CONODONT BIOFACIES AND CARBONATE LITHOFACIES OF LOWER ORDOVICIAN MEGACONGLOMERATES, COW HEAD GROUP, WESTERN NEWFOUNDLAND

CENTRE FOR NEWFOUNDLAND STUDIES

TOTAL OF 10 PAGES ONLY
MAY BE XEROXED

(Without Author's Permission)

SUSANNE MARGARETE LUISE POHLER

National Library of Canada
Bibliothèque nationale du Canada

Canadian Theses Service
Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, tests publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30.

NL-339 (r. 88/04)

Canada

Conodont biofacies and carbonate lithofacies of Lower Ordovician megaconglomerates, Cow Head Group, western Newfoundland

by

(C) Susanne Margarete Luise Pohler, M.Sc.

A thesis submitted to the school of Graduate Studies in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Department of Earth Sciences
Memorial University of Newfoundland

August 1987

St. John's Newfoundland

Permission has been granted to the National Library of Canada to microfilm this thesis and to lend or sell copies of the film.

The author (copyright owner) has reserved other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without his/her written permission.

L'autorisation a été accordée à la Bibliothèque nationale du Canada de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur (titulaire du droit d'auteur) se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation écrite.

ISBN 0-315-39480-3

ABSTRACT

Lower Ordovician (Arenig) strata in the Humber Zone of the northern Appalachians record the transition from a tectonically passive (Atlantic-type) margin to an active margin, whose rocks were thrust onto co-eval platform carbonates during the Middle Ordovician. The Cow Head Group represents a well preserved fragment of the continental slope of the early Paleozoic Iapetus Ocean. Cow Head Group strata are characterized by conglomerate beds intercalated with deep water carbonates and minor siliciclastics. Three megaconglomerate units (beds 10, 12 and 14) on Cow Head Peninsula with lateral and distal equivalents exposed at Lower Head, on Stearing Island, at St. Pauls Inlet, Western Brook Pond and Martin Point yield clasts and boulders from shelfedge and upper slope of the Iapetus Ocean. These clasts represent superbly preserved remains of this segment of the continental margin, a rarely preserved facies around the North American craton. This study comprises a documentation of carbonate lithofacies and conodont biofacies deduced from fragments of the shelf margin facies for the purpose of reconstructing the inner marginal environment and its evolution through the Arenig interval.

The study is divided into two parts: (1) Conodont biofacies with study of conodont biostratigraphy, paleoecology and taxonomic remarks and (2) carbonate lithofacies with description of conglomerate beds, clast lithologies and interpretation of clast origin. Over 500 thin sections were prepared to describe lithologies and about 300 conodont samples were collected and processed.

(1) Conodont biofacies.

Among the 12492 conodont specimens obtained 132 different form and multi-element species were recognized. A new genus *Texania* was established to include species of *Microzarkodina*? McTavish. Several new species were recognized and described, four new species were named: *Texania heligma*, *Prioniodus (P.) serratus*, *Prioniodus (P.) marginalis* and *Serratognathus dougli*.

Faunal assemblages from clasts contained conodonts of North Atlantic and North American Midcontinent faunal aspect as well as endemic and cosmopolitan species. Bed 10 clasts yielded conodonts of the *Paroistodus proteus* and *Prioniodus (P.) elegans* zones of Balto-Scandia, together with faunal elements of faunas D and basal E of the Midcontinent zonal scheme. Bed 12 clasts yielded older clasts with conodonts of the *Prioniodus (O.) evae* Zone and younger clasts with dominantly *Periodon aculeatus* together with faunal elements typically found in Fauna E-1 (e.g.*Protoprioniodus aranda*) of the Midcontinent faunal scheme. Boulders from Bed 14 also produced abundant *P. aculeatus* and the occurrence of *Tripodus laevis* and *Pteracontiodus cryptodens* suggests basal Whiterock age. Correlation to Scandinavia is problematic and upper Bed 11 to Bed 14 probably include *P. (B.) triangularis/navis, P.originalis, M. flabellum parva* and lower *?E. suecicus* zones. Conodonts from the matrix of beds 10-14 are of mixed ages with most being age-equivalent to, and none being younger than the clasts. The oldest clast faunas are of late Cambrian age.

Faunas of clasts show in general closer affinity to those found in the bedded lower slope sediments than to those from the shelf with regard to the dominating species. Four different biofacies were recognized in the three conglomerate beds: Bed 10 foreign lithologies derived from upper slope and shelfbreak yielded a *Prioniodus-Texania* Biofacies, Bed 12 older margin derived clasts yielded a distinct *Prioniodus-Periodon* biofacies with a mixed North Atlantic and Argentinian fauna, younger clasts in Bed 12 contain conodonts of a *Periodon-Texania* Biofacies with species of Australian and Midcontinent affinity; in Bed 14-clasts a *Periodon-Parapanderodus* Biofacies occurs The shelfbreak and upper slope environment is found to represent a independent faunal realm with distinct conodont assemblages. The composition of the various biofacies is controlled by environmental changes on the shelf such as sea level fluctuations which induced on- or offshelf migrations of the faunas.

(2) Carbonate lithofacies

Among clasts in the megaconglomerates local (lower slope derived), foreign (shelf-, shelfbreak- and upper slope-derived) and older clasts were distinguished. Study of facies relationships and abundances of the different clast lithologies enable reconstruction of the upper slope/shelfbreak sedimentary environment as follows: Bed 10 foreign clasts are interpreted as being derived from a shelf margin with a low angle shelfbreak situated in relatively deep water. The foreign lithologies found in Bed 10 are interpreted as remains of mud banks and mounds formed with the aid of *Girvanella* algae and lithistid sponges. Stromatactoid voids and dilatational fractures are characteristic features associated with these rocks. Calcirudites with cm-sized algal and mud lumps are interpreted as mound talus and intraformational breccias.

Foreign clasts in Bed 12 record a shelf edge where muddy calcarenites were deposited during lower Bed 11-time and possibly exposed with shallowing of the water during upper Bed 11-time. Boundstones and massive wackestones developed from low diversity algal dominated types to high diversity buildups with *Pulchrilamina*-like organisms and several algal species. Lumpy wackestones which encrouched onto the upper slope and platform edge during high sea level stand recorded in lower Bed 11 retreated with the regression during upper Bed 11-time.

In Bed 14 complex organic buildup facies accumulated at the shelfedge probably with steep slopes surrounded by coarse talus clastics. Shallower water on the shelf itself (Aguathuna Fm.) forced continuous seaward growth of the shelfedge buildups which led to overloading and finally failure of an entire segment of the margin. The Bed 14 megaconglomerates record this episode with their high abundance of old clasts and huge boulder sizes. The event may be related to synsedimentary faulting on the platform recorded in the Aguathuna Formation.

ACKNOWLEDGEMENTS

Firstly I wish to thank C.R. Barnes, H.P. Schönlaub and the Department of Earth Sciences who provided me with the opportunity to come to Memorial University. I greatly appreciated the ideas, discussions and knowledge shared by my supervisors C.R. Barnes, N.P. James and R.K. Stevens. I also gratefully acknowledge their financial support which allowed me to visit several collegues and attend meetings. S.M. Bergström, R.L. Ethington, L.F. Fahraeus, L. Jeppsson, A. Löfgren, K.J. Müller, G.S. Nowlan, J.E. Repetski, S.S. Stouge, G. Stouge-Bagnoli and W.A. van Wamel provided valuable information about their studies of Arenig conodonts. Similarly D.I. Johnston shared his thoughts and ideas about Cow Head conodonts. Fruitful discussion on Cow Head stratigraphy and sedimentology was provided by M. Coniglio, A. Desrochers, T. Lane, P. Myrow, G. Narbonne, F. O'Brien, K. Rigby, S. Stenzel, S.H. Williams and many others. Much technical support was given by C. Emerson, W. Marsh, S. Neuland, F. O'Brien, A. Phillips, A. Pye and the workshop staff. I especially extend my thanks to D. Haywick for cheerful company and moral support in long hours of writing term papers and preparing thin sections. C.R. Barnes, N.P. James and the Department of Earth Sciences are gratefully acknowledged for their continuous research funding. The cooperation of the administration and staff of Gros Morne National Park is also acknowledged.

