problem. Although the scope of this paper does not include a regional, stratigraphic study of the Chapman Ridge Sandstone, certain observations on source area have arisen from this work and seem pertinent to it. As referred to in Chapter I, most workers have assumed a source area to the southeast of the present outcrop belts for these as well as other Ordovician

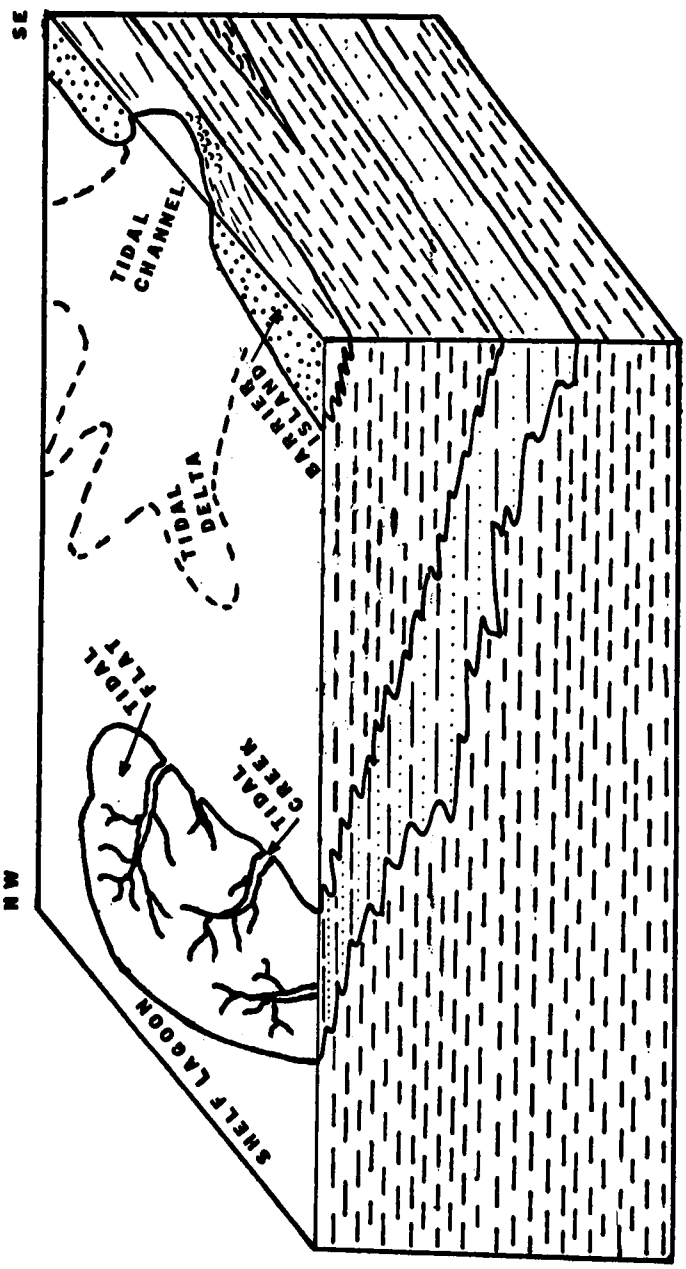



FIGURE 51. Barrier island-lagoon-tidal flat model of Stage II during Chapman Ridge deposition.

clastic sediments of east Tennessee. If one accepts a peleogeographic model similar to Walker's for this area (Figure 46, page 68), there are four potential source directions from which these sediments could have been derived: northwest, northeast, southeast, and southwest. A northwestwardly direction is discarded as this area was the site of carbonate deposition throughout the Middle Ordovician, and also because, as Cattermole (1956) has observed, the Chapman Ridge thins and pinches out in the Ottosee Shale northwest of the Saltville fault. To the northeast, it also thins and feathers out in the Ottosee in the Jefferson-Hamblen County area (Swingle et al., 1967). To the southeast of the Dumplin Valley fault, the Chapman Ridge is not mapped; however, Cattermole (1956) and Neuman (1955) suggested that this formation is equivalent to the predominantly carbonate Chota Formation (sandstone lentil of Keith, 1895) in Monroe County and to the Sevier shales of Blount and Sevier counties. Thus, two major questions arise in assuming a southeastern source for these rocks: Where are the nearshore, coarser sediments and how does one account for the Chapman Ridge sands grading into finer-grained, equivalent rocks (Figure 47, page 69) closer to the presumed source area?

The southwestern extent of the Chapman Ridge Sandstone is uncertain because these units are missing by erosion in the extreme southeastern part of the state (Figure 1, page 3); Rodgers (1953) has mapped the "Chapman Ridge" (referred to as Tellico and included with the Holston ) in McMinn County, and Smith (personal communication) has found it to be approximately 60 meters thick in northeastern Bradley County. However, several students (Miller, 1953; and Moehl, 1965)

discovered in mapping the Knoxville-Friendsville strike belt in Loudon County that the Chapman Ridge sands here vary between 150 and 180 meters thick and contain conglomeratic beds of chert, limestone, quartz, shale, and slate pebbles. Certainly, detailed field work would be required before any generalizations could be made on the peleogeographic significance of these coarser units; however, the writer suggests that these rocks may possibly represent a nearer-to-the-source depositional sequence for Chapman Ridge sands which were then transported via longshore drift into the Knoxville area in the form of a barrier island complex.

# CHAPTER IV

## SUMMARY AND CONCLUSIONS

The Chapman Ridge Formation in the study area records the first major influx of clastic sediments during the Ordovician. Although small, local patch reefs and carbonate build-ups are known to have existed during and after this episode, the Chapman Ridge sands effectively prevented the re-establishment of the formerly prolific Holston reef. There is evidence to suggest that a combination of the lowering of sea level and an increased supply of terrigenous grains to this area during early Chapman Ridge time destroyed this shelf edge reef complex. Following resubmergence and prior to inundation by terrigenous silts and sands, a carbonate shoal-bank-lagoon complex of short duration was established over this area. An inferred deeper water shale basin which lay to the southeast of this area had been continually filling up with sediments during Holston and early Chapman Ridge time (Walker, 1974). As this basin became filled, terrigenous silts and clays were transported northwestward across the former catchment basin and into the area covered by this report. These fine grained sequences "drowned" the early carbonate bank complex and allowed for the development of tidal mud flats and lagoons. Later, to the southwest of the study area, coarser, terrigenous sediments were brought in from the southeast and transported northeastward by longshore drift into the study area. These quartzose sands were deposited as subtidal sand flats and barrier islands which eventually replaced the lagoonal-tidal flat complexes.