Table of Contents

1. INTRODUCTION 1
   1.1. Purpose 3
   1.2. Previous work 5
   1.3. Methods of study 8
      1.3.1. Conodont biofacies 8
      1.3.2. Carbonate lithofacies 8
2. GEOLOGIC SETTING 10
   2.1. General geologic setting 10
   2.2. Stratigraphy 17
   2.3. Sedimentology 21
   2.4. Stratigraphy of Arenig units of the slope sequence 21
      2.4.1. Beds 9 and 10 22
      2.4.2. Beds 11 and 12 22
      2.4.3. Beds 13 and 14 23
      2.4.4. Bed 15 23
   2.5. Stratigraphy of the Upper Canadian to Lower Whiterock part of the shelf sequence 23
      2.5.1. Boat Harbour Formation 24
      2.5.2. Catoche Formation 24
      2.5.3. Aguathuna Formation 26
   2.6. Depositional setting 26
   2.7. Paleogeography 28
3. BIOSTRATIGRAPHY 31
   3.1. Introduction 31
   3.2. Previous work 33
   3.3. Conodont provincialism 33
   3.4. Biostratigraphy of the shelf sequence 34
      3.4.1. Shelly fossils 34
      3.4.2. Graptolites 35
      3.4.3. Conodonts 35
   3.5. Biostratigraphy of the slope sequence 36
      3.5.1. Graptolites 36
      3.5.2. Shelly fossils 38
   3.6. Conodont biostratigraphy of the Cow Head Group 38
      3.6.1. Bed 10 and equivalents 42

3.6.2. Bed 12 and equivalents 43
3.7. Lower/Middle Ordovician boundary in North America 45
3.7.1. Bed 13 and equivalents 47
3.8. Conclusions 49
4. CONODONT PALEOECOLOGY 50
4.1. Introduction 50
4.2. *Paroistodus - Drepanoistodus* Biofacies 54
4.3. *Prioniodus - Texania* Biofacies 55
4.4. Comparison with contemporaneous faunas from other regions 57
4.4.1. Lower slope deposits (Bed 9) of the Cow Head Group 57
4.4.2. Baltoscandian biofacies 57
4.4.3. Midcontinent biofacies 58
4.4.4. Other regions 59
4.5. Conclusions 60
4.6. *Prioniodus-Periodon* Biofacies 63
4.7. Comparison with contemporaneous faunas from other regions 64
4.7.1. Lower slope biofacies (lower Bed 11) of the CHG 64
4.7.2. Baltoscandian biofacies 64
4.7.3. Midcontinent biofacies 65
4.7.4. Other regions 65
4.8. Conclusions 65
4.9. *Periodon-Texania* biofacies 68
4.10. Comparison with other regions of equivalent age 69
4.10.1. Lower slope biofacies (Bed 13) of the CHG 69
4.10.2. Baltoscandian biofacies 69
4.10.3. Midcontinent biofacies 70
4.10.4. Other regions 71
4.11. Conclusions 71
4.12. *Periodon-Parapanderodus* Biofacies 74
4.13. Comparison with contemporaneous faunas from other regions 75
4.13.1. Lower slope biofacies 75
4.13.2. Baltoscandian biofacies 76
4.13.3. Midcontinent biofacies 76
4.13.4. Other regions 77
4.14. Conclusions 78
4.15. Summary and conclusions 78
5. TAXONOMY 85
5.1. Introduction 85
6. CONGLOMERATE SEDIMENTOLOGY 237
6.1. Introduction 237
6.2. Clast character 238
6.3. Investigative techniques 239
6.4. Previous work 242
6.5. Description of conglomerate horizons 243

6.6. Bed 10, proximal sections 243
6.6.1. Lower Head West 248
6.6.2. Cow Head Peninsula 249
6.6.3. Stearing Island 252
6.7. Bed 10, distal sections 255
6.7.1. St Pauls Inlet 255
6.7.2. Martin Point-South 256
6.7.3. Western Brook Pond 257
6.8. Bed 12, proximal facies 257
6.8.1. Cow Head Peninsula 257
6.8.2. Lower Head 263
6.8.3. Stearing Island 263
6.8.4. Martin Point North 263
6.9. Bed 12, distal sections 266
6.9.1. Martin Point South 266
6.9.2. St. Pauls Inlet 267
6.9.3. Western Brook Pond 268
6.9.4. Green Point 270
6.10. Bed 14, proximal sections 270
6.10.1. Lower Head 270
6.10.2. Cow Head Peninsula 276
6.11. Bed 14, distal sections 276
6.11.1. St. Pauls Inlet 276
6.11.2. Martin Point 279
6.12. Summary of conglomerate biostratigraphy 286
6.13. Lower Ordovician conglomerate localities in the Appalachians and the Ouachita-Marathon region 286
6.14. Comparable megaconglomerates 288
6.15. Recent equivalents 289
6.16. Variations of CH megaconglomerate facies 290
6.16.1. Bed thickness 290
6.16.2. Ratio clast:matrix 291
6.16.3. Matrix composition 291
6.16.4. Ratio of foreign:local clasts 291
6.16.5. Average clast size and largest clast size 292
6.16.6. Top of conglomerate horizons 292
6.16.7. Temporal variations 295
7. CLAST LITHOLOGIES OF BED 10 **299**
7.1. Introduction 299
7.2. A. Local penecontemporaneous clasts 302
7.3. B. Foreign penecontemporaneous lithologies 311
7.4. C. OLDER CLASTS 347

8. CLAST LITHOLOGIES OF BED 12 350
8.1. Introduction 350
8.2. A. Local penecontemporaneous clasts 350
8.3. B. Foreign penecontemporaneous clasts 360
8.4. C. Older clasts 389
9. CLAST LITHOLOGIES OF BED 14 394
9.1. Introduction 394
9.2. A. Local penecontemporaneous lithologies 394
9.3. B. Foreign penecontemporaneous lithologies 408
9.4. C. Older clasts 428
10. SYNTHESIS OF LITHOFACIES 439
10.1. Bed 10 lithofacies 439
10.1.1. Introduction 439
10.1.2. Lithofacies 439
10.1.3. Vertical relationships of facies 442
10.1.4. Lateral facies relationships 442
10.1.5. Role of organisms 445
10.1.6. Synthesis and model 449
10.2. Bed 12 Lithofacies 453
10.2.1. Introduction 453
10.2.2. Vertical facies relationships 454
10.2.3. Comparison of Bed 10 and Bed 12 lithofacies 454
10.2.4. Lateral facies relationships 455
10.2.5. Role of organisms 458
10.2.6. Synthesis and model 461
10.3. Bed 14 Lithofacies 465
10.3.1. Introduction 465
10.3.2. Lateral facies relationships 466
10.3.3. Role of organisms 466
10.3.4. Synthesis and model 468
11. SUMMARY AND CONCLUSIONS 471
11.1. Summary 471
11.1.1. Introduction and geological setting 471
11.1.2. Conodont taxonomy 471
11.1.3. Conodont biostratigraphy 472
11.1.4. Conodont paleoecology 473
11.1.5. Conglomerate sedimentology 474
11.1.6. Clast lithofacies 475
11.2. Conclusions 477
11.2.1. Bed 10 477
11.2.2. Bed 12 479
11.2.3. Bed 14 480

REFERENCES 486
Appendix 5. Conodont overgrowth 527
Appendix 6. Previous work 529
Appendix 7. Appalachian conglomerates 533
Appendix 8. Similar deposits 538
Appendix 9. Recent megaconglomerates 540
Appendix 10. Clast faunas 542

List of Figures

Figure 1-1:	Study area with localities	2
Figure 1-2:	Schematic diagram illustrating the relationship between shelf- and slope deposits.	4
Figure 2-1:	Principal rock units of autochtonous platformal sequences and allochthonous slope successions in western Newfoundland	11
Figure 2-2:	Geological map of the Cow Head area and map of Lower Head.	13
Figure 2-3:	Maps of Cow Head Peninsula and Stearing Island (from James and Stevens, 1986).	14
Figure 2-4:	Maps of areas studied at St. Pauls Inlet, Martin Point and Western Brook Pond.	15
Figure 2-5:	Occurrences of outcrops of Arenig conglomerates in the Cow Head area.	16
Figure 2-6:	Proximal sections of Arenig age of the CHG.	18
Figure 2-7:	Distal sections of the Arenig part of the Cow Head Group.	20
Figure 2-8:	Lithostratigraphy of the Arenig part of the St. George Group.	25
Figure 2-9:	Diagram illustrating interpretive crossection of Early Ordovician Cow Head strata.	29
Figure 3-1:	Correlation chart of Cow Head conodonts with other key areas and fossil groups	40
Figure 4-1:	Composition of the *Prioniodus-Texania* Biofacies	56
Figure 4-2:	Conodont biofacies distribution and composition during Bed 9/10 time	61
Figure 4-3:	Composition of the *Prioniodus - Periodon* Biofacies	64
Figure 4-4:	Conodont biofacies distribution and composition during lower Bed 11-time.	66
Figure 4-5:	Composition of the *Periodon - Texania* Biofacies	68
Figure 4-6:	Conodont biofacies distribution and composition during upper Bed 11-time	72
Figure 4-7:	Composition of the *Periodon - Parapanderodus* Biofacies	75
Figure 4-8:	Conodont biofacies distribution and composition during Bed 13/14 time	79