Several intriguing areas of further work have been uncovered by this study. Although only touched on in this report, there is evidence which suggests that Chapman Ridge sands in this vicinity cannot be directly traced to a southeasterly source. Detailed mapping, both southeast and southwest of this area, is needed to support or disclaim this hypothesis. Also, further study into the significance of lower Chapman Ridge oncolites and "quiet water" ooids appears warranted; the writer has observed similar and larger occurrences of them at the same stratigraphic level in Bradley County. The origin of hematite in these sandstones is also an area where additional research is needed.

# BIBLIOGRAPHY

## BIBLIOGRAPHY


Ball, R. 1967. Carbonate sand bodies of Florida and the Bahamas. Jour. of Sed. Pet., v. 37, p. 556-591.

Bathurst, R. 1967. Oolitic films on low energy carbonate sand grains, Bimini Lagoon, Bahamas. Marine Geol., v. 5, p. 89-109.

_____. 1971. Carbonate sediments and their diagenesis. Elsevier Publishing Co., New York, 620 p.

Blatt, H., Middleton, G., and Murray, R. 1972. Origin of sedimentary rocks. Prentice-Hall, Inc., 634 p.

Bridge, J. 1945. Geologic map and structure sections of the Mascot-Jefferson City zinc district. Tenn. Div. of Geol. Bulletin.

Burchard, E. F. 1913. The red iron ores of east Tennessee. Tenn. Geol. Survey Bull. 16, 173 p.

Castano, J. R., and Garrels, C. L. 1950. Experiments on the deposition of iron with special reference to the Clinton deposits. Econ. Geol., v. 45, p. 755-770.

Cattermole, J. M. 1955. Geology of the Shooks Gap quadrangle, Tennessee. U. S. G. S. Quad Map GQ 76.

_____. 1958. Geologic map of the Knoxville quadrangle, Tennessee. U. S. G. S. Quad Map GQ 115.

_____. 1960. Geologic map of the Bearden quadrangle, Tennessee. U. S. G. S. Quad Map GQ 126.

_____. 1962. Geology of the Maryville quadrangle. U. S. G. S. Quad Map GQ 163.

_____. 1966. Geologic map of the John Sevier quadrangle, Tennessee. U. S. G. S. Quad Map GQ 514.

Chayes, F. 1954. The theory of thin-section analysis. Jour. of Geol., v. 62, p. 92-101.

Ferrigno, K. F. 1973. Paleoecology of the reef of the Holston Formation. Unpublished Doctoral dissertation, The University of Tennessee, 143 p.

Folk, R. L. 1959. Practical classification of limestones. Amer. Asso. of Petro. Geol. Bull., v. 43, p. 1-30.

Folk, R. L., and Robles, R. 1964. Carbonate sands of Isla Perez, Alacran reef complex, Yucatan. Jour. Geol., v. 72, p. 255-292.

Freeman, T. 1962. Quiet water oolites from Laguna Madre, Texas. Jour. of Sed. Pet., v. 32, p. 475-483.

Friedman, G. M. 1959. Identification of carbonate minerals by staining methods. Jour. of Sed. Pet., v. 29, p. 87-97.

Garrels, R. M., and Christ, C. L. 1965. Solutions, minerals, and equilibria. Harper and Row, New York, 445 p.

Geblein, C. 1969. Distribution, morphology, and accretion rate of subtidal algal stromatolites, Bermuda. Jour. of Sed. Pet., v. 39, p. 49-69.

Gibbs, C. 1965. The geology of the northeast portion of the Louisville Quadrangle, Knox and Blount Counties, Tennessee. Unpublished Master's thesis, The University of Tennessee, 58 p.

Ginsburg, R. N. 1960. Ancient analogues of recent stromatolites. 21st Internat. Geol. Cong., Copenhagen, pt. 2, p. 26-35.

Goddard, E. N., et al. 1963. Rock Color Chart. U. S. G. S.

Gordon, C. H. 1924. Marble deposits of East Tennessee; occurrence and distribution. State of Tenn., Dept. of Conserv., Div. of Geol., Bull. 28, pt. I, p. 1-86.

Hessland, I. 1949. Lower Ordovician penetrative and enveloping algae from the Siljan district. Upsala Universitet Mineralogisk-Geologiska Institut Bull., v. 32, p. 409-428.

_____. 1949. Lithogenesis and changes of level in the Siljan district during a period of the Lower Ordovician. Upsala Universitet Mineralogisk-Geologiska Institut Bull., v. 33, p. 439-509.

Hunter, R. E. 1970. Facies of iron sedimentation in the Clinton Group. In Studies of Appalachian geology. Interscience, p. 101-102.

Ingram, R. L. 1954. Terminology for the thickness of stratification and parting units in sedimentary rocks. Geol. Soc. of Amer. Bull., v. 65, p. 937-938.

James, H. L. 1954. Sedimentary facies of iron formation. Econ. Geol., v. 49, p. 235-293.

Keith, A. 1895. Knoxville Folio. U. S. G. S. Atlas, No. 16.

Knox, R. W. O'B. 1970. Chamosite ooliths from the Winter Gill ironstone (Jurassic) of Yorkshire, England. Jour. of Sed. Pet., v. 40, p. 1216-1225.

LaFollette, S. 1974. Paleoenvironmental and paleoecological analysis of the Vestal Limestone in Knox County, Tennessee. Unpublished Master's thesis, The University of Tennessee, 143 p.

Laporte, L. F. 1967. Carbonate deposition near mean sea-level and resultant facies mosaic. Manlius Formation, Lower Devonian of New York State. Amer. Asso. of Petro. Geol. Bull., v. 51, p. 73-102.

LeRoux, G. B. 1974. Sedimentological and environmental interpretation of the Chota-Sevier formations in easternmost Tennessee. Unpublished Master's thesis, The University of Tennessee, 106 p.