Figure 4-9:	Relationship of biofacies composition and sealevel history.	82
Figure 5-1:	Lateral views of acodontiform element 1.	94
Figure 5-2:	Lateral views of acodontiform element 2.	96
Figure 5-3:	a) Posterior, b) lateral view of element of *A.* sp. aff. *A. latus*.	98
Figure 5-4:	a) Posterior and b) lateral view of *Acontiodus* sp. 2 showing cross section of cusp and outline of basal cavity.	100
Figure 5-5:	Lateral views of a) asymmetrical and b) symmetrical elements of *Drepanodus*? sp. 1.	106
Figure 5-6:	Sketch of drepanodontiform element 1 showing cross sections of cusp and outline of basal cavity.	109
Figure 5-7:	Lateral views of drepanodontiform element 2.	110
Figure 5-8:	Lateral views of two different specimens of *Oistodus* sp. 1 s.f.	121
Figure 5-9:	Lateral views of oistodontiform element 2.	123
Figure 5-10:	Aboral and lateral views of oistodontiform element 3.	124
Figure 5-11:	A) Acostate and b) costate elements of *Paltodus*? sp. s.f.	126
Figure 5-12:	Lateral view of *Parapanderodus* sp. 1 illustrating deep basal cavity, cross section of cusp and outline of basal cavity.	132
Figure 5-13:	Lateral views of *Protoprioniodus* sp. 1.	161
Figure 5-14:	Illustrations of a) drepanodontiform, b) bicostate and c) unicostate scandodontiform elements of *Scalpellodus* sp 1.	165
Figure 5-15:	Elements of *"Scandodus" pseudoramis*.	168
Figure 5-16:	1) Costate and 2) acostate element types of scandodontiform element 1.	170
Figure 5-17:	Lateral view of scandodontiform element 2.	172
Figure 5-18:	Posterior (a) and lateral (b, c) views of *Scolopodus multicostatus*.	174
Figure 5-19:	a) Posterior and b) aboral-lateral views of *?Scolopodus* sp.	176
Figure 5-20:	a) Postero- and b) antero-lateral views of scolopodontiform element 1.	178
Figure 5-21:	Comparison of elements of different species of *Texania*.	185
Figure 5-22:	Comparison of apparatuses of different genera related to *Texania*	188
Figure 5-23:	Elemental composition of the apparatus of *Tripodus* sp. aff. *T. laevis*.	196
Figure 5-24:	Lateral views of a) the trichonodelliform and b) the drepanodiform element of *Tripodus* sp.	198
Figure 5-25:	a) Posterior and b)anterior views of New Genus A new species 1.	202
Figure 5-26:	a) Antero-lateral and b) posterior view of New gen. A n.sp. 2.	203

Figure 5-27:	a) Anterior and b) posterior views of New Genus B new species 1.	205
Figure 5-28:	Lateral view of New Genus C new species 1.	206
Figure 6-1:	Conglomerate types in the Cow Head Group.	237
Figure 6-2:	Origin of clasts found in the megaconglomerates of the Cow Head Group	240
Figure 6-3:	Bio- and lithostratigraphy of Bed 10 and equivalents.	247
Figure 6-4:	Sketch of Bed 10 at Lower Head.	249
Figure 6-5:	Field sketch of Bed 10 as seen at the seaward outcrop at The Ledge.	250
Figure 6-6:	Clast counts and clast/matrix ratios in Bed 10 and equivalent conglomerates of the proximal facies.	253
Figure 6-7:	Field sketch of Bed 10 exposed in St. Pauls Inlet	255
Figure 6-8:	Clast counts and clast/matrix ratios of Bed 10 and equivalents.	258
Figure 6-9:	Clast counts and clast/matrix ratio of Bed 12-conglomerates.	261
Figure 6-10:	Bio- and lithostratigraphy of Bed 12 and equivalents.	264
Figure 6-11:	Field sketch of Bed 12 at Martin Point South	267
Figure 6-12:	Field sketch of Bed 12 at Western Brook Pond-South	269
Figure 6-13:	Clast counts and clast/matrix ratios of Bed 12 equivalents in the distal facies.	271
Figure 6-14:	Bio- and lithostratigraphy of proximal sections of Bed 14.	274
Figure 6-15:	Clast counts and clast/matrix ratios of proximal sections of Bed 14.	277
Figure 6-16:	Field sketch of Bed 14 at Martin Point South	279
Figure 6-17:	Clast counts and clast/matrix ratio in distal sections of Bed 14.	282
Figure 6-18:	Comparison of percentages of local, foreign and old clasts in different conglomerates.	293
Figure 6-19:	Abundances of local and foreign clasts in beds 10, 12 and 14.	296
Figure 7-1:	Geomorphology of the slope and its environs.	300
Figure 7-2:	Different types of rhythmic limestones among local penecontemporaneous clasts. Scale is 1:10	306
Figure 7-3:	Diagram illustrating inferred relationships between different types of calcirudite.	337
Figure 8-1:	Types of burrows in foreign clasts of Bed 12.	363
Figure 9-1:	Conglomeratic clast lithologies in Bed 14.	400
Figure 10-1:	Abundances of foreign lithologies in counted sections	440
Figure 10-2:	Reconstruction of the shelf margin during Bed 9-time	450
Figure 10-3:	Development of the shelf margin from lower to upper Bed 11-time	462

Figure 10-4: Reconstruction of the shelf margin during Bed 13-time 469
Figure 11-1: Diagram illustrating the evolution of the shelf margin and the succession of biofacies. 481

List of Tables

Table 6-1:	Summary of conglomerate descriptions of Bed 10 and equivalents.	244
Table 6-2:	Summary of conglomerate descriptions of Bed 12 and equivalents.	245
Table 6-3:	Summary of conglomerate descriptions of Bed 14 and equivalents.	246
Table 7-1:	Local clasts of Bed 10.	303
Table 7-2:	Foreign clasts of Bed 10.	304
Table 7-3:	Older clasts in Bed 10.	305
Table 7-4:	Comparison of lithological characteristics of mound facies and massive wackestones of Bed 10.	323
Table 8-1:	Local clast lithologies in Bed 12.	351
Table 8-2:	Foreign clast lithologies in Bed 12.	352
Table 8-3:	Old clast lithologies in Bed 12.	353
Table 9-1:	Summary of local clast lithologies in Bed 14	395
Table 9-2:	Summary of foreign clast lithologies in Bed 14	396
Table 9-3:	Summary of old clast lithologies in Bed 14	397

Chapter 1
INTRODUCTION

The Cow Head Group (Kindle and Whittington, 1958) is located in western Newfoundland and is part of the Humber Zone, a major tectonostratigraphic element of the northern Appalachians (Williams, 1975, 1979). It comprises a sequence of bedded limestones, conglomerates and fine grained siliciclastics and extends along the west coast of Newfoundland from Portland Creek Pond in the north to Rocky Harbour in the south. To the east, Grenvillian rocks of the Long Range Mountains and to the south, the Gulf of St. Lawrence represent geographical boundaries. Much of the Cow Head Group lies within Gros Morne National Park which has been established to ensure preservation of the unique rocks. Excellent coastal exposures can be found over a distance of approximately 60km. The type sections and an informal stratigraphic nomenclature of the Cow Head Group were established on Cow Head Peninsula by Kindle and Whittington (1958). A new nomenclature was recently proposed by James and Stevens (1986) and their scheme is followed herein. These authors also provided a thorough review of the previous nomenclature to which the reader is referred.