Matthews, R. K. 1966. Genesis of recent lime and mud in southern British Honduras. Jour. of Sed. Pet., v. 36, p. 428-454.

McKee, E. D. 1964. Inorganic sedimentary structures. In Approaches to Paleoecology (Imbrie, J., and Newell, N., Eds.). John Wiley and Sons, Inc., New York, p. 275-295.

McLaughlin, R. E. 1973. Observations on the biostratigraphy and stratigraphy of Knox County, Tennessee, and vicinity. In Geology of Knox County, Tennessee. Tennessee Division of Geology, Bull. 70, p. 26-62.

Miller, G. 1953. The geology of the Middle Ordovician of the Knoxville belt, Concord Quadrangle, Loudon County, Tennessee. Unpublished Master's thesis, The University of Tennessee, 42 p.

Moehl, W. R. 1965. A study of the Lenoir Formation in the Knoxville-Friendsville belt. Unpublished Master's thesis, The University of Tennessee, 68 p.

Murray, R. C., and Pray, L. C. 1965. Dolomitization and limestone diagenesis--an introduction. In Dolomitization and Limestone Diagenesis: A Symposium. Soc. of Econ. Paleo. and Mineral, Spec. Pub. No. 13, p. 1-2.

Neuman, R. B. 1955. Middle Ordovician rocks of the Tellico-Sevier belt, eastern Tennessee. U. S. G. S. Prof. Paper 274 F, p. 141-178.

Purdy, E. 1961. Bahamian oolite shoals. In Geometry of Sandstone Bodies. Amer. Asso. of Petro. Geol., p. 53-62.

Purdy, E. G. 1964. Sediments as substrates. In Approaches to Paleoecology (Imbrie, J., and Newell, N., Eds.). John Wiley and Sons, Inc., New York, p. 238-271.

Reineck, H., and Wunderlich, F. 1968. Classification and origin of flasure and lenticular bedding. Sedimentology, v. 11, p. 99-104.

Rhoads, D. C. 1967. Biogenic reworking of intertidal and subtidal sediments in Barnstable Harbor and Buzzards Bay, Mass. Jour. Geol., v. 75, p. 461-475.

Rodgers, J. 1952. Geology of the Athens quadrangle, Tennessee. U. S. G. S. Quad Map.

_____. 1953. Geology of the Niota quadrangle, Tennessee. U. S. G. S. Quad Map.

_____. 1953. Geologic map of east Tennessee with explanatory text. Dept. of Conserv., Div. of Geol., Nashville, 168 p.

Safford, J. M. 1869. Geology of Tennessee. State of Tennessee, Nashville, 550 p.

Sheldon, R. P. 1964. Barrier islands and lagoonal iron sedimentation in the Silurian of Alabama. Abstract. Geol. Soc. of Amer. Spec. Paper 82, p. 182.

_____. 1970. Sedimentation of iron-rich rocks of Llandovery age (Lower Silurian) in the southern Appalachian basin. Geol. Soc. of Amer. Spec. Paper 102, p. 107-112.

Stevenson, J. P. 1973. Environmental analysis of the Lenoir Limestone of southern Knox County, Tennessee. Unpublished Master's thesis, The University of Tennessee, 99 p.

Stose, G. W., and Schrader, F. C. 1923. Manganese deposits of east Tennessee. U. S. G. S. Bull. 737, 154 p.

Swingle, G. 1959. Geology, mineral resources, and ground water of the Cleveland area, Tennessee. Tenn. Div. of Geol. Bull. 61, 87 p.

_____, et al. 1967. Geologic map of the Luttrell quadrangel, Tennessee. Tenn. Div. of Geol. Quad Map GM 155 NW.

van Stratten, L. M. J. U. 1954. Sedimentology of recent tidal flat deposits and the Psammites du Condroz (Devonian). Geol. Mijnbouw, v. 16, p. 25-47.

Walker, K. R. 1974. Community patterns. Middle Ordovician of Tennessee, Chapter 9 of Principles of benthic community analysis (notes for a short course) by Zeigler, A. M., et al. Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmosphere Science, University of Miami, p. 9.1-9.9.

_____, and Albertstadt, L. P. 1973. A new facies hypothesis concerning the Middle Ordovician of the Southern Appalachians. Abstract. Geol. Soc. of Amer. Southeastern Section Meeting, p. 447-448.

Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. Jour. Geol., v. 30, p. 377-392.

# APPENDIXES

## APPENDIX A

TABLE III. Volume Percent Analysis of Samples 1-T-1 Through 1-F-4.

| Sample Number | Micrite | Noncalcareous Mud Matrix | Detrital Quartz | Pelmatozoa | Trilobites | Ramose Bryozoa | Incrusting Bryozoa | Brachiopods | Unidentified Mollusks | Cephalopods | Oncolites | Fecal Pellets | Ooids | Hematite Clasts | Hematite Cement | Metamorphic Rock Fragments | Plagioclase | Glauconite | Dolomite | Peloids | Noncalcareous Mud Clasts | Unidentifiable Fossil Fragments | Spar Cement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-T-1 | 41 | 1 | 1 | 22 | Tr | 22 | 6 | 1 | 4 | - | - | - | - | Tr | - | - | - | - | - | - | - | - | 2 |
| 1-T-4 | 49 | Tr | 2 | 19 | 2 | 14 | - | 1 | 5 | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1-X-1 | - | - | 2 | 40 | 1 | 12 | 6 | Tr | 1 | - | - | - | - | - | 5 | - | - | - | - | - | - | - | 34 |
| 1-X-4 | - | - | 4 | 45 | Tr | 8 | 5 | Tr | Tr | - | - | - | - | Tr | 9 | - | - | - | - | - | - | - | 29 |
| 1-X-7 | - | - | 3 | 36 | 2 | 17 | 2 | Tr | - | - | - | - | - | - | 9 | - | - | - | - | - | - | - | 29 |
| 1-X-10 | - | - | 1 | 48 | Tr | 13 | 3 | Tr | Tr | - | - | - | - | Tr | 4 | - | - | - | - | - | - | - | 29 |
| 1-A-1 | - | - | 31 | 11 | 2 | 2 | - | Tr | - | - | - | - | - | 2 | 5 | Tr | - | Tr | 1 | 18 | 1 | - | 24 |
| 1-C-2 | - | - | 34 | 10 | 2 | 3 | - | 1 | - | - | - | - | - | 1 | 16 | Tr | Tr | Tr | - | 10 | Tr | - | 22 |
| 1-C-5 | - | - | 48 | 3 | 1 | 2 | - | Tr | - | - | - | - | - | 1 | 5 | 1 | Tr | 1 | Tr | 8 | Tr | - | 30 |
| 1-E-6 | - | - | 8 | 27 | 7 | 18 | - | 2 | - | - | - | - | - | 1 | 2 | - | - | - | - | 15 | - | - | 22 |
| 1-F-4 | - | - | 17 | 8 | 2 | 16 | - | 1 | - | - | - | - | - | 4 | 4 | 1 | Tr | - | - | 13 | 4 | - | 30 |