In this thesis conglomerate horizons of Arenig age were investigated at several localities both along the coast and inland. From north to south these are Lower Head, Stearing Island, Cow Head Peninsula, St. Pauls Inlet, Martin Point and Western Brook Pond (Fig. 1-1). The clasts in the conglomerates are derived from the shelfedge and upper slope of the Cambro-Ordovician Iapetus Ocean

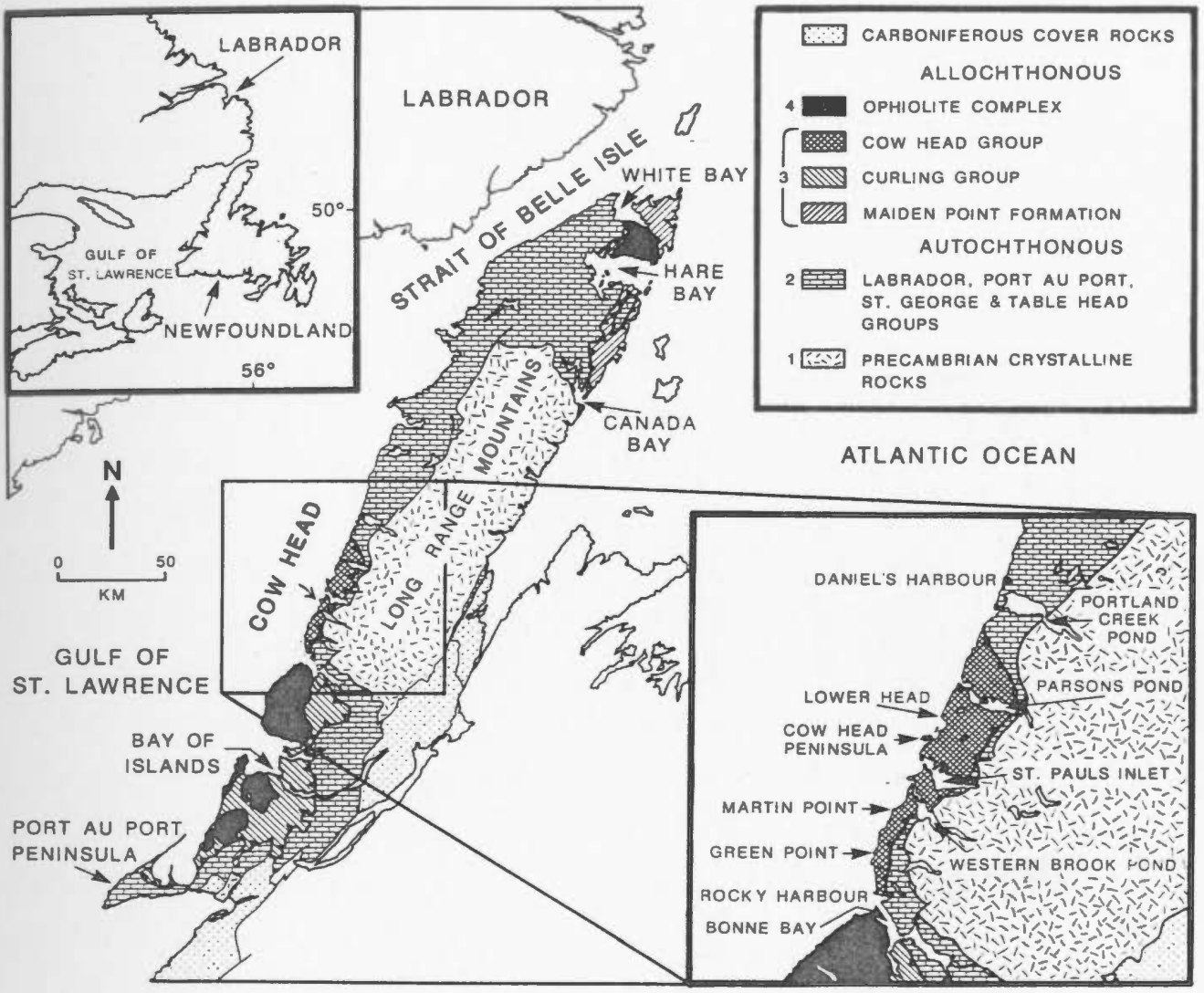


Figure 1-1: Study area with localities (after James and Stevens, 1986).

1.1. Purpose

The Cow Head Group is generally accepted to represent a well preserved, though tectonically complicated, fragment of the northwestern continental slope of the early Paleozoic Iapetus Ocean. Adjacent rocks are the remains of the coeval continental shelf (Port au Port, St. George and Table Head groups) and of the basin floor (Bay of Islands complex). The clasts and boulders within three Arenig mega-conglomerate horizons (beds 10, 12 and 14 of Kindle and Whittington, 1958) in the Cow Head Group are the focus of this study. These deposits are interpreted as debris flows (Hiscott and James, 1985) involving unstable coeval shelf and slope sediments and eroding locally into stratigraphically older strata. The flows came to rest at the toe of the ancient slope (James and Stevens, 1986) having assembled boulder to pebble sized clasts from the various facies belts across the shelfbreak down through the upper and lower slopes, (Fig. 1-2). The depositional setting of the Cow Head Group on the lower slope or deeper is indicated by the nature of the stratified sequences between the debris sheets (i.e. shales and thin-bedded hemipelagic limestones). Large rafts of bedded fine-grained peri-platform sediments within the conglomerates are different from underlying lithologies and must have been acquired up-slope. Other "foreign" boulders are of shallow water origin (James, 1981). Many of the clasts in the debris flows are fragments of a carbonate platform margin facies that was obliterated by later tectonism.

The shelf carbonates represented by the Port-au-Port, St. George and Table Head Groups have received recent attention by several authors (Stouge, 1984; Chow, 1986; Knight and James, in press). as have the lower slope deposits of the Cow Head Group (Hiscott and James, 1985; James and Stevens, 1986, Coniglio, 1985). The zone of the shelfbreak and upper slope in contrast represents a rarely preserved and therefore poorly understood segment of ancient margins, which is usually obstructed during orogeny. It represents a hinge-zone between two distinct faunal realms which enables study of distributional patterns and migrations and aids in correlating shelf and slope faunas. Furthermore the nature

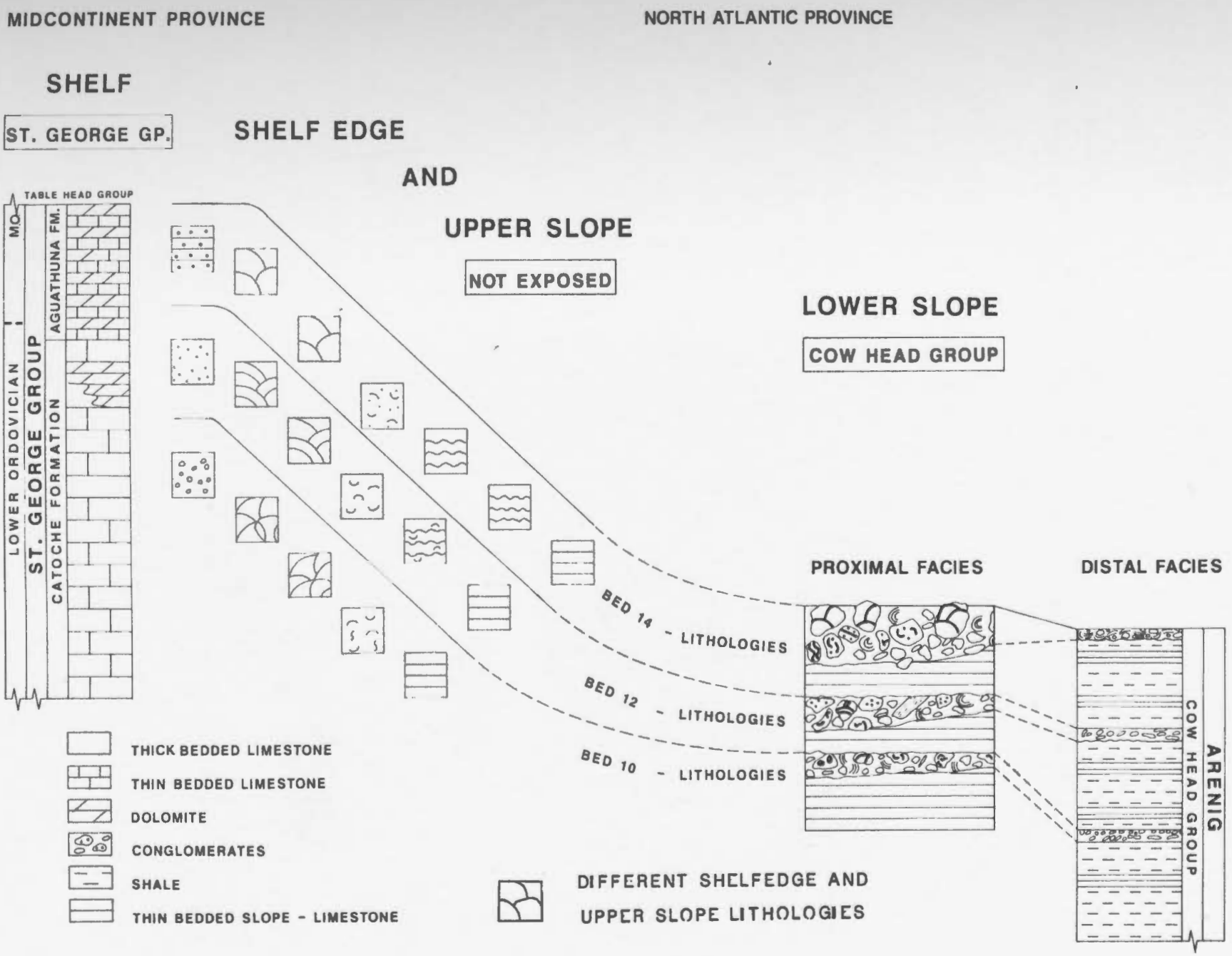


Figure 1-2: Schematic diagram illustrating the relationship between shelf- and slope deposits.

of upper slope and shelfbreak controls sedimentation on the lower slope and, to a certain degree on the shelf platform. The nature of the sedimentary "missing link" is thus important to understand shelf and slope sedimentation. This study is an attempt to reconstruct the inner margin (i.e. shelfedge and upper slope) with respect to sedimentology and conodont biofacies of the northwestern edge of the Iapetus Ocean as it existed during Arenig time. It employs data derived from the different clast lithologies found in the megaconglomerates through the combined application of carbonate lithofacies and conodont biofacies analysis.

1.2. Previous work

The Cow Head Group is famous for the unique preservation of a Cambro-Ordovician segment of a continental margin. It provides the opportunity to study an ancient margin and to correlate shelf- and deepwater faunas among many other aspects. Study of Cow Head rocks has a longer history than many other rocks in the province and several aspects of its geology and paleontology have been addressed in the last hundred years. James and Stevens (1986) have reviewed most of these contributions and documented the development of thought. The first report of the Cow Head Group was by Richardson (in Logan, 1863) who noted the presence of coarse conglomerates in the Cow Head region. At that time the Cow Head rocks were regarded as correlatives of the Quebec Group which in turn was considered to be a fragment of the continental margin of a Paleo-Atlantic which was transported westwards (Logan, 1863). The fossils collected by Richardson were subsequently described by Billings (1865). The first detailed stratigraphic study of the Cow Head area was conducted by Schuchert and Dunbar (1934). These authors recognized two separate lithological units in the area: 1. the Cow Head Limestone Breccia which includes rocks of the proximal slope facies of the Cow Head Group and younger conglomerates of the Cape Cormorant Formation (Klappa and James, 1980) and 2. the Green Point Formation (or series) which includes rocks of the distal Cow Head facies. The units were assigned Middle and Early Ordovician ages respectively. The origin of the coarse conglomerates was thought to be the result tectonic activity. Johnson

(1941) reexamined the Cow Head area and recognized the different ages of rocks included in the Green Point Series. He divided the rocks into Green Point Group, Western Brook Pond Group and St. Pauls Group. His graptolite collections were studied by Ruedemann (1947). Oxley (1953) mapped the area between St. Pauls and Parson's Pond and recognized several thrust belts which led him to emphasize the tectonic origin of the Cow Head conglomerates. Nelson (1955) mapped north of Cow Head in the Portland Creek area. He noted the limited range of lithologies within his breccia units and concluded that they were the result of localized earthquakes. Kindle and Whittington (1958) carried out the first detailed paleontological study and recognized that the faunas contained in the rocks are late Middle Cambrian to early Middle Ordovician in age. They established the type section of the Cow Head Group on Cow Head Peninsula and divided it informally into 14 units (beds 1-14). They described the trilobite and graptolite faunas (Kindle and Whittington, 1958, 1959; Whittington, 1963; Kindle, 1982) and interpreted the Cow Head Group as a flysch deposit and the conglomerates as intraformational, brought into place by sliding down submarine slopes. Baird (1960) mapped the area around Cow Head and discussed the origin of the conglomerates. He recognized both shallow and deepwater conglomerates concluding that they were derived from fault scarps. He also included the Cape Cormorant conglomerates in the Cow Head Group. The regional relationships of the Cow Head Group were addressed in an important contribution by Rodgers and Neale (1963). They, too, recognized the similarity of the geology of western Newfoundland with that of the Taconic region and suggested that the coastal rocks exposed from Parsons Pond to Bay of Islands represent a "Taconic Klippe" emplaced by gravity sliding at their present location on top of the carbonate platform. Stevens (1970) named the Humber Arm Supergroup and divided it into proximal (Cow Head Group) and distal (Curling Group) sequences. He suggested that the steep oceanward edge of a carbonate platform was the source for the coarse conglomerates. Erdtmann's (1971) study of graptolites from the Cow Head Group and adjacent sequences in central Newfoundland indicated that faunas of Pacific and Baltic provincial aspect are present. He suggested that western and

central Newfoundland faunas were separated by a physical barrier such as an island arc system. Closure of the Iapetus ocean united these faunas now found in neighbouring rocks. Callahan (1974), Fahraeus et al. (1974), Jansa (1974) and Nowlan (1974) examined various aspects of sedimentology and paleontology of the Cow Head Group. Callahan's contributions were later included in a publication by Hubert et al. (1977). Based on field measurements these authors suggested a complex platform-slope model with two southeast dipping carbonate shelf platforms as source areas for sediments. Suchecki et al. (1977) studied the clay mineralogy of Cow Head sediments and determined three different types of clay, some of which seem to be derived from Mg-rich volcanic detritus. Some results of Fahraeus (1970) and Nowlan (1974) were later published in Fahraeus and Nowlan (1978). These authors were the first to give an account of the conodont biostratigraphy of Cow Head Peninsula. James (1981) studied the nature of white limestone boulders found in some of the megaconglomerates and concluded that they are the remains of *Epiphyton* algal buildups which grew along the shelfedge. James and Stevens (1982) provided a preliminary summary of Cow Head stratigraphy followed by a detailed monograph in 1986. Hiscott and James (1985) investigated the nature of the different conglomerates which are distinct sedimentary facies of the proximal Cow Head Group and concluded that most conglomerates are debris flow deposits and turbidites. They also suggested that the shallow water carbonate platform margin progressively steepened through time causing larger and coarser debris flows. Coniglio (1985) completed a PhD thesis on the sedimentology of fine grained sediments of the Cow Head Group and has published on the origin and diagenesis of the sediments (Coniglio and James, 1984; 1985).

1.3. Methods of study

1.3.1. Conodont biofacies

300 conodont samples were collected, mainly from conglomerate clasts with 30 from the bedded sequence and conglomerate matrices. Each sample weighed an average of 3 kg. Samples were processed in 10-15% acetic acid or in 10% formic acid in case of dolomite rich lithologies. Acid residues were separated with tetrabromoethane at S.G. 2.83. Techniques are discussed in detail in Austin (1987). Selected conodont species were photographed with a light microscope (Wild M 400) or with a scanning electron microscope (Hitachi S 570).

1.3.2. Carbonate lithofacies

Study of the carbonate lithofacies of clasts in the debris flows is essential to interpretation of their possible origin. Depending on where the flow originated, the clasts incorporated in the debris sheets may have been derived from the shelf, shelf edge, upper slope, middle to lower slope or from older eroded underlying strata. In an attempt to classify and distinguish the nature and the abundance of clasts contributed from each of the environments cited above the following procedures were applied:

1. Determination of the different clast lithologies in the field. This included classification of the boulders and clasts contained in the conglomerate beds and description of their lithologies. To understand the lateral and vertical facies relationships, detailed study focusses mainly on the large boulders (over 30 cm in diameter or length) because they display the entire spectrum of variability within each lithofacies.

2. Determination of abundances of the different clasts. To recognize all the lithologies present, $5m^2$ areas were chosen and demarcated in selected outcrops in which all clasts over 10 cm maximum diameter or length were classified according to their lithofacies and then point-counted using a 10 cm spaced grid. The results of the count were converted to percentages.