TABLE IV. Volume Percent Analysis of Samples 1-G-1 Through 2-C-1.

| Sample Number | Micrite | Noncalcareous Mud Matrix | Detrital Quartz | Pelmatozoa | Trilobites | Ramose Bryozoa | Incrusting Bryozoa | Brachiopods | Unidentified Mollusks | Cephalopods | Oncolites | Fecal Pellets | Ooids | Hematite Clasts | Hematite Cement | Metamorphic Rock Fragments | Plagioclase | Glauconite | Dolomite | Peloids | Noncalcareous Mud Clasts | Unidentifiable Fossil Fragments | Spar Cement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-G-1 | - | 81 | 5 | 2 | Tr | 2 | - | - | - | - | - | 5 | - | - | - | - | - | - | - | - | - | 3 | 5 |
| 1-H-2 | - | - | 38 | Tr | - | - | - | - | - | - | - | - | 7 | - | - | 1 | Tr | Tr | - | 18 | 7 | - | 30 |
| 1-J-1 | - | - | 33 | 9 | 1 | Tr | - | - | - | - | - | - | 8 | 1 | 1 | 2 | Tr | - | - | 17 | Tr | - | 29 |
| 1-L-4 | - | - | 43 | 8 | 1 | 5 | - | - | - | - | - | - | - | 1 | 7 | 1 | - | Tr | - | 12 | - | - | 23 |
| 2-R-1 | 41 | - | 4 | 10 | 4 | 3 | - | Tr | 5 | 4 | 23 | - | 1 | - | - | - | - | Tr | - | - | - | - | 3 |
| 2-S-1 | 16 | 59 | 3 | 6 | 5 | 2 | - | - | 3 | - | 1 | - | - | - | - | - | - | - | - | - | 5 | Tr | - |
| 2-T-1 | - | - | - | 29 | 32 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 5 | - | 34 |
| 2-Ott-1 | - | 66 | 20 | Tr | Tr | - | - | - | - | - | - | 2 | - | - | - | 1 | - | - | - | 5 | 1 | 1 | 5 |
| 2-A-1 | - | 17 | 51 | Tr | - | - | - | - | - | - | - | - | - | Tr | - | 1 | - | Tr | - | 14 | - | - | 17 |
| 2-B-1 | - | 83 | 16 | - | - | - | - | - | - | - | - | Tr | - | Tr | - | - | - | - | - | - | - | 2 | - |
| 2-C-1 | - | 2 | 43 | 10 | - | - | - | - | - | - | - | - | - | Tr | - | - | - | Tr | 1 | 19 | - | Tr | 24 |

TABLE V. Volume Percent Analysis of Samples 2-D-1 Through 3-C-2.

| Sample Number | Micrite | Noncalcareous Mud Matrix | Detrital Quartz | Pelmatozoa | Trilobites | Ramose Bryozoa | Incrusting Bryozoa | Brachiopods | Unidentified Mollusks | Cephalopods | Oncolites | Fecal Pellets | Ooids | Hematite Clasts | Hematite Cement | Metamorphic Rock Fragments | Plagioclase | Glauconite | Dolomite | Peloids | Noncalcareous Mud Clasts | Unidentifiable Fossil Fragments | Spar Cement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-D-1 | – | 53 | 19 | – | – | – | – | – | – | – | – | 1 | – | Tr | – | – | Tr | – | – | 6 | – | – | 22 |
| 2-E-1 | – | 62 | 17 | – | – | – | – | – | – | – | – | – | – | 2 | – | – | – | – | – | 3 | – | – | 16 |
| 2-E-3 | – | 8 | 26 | 6 | – | – | – | – | – | – | – | – | – | Tr | – | – | – | – | – | 20 | – | – | 27 |
| 2-H-1 | – | – | 25 | 18 | 8 | – | – | – | – | – | – | – | – | 1 | – | Tr | – | 1 | – | 7 | 14 | – | 26 |
| 2-I-2 | – | 54 | 25 | – | – | – | – | – | – | – | – | Tr | – | Tr | – | 1 | – | Tr | Tr | 4 | – | 1 | 14 |
| 2-J-2 | – | 12 | 34 | 10 | – | – | – | – | – | – | – | Tr | – | – | – | 2 | Tr | 1 | – | 16 | – | – | 25 |
| 2-M-3 | – | 10 | 34 | 15 | – | – | – | – | – | – | – | – | – | – | – | 2 | Tr | 1 | – | 15 | – | – | 24 |
| 2-N-1 | – | – | 37 | 16 | – | – | – | – | – | – | – | – | – | Tr | – | 1 | Tr | Tr | – | 22 | – | – | 23 |
| 3-A-1 | 40 | – | 16 | 8 | 4 | 6 | – | Tr | 11 | 8 | – | – | – | – | – | – | – | – | – | 4 | – | – | 1 |
| 3-B-1 | – | 80 | 12 | 2 | – | 1 | – | – | – | – | – | – | – | – | – | – | Tr | Tr | – | 4 | – | 2 | – |
| 3-C-2 | 62 | – | 4 | 6 | 3 | 1 | – | Tr | 8 | – | 12 | – | 5 | – | – | – | – | – | – | Tr | – | – | – |

TABLE VI. Volume Percent Analysis of Samples 3-D-1 Through 5-1.