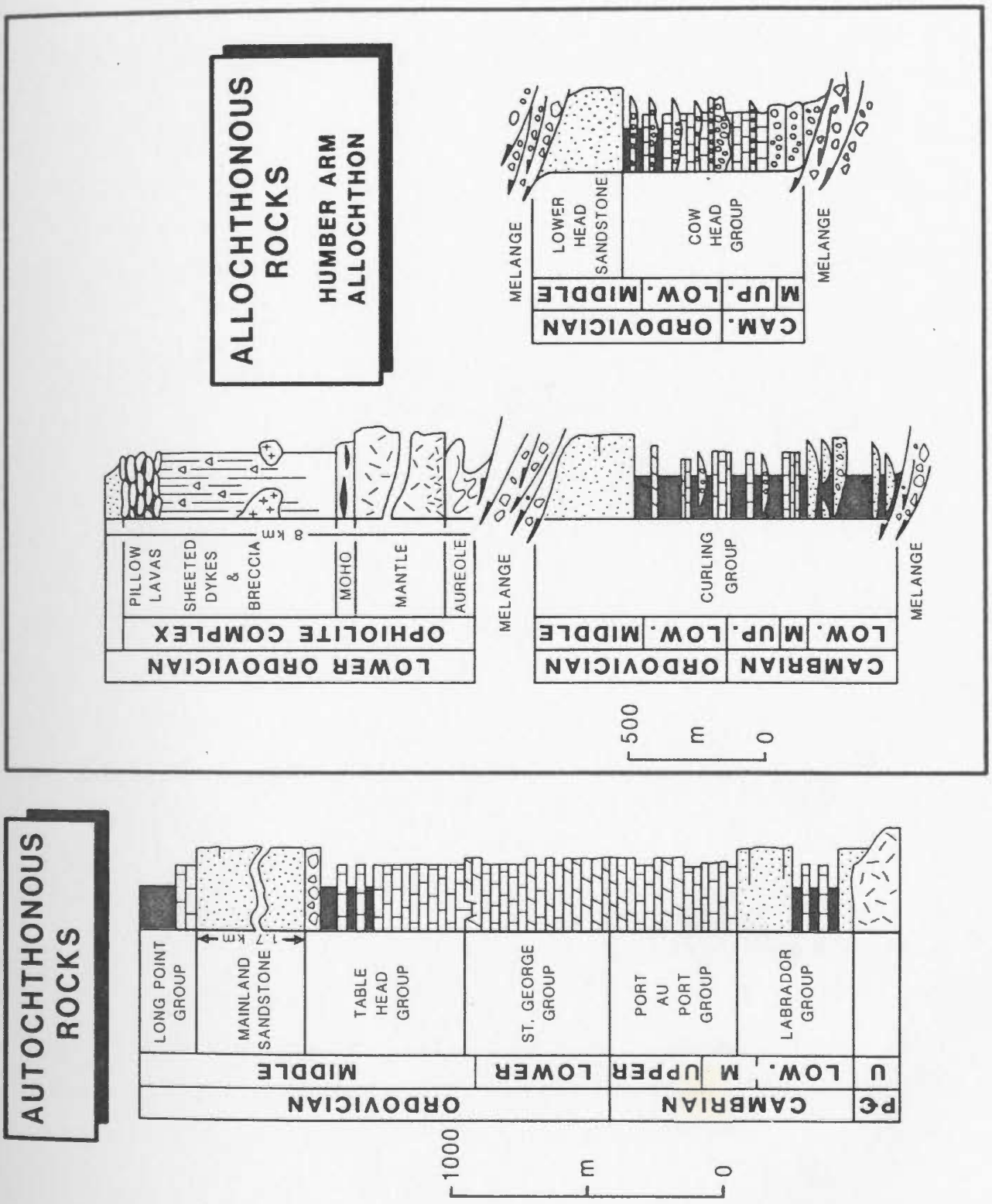
Lithofacies types are described using additional information derived from 500 thin sections, polished slabs, acetate peels and acid residues. The carbonate classifications of Folk (1972) and Dunham (1962) with the additions of Embry and Klovan (1972) were used. To distinguish dolomites and limestones as well as ferrroan carbonates most thin sections were stained with Alizarin Red-S and potassium ferricyanide applying the procedure outlined in Dickson (1966). Thin section photomicrographs were taken with a Wild M 400 Photomakroskop.

Chapter 2
GEOLOGIC SETTING

2.1. General geologic setting

The Middle Cambrian to Middle Ordovician Cow Head Group comprises a 300-500m thick succession of sedimentary rocks which are interpreted as a carbonate slope apron, deposited on the flank of the late Precambrian to lower Paleozoic Iapetus Ocean and subsequently transported westward (James and Stevens, 1986). The sediments occur in a series of southeast dipping thrust slices and are composed of coarse conglomerates, calcarenites, bedded limestones, shales, cherts, dolomitic siltstones and quartz-rich calcarenites. Overlying green sandstones (Lower Head Sandstone) are interpreted as flysch deposits. Shale-dominated sequences which occur south and north from the Cow Head outcrops in the Humber Arm Allochthon, were included in the Curling Group (Stevens, 1970). The Lower Cambrian to Middle Ordovician Curling Group is currently subject to revision (James et al, in press). Both groups together constitute the Humber Arm Supergroup which is interpreted as part of a continental slope-rise complex (Stevens, 1970) with a restored width of at least 200km (Williams, 1979). The sedimentary thrust slices are structurally overlain by the Bay of Islands and Hare Bay ophiolite suites which are interpreted as transported fragments of obducted ocean floor and mantle (Church and Stevens, 1971; Searle and Stevens, 1984) (Fig. 2-1). Rocks of the Fleur de Lys Super Group exposed at Baie Verte and on the westside of White Bay are interpreted as metamorphosed equivalents of the Cow Head and Curling groups. (Stevens, 1970; Bursnall and de Witt, 1975; Lock, 1972). During the Taconic Orogeny eastward imbricated slices of ophiolite travelled towards the western flank of the ocean basin in Lower to Middle

Figure 2-1: Principal rock units of autochtonous platformal sequences and allochthonous slope successions in western Newfoundland (after James and Stevens, 1986).



Ordovician times and were finally obducted onto the platform (Rodgers and Neale, 1963; Stevens, 1970). As a result of possible aborted subduction and of tectonic loading during emplacement of the allochthonous suites the Middle Ordovician platform foundered and easterly derived diachronous flysch capped first the slope complexes (Lower Head Sandstone) and then the platformal successions (Mainland Sandstone) (Williams et al., 1984). Slope sediments were subsequently thrust westward and emplaced on the shallow water carbonate platform (Stevens, 1970; Williams, 1979). The transported rocks now found along the west coast of Newfoundland comprise the Humber Arm Allochthon. They were emplaced during the Llandeilo or early Caradoc being overlain by the early Caradoc Long Point Group (Fahraeus, 1973; Bergström et al, 1974); the Hare Bay Allochthon in the north may have been emplaced somewhat earlier (Stevens, 1970; James and Stevens, 1986). Adjacent to and underlying the allochthons is a 2000m thick sequence of shallow water carbonates and siliciclastics ranging from Lower Cambrian (Port au Port Group) to Middle Ordovician (St. George and Table Head groups). This platformal sequence rests on Grenville (Precambrian) crystalline basement.

The geological maps of Oxley (1953) and Williams et al. (1985) show northeast-southwest striking repeated belts of Cow Head successions which dip to the southeast. These belts are interpreted as thrust slices (cf. Fleming, 1970) which show important changes from NW to SE. The facies changes include a decrease in clast size in the conglomerates and increase in shale from NW to SE and are characteristic of proximal to distal slope deposition. Rocks of the proximal facies are found at Lower Head, on Stearing Island and on Cow Head Peninsula (Figs. 2-2, 2-3), those of the distal facies at St. Pauls Inlet, Broom Point, Martin Point, Western Brook Pond and Green Point (Fig. 2-4). Occurrences of the Arenig conglomerate horizons are plotted on Fig. 2-5. The different successions have been grouped into 4 separate belts by James and Stevens (1986, p. 18): 1. Shallow Bay Belt; 2. Broom Point Belt; 3. Central Ridge Belt; 4. Inner Ridge Belt.