| Sample Number | Micrite | Noncalcareous Mud Matrix | Detrital Quartz | Pelmatozoa | Trilobites | Ramose Bryozoa | Incrusting Bryozoa | Brachiopods | Unidentified Mollusks | Cephalopods | Oncolites | Fecal Pellets | Ooids | Hematite Clasts | Hematite Cement | Metamorphic Rock Fragments | Plagioclase | Glauconite | Dolomite | Peloids | Noncalcareous Mud Clasts | Unidentifiable Fossil Fragments | Spar Cement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3-D-1 | - | - | 15 | 19 | 28 | 2 | - | Tr | - | - | - | - | - | Tr | - | - | - | Tr | - | 5 | - | - | 29 |
| 3-D-3 | - | - | 3 | 5 | 1 | Tr | - | - | - | - | - | - | 54 | - | - | - | - | - | - | 2 | - | - | 35 |
| 5-1 | - | - | 3 | 25 | 1 | 11 | - | 1 | 1 | - | - | - | 22 | - | - | - | - | - | - | 3 | - | - | 32 |

# APPENDIX B

## EXPLANATORY NOTE

The grain abundance terms (trace, less than 1 percent; minor, 1 percent to 8 percent; common, 8 percent to 16 percent; and abundant, greater than 24 percent) used in the unit descriptions are taken from LaRoux (1974). Each section description begins at the Holston-Chapman Ridge contact and progresses higher in the sequence. Unit thickness and cumulative thickness are provided at the beginning of each separate unit; they are abbreviated "U. T." and "C. T.," respectively. Those samples which were thin sectioned are underlined, and point counted samples are doubly underlined.

SECTION A

Unit 4-A U. T. 0.8 meters C. T. 0.8 meters

Mottled medium dark gray N4 and grayish red 5R 4/2, thin to medium-bedded, partially limonite stained biomicrite. All fossils are bored and most enveloped in micrite. Fossils are dominated by approximately equal amounts of ramose and incrusting bryozoan which together compose 50 to 60 percent of the fauna. Minor amounts of pelmatozoa and trilobites are noted. Gastropods and other unidentifiable mollusks are present in trace amounts.

Sample 4-A-1 at base

Unit 4-B U. T. 0.9 meters C. T. 1.7 meters

Medium gray N5, thin-bedded, slightly silty biomicrite. Most fossils are bored. The lithology is very similar to Unit 3-A with the following exceptions: (1) silt size, rounded fecal pellets are dispersed through sediment in minor abundance; (2) silt size metamorphic rock fragments and plagioclase are present in trace amounts; and (3) several horizontal burrows are noted.

Sample 4-B-1 at 0.25 meters Sample 4-B-2 at 0.3 meters

Unit 4-C U. T. 0.7 meters C. T. 2.4 meters

Medium gray N5, thinly-bedded, slightly calcareous shale with several thin, discontinuous horizontal laminae of light gray N6 highly silty biosparite. Occasional 0.5 mm thick horizontal burrows observed in the shales, frequently filled with 0.2 mm clusters of fecal pellets.

Biosparite laminae contain minor amounts of peloids and trace quantities of metamorphic rock fragments.

Sample 4-C-1 at 0.3 meters

Unit 4-D U. T. 4.3 meters C. T. 6.7 meters

Similar to Unit 4-C except biosparites are thicker and consist of thin interbeds, constituting approximately 50 percent of the lithology. Bedding is locally disturbed by horizontal burrows.

Sample 4-D-1 at 0.9 meters Sample 4-D-2 at 4.3 meters

SECTION B

Unit 1-T U. T. 1.3 meters C. T. 1.3 meters

Light brownish gray 5YR 6/1 thin-bedded, highly weathered biomicrite with occasional very thin interbeds of medium brown, slightly gray 5YR 4/1 intraclast-bearing, laminated biomicrite. Both lithologies contain similar, highly bored fossils with ramose bryozoa and incrusting bryozoan common to abundant. Pelmatozoa and trilobites vary from trace to common. Minor amounts of silt size quartz and brachiopods are present. Peloids are rounded, average 2 cm in length, and appear identical to 5YR 6/1 lithology.

Sample 1-T-1 at base Sample 1-T-3 at 0.6 meters

Sample 1-T-4 at 0.3 inches

Unit 1-X U. T. 6.6 meters C. T. 7.9 meters

Grayish red 5R 4/2, medium to thick-bedded, pelmatozoa-rich biosparite. Occasional trough and planar cross-bedding are noted. Ramose bryozoan are common; incrusting types are present in minor amounts.

Occasional fine sand size clasts of hematite are found, and most other grain types exhibit hematite rims.

| | |
|---|---|
| Sample 1-X-1 at base | Sample 1-X-2 at 1.1 meters |
| Sample 1-X-3 at 1.9 meters | Sample 1-X-4 at 2.8 meters |
| Sample 1-X-5 at 4.4 meters | Sample 1-X-6 at 6.0 meters |
| Sample 1-X-7 at 6.7 meters | Sample 1-X-8 at 3.1 meters |
| Sample 1-X-9 at 3.4 meters | Sample 1-X-10 at 4.0 meters |
| Sample 1-X-11 at 4.6 meters | Sample 1-X-12 at 5.1 meters |

Unit 1-A U. T. 0.7 meters C. T. 8.6 meters

Medium gray N6, thin to medium-bedded, fine, highly sandy biosparite. The unit contains ripple-drift cross laminae of fine sand size fossil debris. Several 15 to 20 cm long orthocone cephalopods were observed on the base of beds. Fine sand size peloids and pelmatozoan grains are common. Trilobite and bryozoan fragments along with fine sand size hematite clasts and plagioclase are noted in minor abundance.

Sample 1-A-1 at base

Unit 1-B U. T. 1.1 meters C. T. 9.7 meters

Brownish gray 5YR 4/1 very thin to medium-bedded, highly calcareous, fine sandstone, with occasional very thin interbeds of fine, white, fossil fragments. The unit is characterized by even, horizontal bedding. Occasional flow casts are observed on base of bedding surfaces.

Sample 1-B-1 at 1.1 meters

Unit 1-C U. T. 3.5 meters C. T. 13.2 meters

Medium brownish gray 5YR 5/1, very thin-bedded (becomes medium-bedded towards top of unit) highly calcareous, fine sandstone. Numerous pinkish-gray 5YR 8/1 of 0.5 mm to 1.0 mm thick lenses of highly fragmented, fine sand size fossil debris are present. The entire unit exhibits micro-ripple-drift cross-bedding. Fossils include minor amounts of pelmatozoan grains, trilobite pieces, and bryozoan fragments. Metamorphic rock fragments and plagioclase are present in minor amounts.