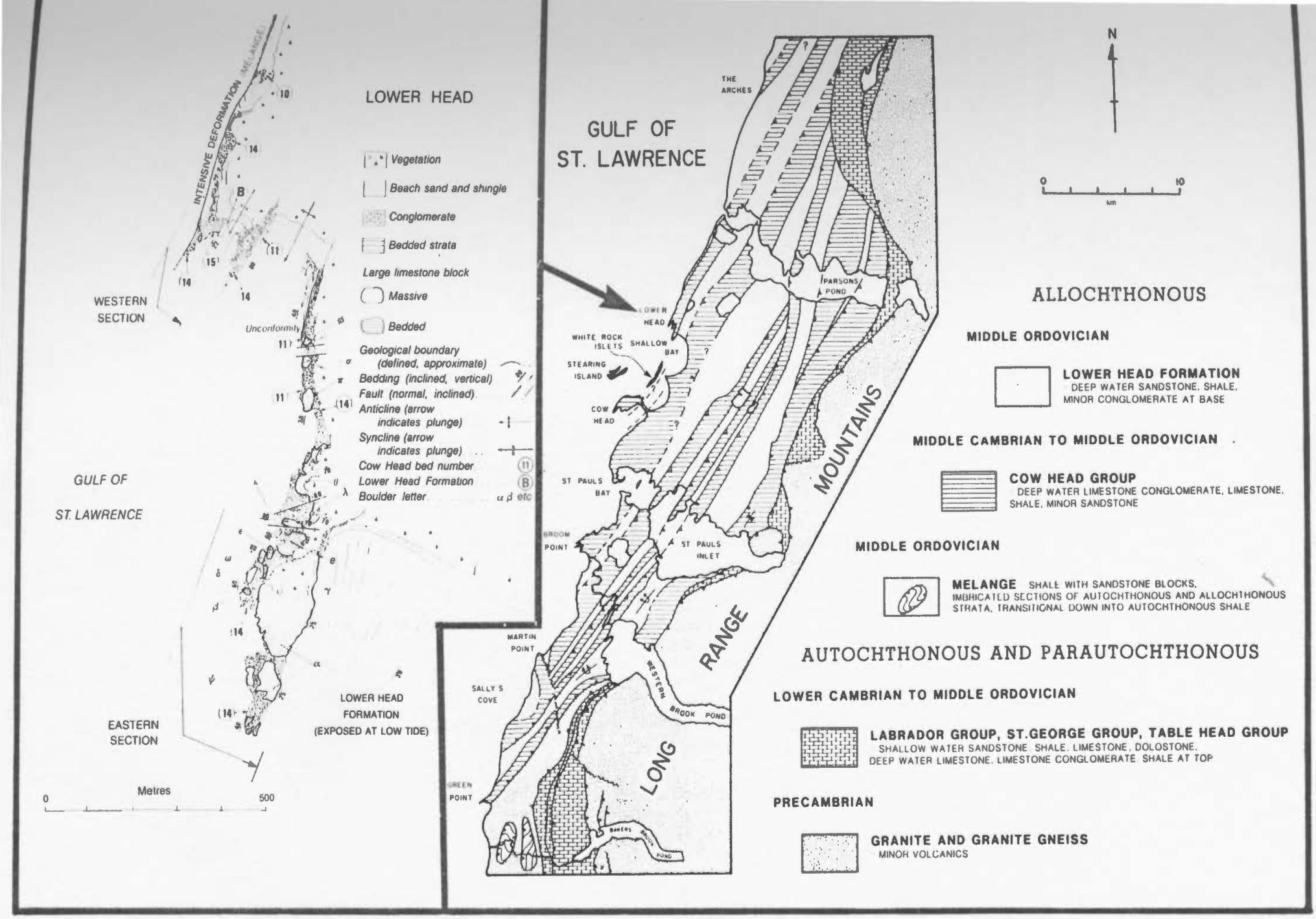
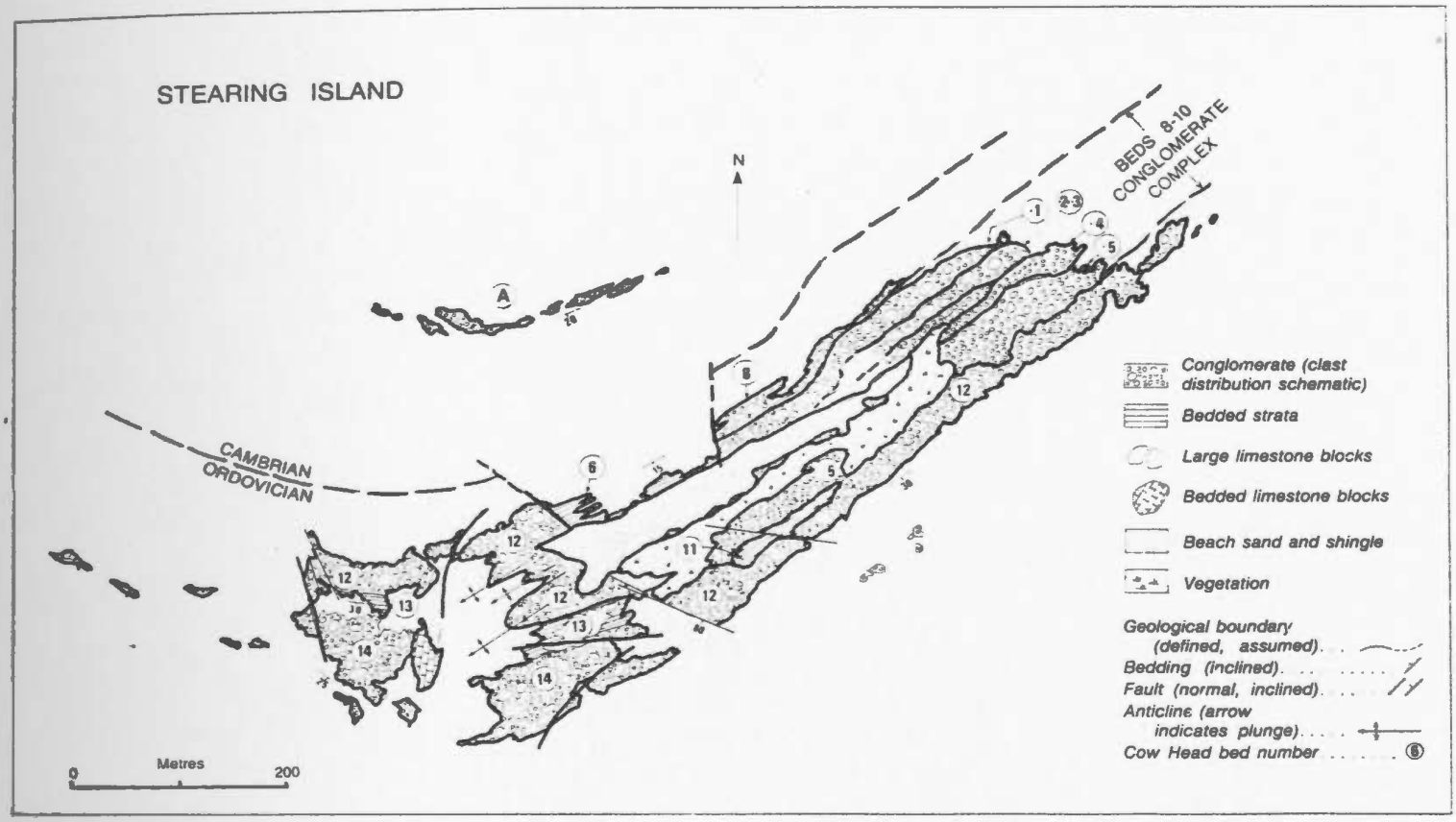


Figure 2-2: Geological map of the Cow Head area and map of Lower Head (from James and Stevens, 1986).

Figure 2-3: Maps of Cow Head Peninsula and Stearing Island (from James and Stevens, 1986).