Sample 1-C-1 at base Sample 1-C-2 at 3.5 meters

Sample 1-C-3 at 2.0 meters Sample 1-C-4 at 3.1 meters

Unit 1-D U. T. 1.4 meters C. T. 14.6 meters

Grayish red 5R 4/2, medium to thick-bedded, slightly calcareous fine sandstone. Lithologically the unit is similar to Unit 1-C but is characterized by the presence of gently dipping, planar cross-beds, especially at the base of the unit. Ripple-drift cross-bedding is locally common. Lenses of fossil fragments are generally lacking.

Sample 1-D-1 at 0.7 meters Sample 1-D-2 at base

Sample 1-D-3 at 1.4 meters

Unit 1-E U. T. 6.5 meters C. T. 21.1 meters

Grayish brown 5YR 3/2, medium-bedded, fine to medium grained, sandy biosparite. Ripple drift bedding is common and some trough cross-beds are noted. Three to five cm thick interbeds of gray calcareous shale are present but not abundant. Scoured bedding surfaces are quite numerous. Most grains are coated with hematite, and fossils which constitute up to 50 percent of the lithology are composed primarily

of abraded pelmatozoan and bryozoan fragments. Fine sand size peloids and glauconite grains are present in trace to minor amounts. Trilobite and brachiopod pieces appear in minor quantities. Fine sand size grains of plagioclase and metamorphic rock fragments are present in trace amounts.

Sample 1-E-1 at base — Sample 1-E-2 at 0.6 meters

Sample 1-E-3 at 2.0 meters — Sample 1-E-4 at 3.4 meters

Sample 1-E-5 at 5.1 meters — Sample 1-E-6 at 6.0 meters

Unit 1-F — U. T. 7.9 meters — C. T. 29.0 meters

Grayish brown 5YR 3/2, medium to thick-bedded, fine to medium grained, sandy biosparite. Trough cross-beds are present, but much of the unit is horizontally bedded. Interbeds of 3 to 5 cm thick medium dark gray N4, calcareous shale are common. Lithology is similar to that of Unit 1-E except for the presence of minor amounts of disc shaped, 0.5 cm to 1.0 cm, angular clasts of dusky brown 5YR 2/1 shale which contain abundant dolomite rhombs and trace amounts of silt size glauconite grains.

Sample 1-F-1 at 0.2 meters — Sample 1-F-2 at 1.9 meters

Sample 1-F-3 at 1.5 meters — Sample 1-F-4 at 2.4 meters

Sample 1-F-5 at 3.0 meters — Sample 1-F-6 at 4.4 meters

Unit 1-G — U. T. 8.5 meters — C. T. 37.5 meters

Medium dark gray N4, thinly to thickly-laminated, highly fissile, slightly calcareous shale. Horizontal burrows are abundant and average 0.3 mm in diameter. Most burrows contain numerous gray-black, round fecal pellets. Fossil fragments average 0.1 mm and are dominated by

bryozoan and pelmatozoan grains. Silt size quartz and dolomite rhombs are noted in minor abundance.

Sample 1-G-1 at 3.8 meters

Approximately 113 meters covered

Unit 1-H U. T. 7.1 meters C. T. 157.6 meters

Medium gray N5, thin-bedded, fine grained highly calcareous sandstone with minor amounts of 0.8-1.0 mm, rounded, medium dark gray N4, calcareous shale clasts. Very thin interbeds and laminae of this same shale lithology are seen frequently. Bedding is predominantly even and horizontal; numerous ripple marks are present on bedding planes. Fossil fragments are generally lacking but pelmatozoan grains are observed in trace amounts. Fine sand size peloids are abundant; ooids and metamorphic rock fragments are noted in minor quantities. Glauconite grains are present in trace amounts.

Sample 1-H-1 at 0.6 meters Sample 1-H-2 at 3.5 meters

Sample 1-H-3 at 6.5 meters

Unit 1-I U. T. 5.1 meters C. T. 162.7 meters

Medium gray N5, thin to medium-bedded, fine grained highly calcareous sandstone. Lithology is very similar to 1-H with following exceptions: shale clasts are seen in trace amounts; ooids are minor in abundance.

Sample 1-I-1 at 0.4 meters

0.9 meters covered

Unit 1-J U. T. 12.4 meters C. T. 175.1 meters

Medium light brownish gray 5YR 5/1, medium to thick-bedded, fine grained, highly sandy biosparite with occasional very thin interbeds and laminae of medium light gray N6, calcareous shale. Generally even, horizontal bedding predominates; most bedding surfaces are rippled. Fine sand size, round ooids are common and frequently contain dolomite rhombs in laminae. Fine sand size peloids are abundant while metamorphic rock fragments, abraded pelmatozoan, trilobite, and bryozoan fragments vary from trace to minor.

Sample 1-J-1 at 0.8 meters Sample 1-J-2 at 0.7 meters

Sample 1-J-3 at 5.0 meters Sample 1-J-4 at 7.1 meters

Approximately 20 meters covered

Unit 1-K U. T. 5.6 meters C. T. 200.7 meters

Medium gray N5, thin to medium-bedded, fine grained highly calcareous sandstone with numerous very light gray N8 lenses, 0.5 to 1.0 cm thick, of fine grained fossil debris. The unit displays excellent examples of ripple-drift cross-bedding. Several 3-5 cm wide calcite veins cut obliquely across bedding. Except within the fossil rich lenses, most grains are hematite coated. Fine grained peloids are common; rounded shale clasts are present only in trace amounts. Trace amounts of plagioclase and metamorphic grains are present.

Sample 1-K-1 at 1.1 meters Sample 1-K-2 at 5.2 meters

Approximately 27 meters covered

Unit 1-L U. T. 27.5 meters C. T. 255.2 meters

Medium gray N5, thin to thick-bedded, moderately calcareous fine sandstone and very light gray N8 moderately sandy biosparite. Thin interbeds and laminae of calcareous shale are observed, especially common in the upper portions of the unit. The unit exhibits planar cross-bedding and ripple-drift cross-bedding. Scoured surfaces and symmetrical ripples frequently mark bedding planes. Peloids are common and average 1.0 mm in size. Fine sand size pelmatozoan grains vary from common to abundant. Metamorphic rock fragments, glauconite and plagioclase grains are minor.

Sample 1-L-1 at 1.9 meters Sample 1-L-2 at 9.2 meters

Sample 1-L-3 at 10.1 meters Sample 1-L-4 at 22.7 meters

SECTION C

Unit 3-A U. T. 0.6 meters C. T. 0.6 meters

Medium gray N5, thin-bedded, highly weathered, slightly silty biomicrite. All fossils appear highly bored and micrite coated. Cephalopods and unidentifiable mollusk debris are common to abundant. Trilobites, pelmatozoan, and ramose bryozoan vary from trace to common. Girvanella is present in trace amounts.

Sample 3-A-1 at 0.2 meters

Unit 3-B U. T. 0.9 meters C. T. 1.5 meters

Dark yellowish brown 10YR 4/2, thin-bedded, highly weathered, slightly calcareous mudstone. Horizontal burrows are common. Fossils

in this unit are silt size fragments consisting of minor amounts of pelmatozoan and bryozoan debris. Peloids vary from trace to minor.

Sample 3-B-1 at 0.5 meters

Unit 3-C U. T. 0.6 meters C. T. 2.1 meters

Medium dark gray N4, thin-bedded, biomicrite with oncolites. All fossils and most oncolites appear bored; fossils possess micrite coatings. Unidentifiable mollusks are common while ramose bryozoan, trilobites, and pelmatozoan are present in minor amounts.

Sample 3-C-1 at 0.4 meters Sample 3-C-2 at 0.6 meters

0.1 meter covered

Unit 3-D U. T. 10.2 meters C. T. 12.3 meters

Medium gray N5, medium-bedded trilobite-rich, slightly sandy biosparite which grades vertically into grayish red 5R 4/2, medium-bedded oosparite. Most grains are hematite coated and all fossils abraded. Pelmatozoan are generally common within the biosparites while peloids and bryozoan are minor. Oosparites contain minor faunal elements, similar to those in the biosparites. Minor to trace amounts of fine sand size quartz grains are found in both lithologies.

Sample 3-D-1 at 0.3 meters Sample 3-D-2 at 6.0 meters

Sample 3-D-3 at 9.0 meters

SECTION D

Unit 2-Q U. T. 1.1 meters C. T. 1.1 meters

Medium brownish gray 5YR 5/1, thin-bedded, friable, moderately calcareous mudstone with numerous 3 to 5 cm medium dark gray N4, rounded

clasts of Girvanella. Occasional 8 cm long orthocone cephalopods and 1 cm long crinoid columnals are apparent in the weathered portions of the outcrop. Mud matrix is laminated and contains minor to trace amounts of coarse sand size, rounded pebbles of dusky yellowish brown 10YR 4/2 mud. Silt size quartz and highly bored pelmatozoan grains are minor.

Sample 2-Q-1 at 0.8 meters

Unit 2-R U. T. 0.6 meters C. T. 1.7 meters

Medium dark gray N4, thin to medium-bedded biomicrite with oncolites and ooids. Numerous six inch long orthocone cephalopods are noted on weathered surfaces. Most fossils are algally laminated and bored. Oncolites and ooids are abundant. Pelmatozoan grains are present in minor amounts; trilobites and bryozoan are generally minor. There are trace amounts of silt size quartz and plagioclase grains.

Sample 2-R-1 at 0.3 meters

Unit 2-S U. T. 0.4 meters C. T. 2.1 meters

Medium brownish gray 5YR 5/1, thin-bedded, moderately calcareous mudstone. Unit appears identical to Unit 2-Z.

Sample 2-S-1 at 0.3 meters Sample 2-S-2 at 0.3 meters

Sample 2-S-3 at 0.4 meters

Unit 2-T U. T. 1.0 meters C. T. 3.1 meters

Medium dark gray N4, thin-bedded, trilobite rich biosparite with abundant pelmatozoan grains. Occasional brownish gray 5YR 4/1, discontinuous thick laminae and angular pebbles of silty mudstone are present.

Tilobites are commonly nested and show slight evidence of abrasion.

Sample 2-T-1 at 0.8 meters  Sample 2-T-2 at 1.0 meters

43.3 meters covered

Unit 2--Ottosee  U. T. 5.4 meters  C. T. 51.8 meters

Medium light olive gray 5Y 5/1, slightly calcareous shale with a few 2 mm to 1 cm thick lenses and pods of medium gray N5, fine, highly sandy biosparite. Scour and fill structures are common; ripple marks and load casts are apparent beneath coarser units. Several 0.2 mm to 4.0 mm thick horizontal burrows observed in shales frequently containing fecal pellets. Dolomite rhombs, tilobite fragments, pelmatozoan grains, and graptolites occur in the biosparites in trace amounts.

Sample 2-Otto-1 at 3.6 meters

Unit 2-A  U. T. 6.0 meters  C. T. 57.8 meters

Medium gray N5, very thin to medium-bedded highly sandy biosparite with intraclasts and thin laminae of slightly calcareous medium dark gray N4 shale. Unit grades vertically into unit 2-B as shale beds become predominant at the expense of the biosparite. Bedding is even and horizontal and most of the coarser units are rippled. Peloids are common, and trace amounts of plagioclase grains are present.

Sample 2-A-1 at 0.6 meters  Sample 2-A-2 at 2.9 meters

Sample 2-A-3 at 4.3 meters  Sample 2-A-4 at 5.4 meters

Unit 2-B  U. T. 3.5 meters  C. T. 61.3 meters

Medium gray N5, slightly calcareous shale with very thin lenses of medium light gray N6, highly sandy biosparite with peloids.

Occasional flasure bedding is present. Numerous fecal pellets are confined to horizontal burrows. Glauconite grains are found in trace amounts in the sands.

Sample 2-B-1 at 1.8 meters Sample 2-B-2 at 2.6 meters

Unit 2-C U. T. 21.8 meters C. T. 83.1 meters

Medium gray N5, thin-bedded, highly sandy biosparite with peloids. A few thin laminae of slightly calcareous shale are present in this unit. Ripple marks and probably small scour channels (averaging 3 cm) are common. Vertical burrows are abundant and filled with quartz grains and fecal pellets.

Sample 2-C-1 at 2.0 meters Sample 2-C-2 at 7.3 meters

Sample 2-C-3 at 14.4 meters Sample 2-C-4 at 23.5 meters

Unit 2-D U. T. 7.9 meters C. T. 91.0 meters

Medium light gray N6, thinly-bedded, highly sandy biosparite with peloids. Thin to thick laminae of dark yellowish brown 10YR 4/2 weathered shale are abundant in this unit. Mineralogy is similar to Unit 2-C.

Sample 2-D-1 at 0.2 meters Sample 2-D-2 at 3.0 meters

Sample 2-D-3 at 5.5 meters Sample 2-D-4 at 7.9 meters

Unit 2-E U. T. 10.6 meters C. T. 101.6 meters

Dark yellowish brown 10YR 4/2, slightly calcareous shale with several 1 to 10 cm lenses and pods of medium light gray N6 biosparite. Most bedding surfaces are gently to moderately undulatory. Burrows are common and mostly vertical. Frequently, burrowing produces a mottling

of the two lithologies. Many of the biosparite laminae are micro-cross-laminated and contain lightly abraded, unrecognizable fine sand size fossil debris.

Sample 2-E-1 at 5.5 meters  Sample 2-E-2 at 6.8 meters

Sample 2-E-3 at 8.9 meters  Sample 2-E-4 at 10.1 meters

Unit 2-F  U. T. 2.7 meters  C. T. 104.3 meters

Mottled, medium light gray N6 biosparite with peloids and medium dark gray N4 calcareous shale. Unit is similar to Unit 2-E except this unit contains a higher percentage of shale.

Sample 2-F-1 at 0.4 meters  Sample 2-F-2 at 2.2 meters

Unit 2-G  U. T. 3.3 meters  C. T. 107.6 meters

Interlaminated, medium light gray N6, highly sandy biosparite with peloids and medium dark gray N4 shale. Unit appears identical to Unit 2-B.

Sample 2-G-1 at 1.1 meters  Sample 2-G-2 at 2.6 meters

Unit 2-H  U. T. 0.5 meters  C. T. 108.1 meters

Medium gray N5, thin-bedded, trilobite-rich, highly sandy biosparite. Intraclasts of medium dark gray N4 shale are locally common. Fossils are abraded and frequently nested, parallel to bedding. Peloids and pelmatozoan grains are common, and trace quantities of fine metamorphic rock fragments and dolomite rhombs are present.

Sample 2-H-1 at 0.2 meters

Unit 2-I U. T. 4.1 meters C. T. 112.2 meters

Laminated medium light gray N6, highly sandy biosparite with peloids and medium gray N5, slightly calcareous shale. Bedding surfaces are undulatory. One 2 cm burrows and graptolite fragments are locally abundant. Dolomite rhombs and glauconite grains are present in trace amounts.

Sample 2-I-1 at 0.6 meters Sample 2-I-2 at 2.0 meters

Sample 2-I-3 at 4.1 meters

Unit 2-J U. T. 2.9 meters C. T. 115.1 meters

Medium gray N5, thin-bedded, moderately argillaceous, highly sandy biosparite with peloids and numerous undulating partings of slightly calcareous medium dark gray N4 shale. Fecal pellets and fine metamorphic rock fragments vary from trace to minor amounts. Unit is vertically burrowed.

Sample 2-J-1 at 1.0 meters Sample 2-J-2 at 2.7 meters

Unit 2-K U. T. 7.3 meters C. T. 122.4 meters

Unit is very similar to Unit 2-I. Burrows have produced mottling of the two lithologies here.

Sample 2-K-1 at 1.2 meters Sample 2-K-2 at 4.5 meters

Sample 2-K-3 at 4.8 meters Sample 2-K-4 at 5.9 meters

Unit 2-L U. T. 2.0 meters C. T. 124.4 meters

Medium gray N5, thin-bedded, highly sandy biosparite with peloids, and numerous thin laminae and partings of medium dark gray N4 shale. All bedding surfaces are rippled; a few of the biosparites are

lense-shaped, but most are laterally continuous. Highly abraded trilobites and peloids are common.

Sample 2-L-1 at 1.2 meters Sample 2-L-2 at 1.7 meters

Unit 2-M U. T. 6.0 meters C. T. 130.4 meters

Medium dark gray N4, thin-bedded, heavily burrowed, slightly calcareous shale with one 2 cm thick pods and lenses of medium light gray N6, highly sandy biosparite with peloids. There are trace amounts of fine glauconite and plagioclase grains in the biosparites. This lithology grades up into a ripple-drift cross-laminated, thin-bedded, biosparite.

Sample 2-M-1 at 0.9 meters Sample 2-M-2 at 3.2 meters

Sample 2-M-3 at 4.0 meters

Unit 2-N U. T. 2.8 meters C. T. 133.2 meters

Medium gray N5, thin to medium-bedded, highly sandy biosparite with peloids. Occasional thin interbeds of shale are noted in outcrop. Horizontal burrows are common throughout the unit.

Sample 2-N-1 at 1.4 meters Sample 2-N-2 at 2.6 meters

Unit 2-O U. T. 3.5 meters C. T. 136.7 meters

This unit appears identical to Unit 2-M.

Sample 2-O-1 at 1.4 meters Sample 2-O-2 at 2.9 meters

Unit 2-P U. T. 2.6 meters C. T. 139.3 meters

This unit appears identical to Unit 2-N.

Sample 2-P-1 at 0.3 meters Sample 2-O-2 at 2.0 meters

# VITA

Edward Burk McWilliams was born October 31, 1947, in Birmingham, Alabama, where he attended elementary school. Following his graduation from Indian Springs High School in Helena, Alabama, he entered Birmingham-Southern College from which he received a Bachelor of Science degree in June, 1969. From 1969 to 1973 he was employed by Chevron Oil Company in New Orleans, Louisiana. In January, 1973, he entered The University of Tennessee and graduated with a Master of Science degree in March, 1975. He is married to the former Dorothy Cheryl Dean, and they have one child, Edward Vaughn, born in December, 1973.