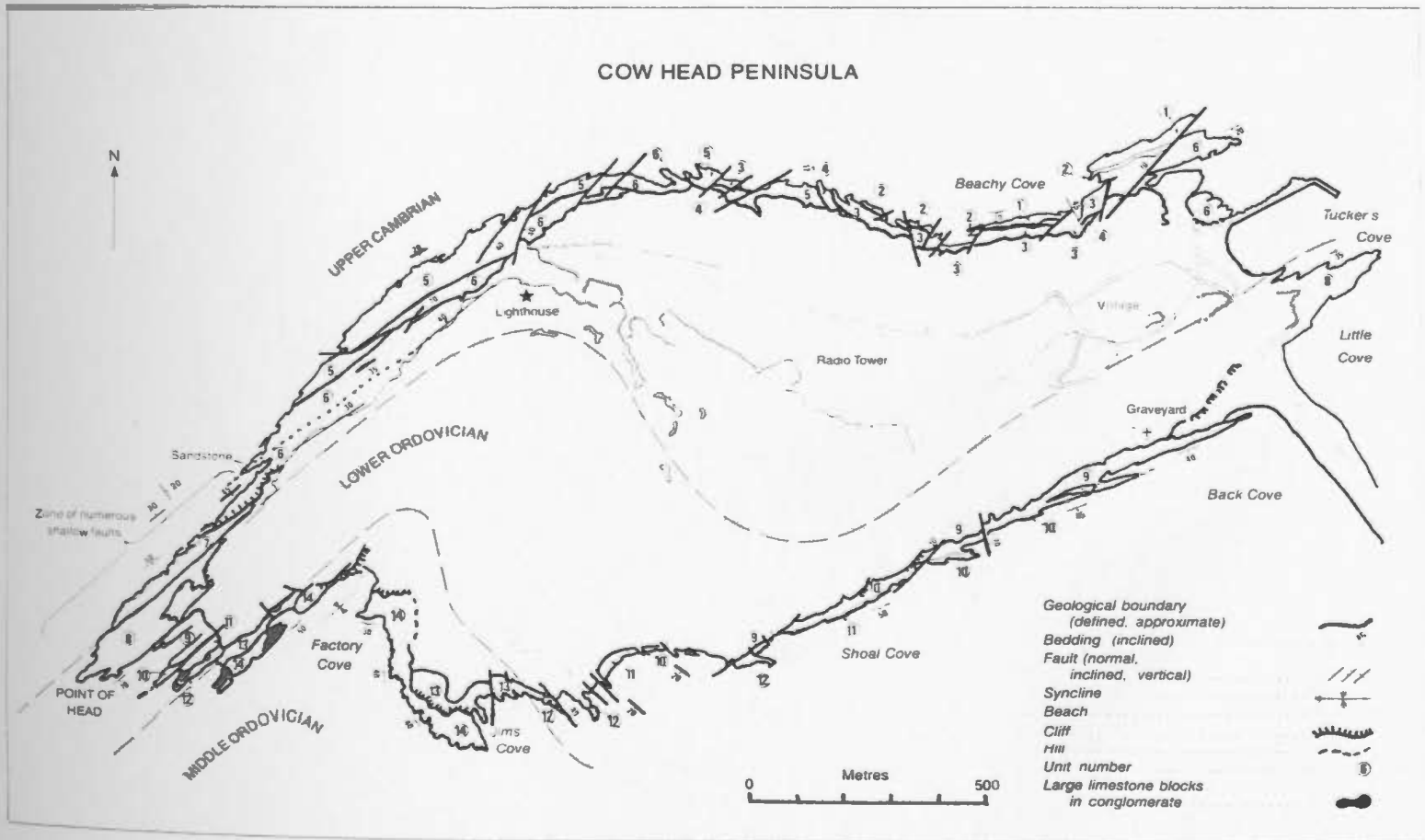


Figure 2-4: Maps of areas studied at St. Pauls Inlet, Martin Point and Western Brook Pond (from James and Stevens, 1986).

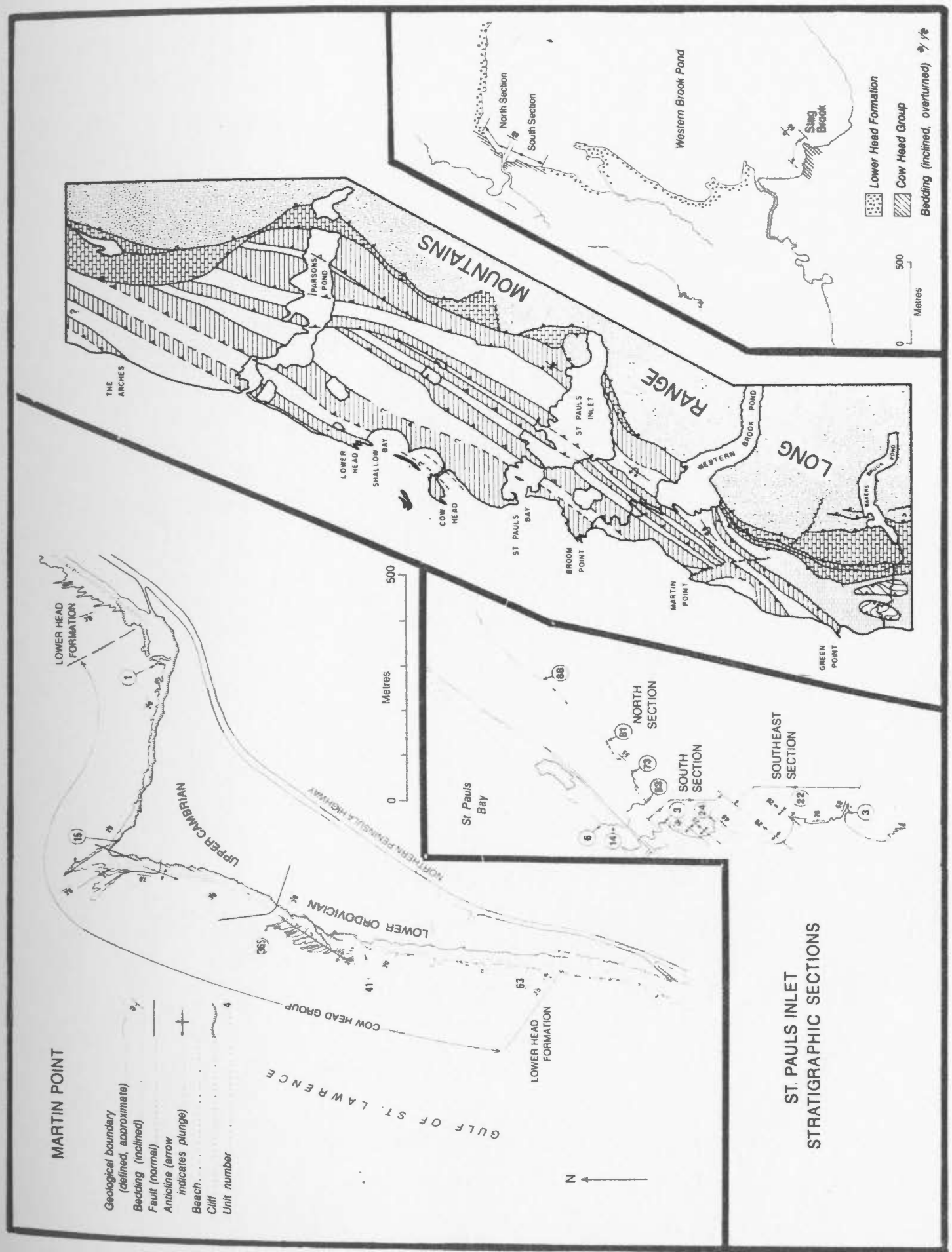
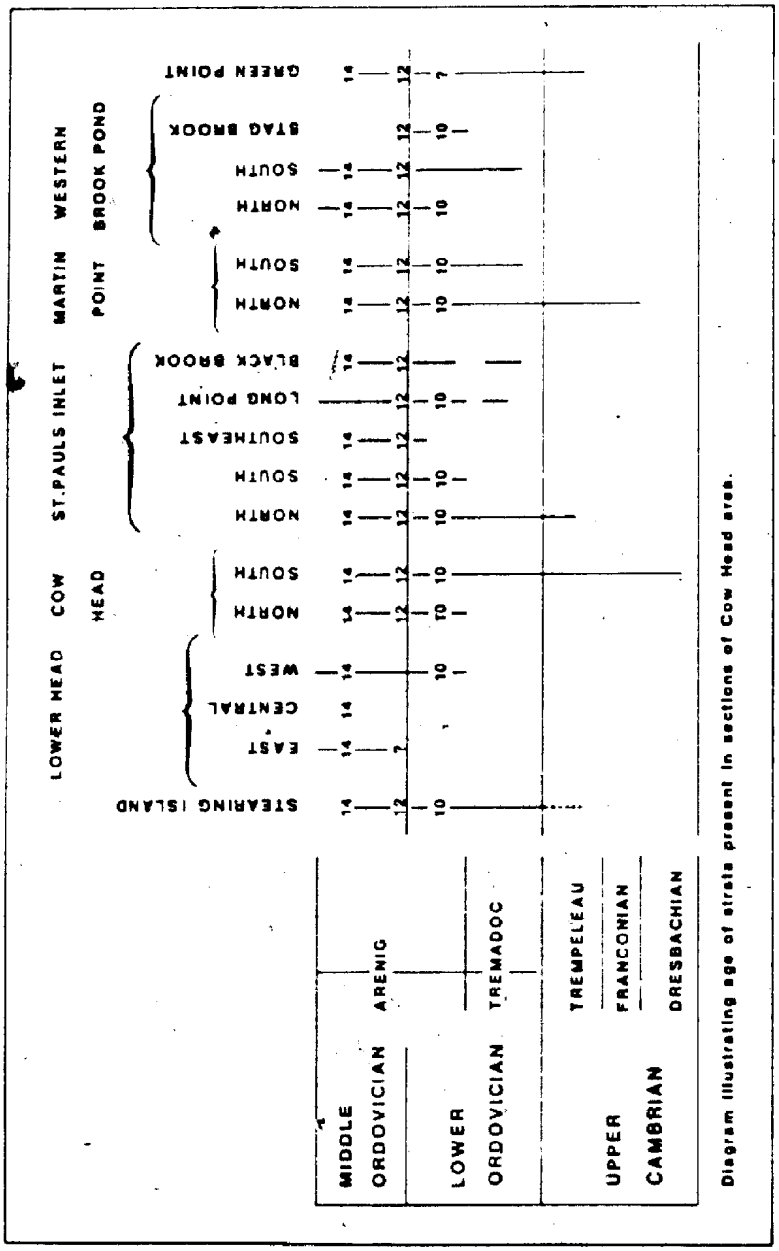


Figure 2-5: Occurrences of outcrops of Arenig age in Cow Head area (after James and Stevens, 1986).

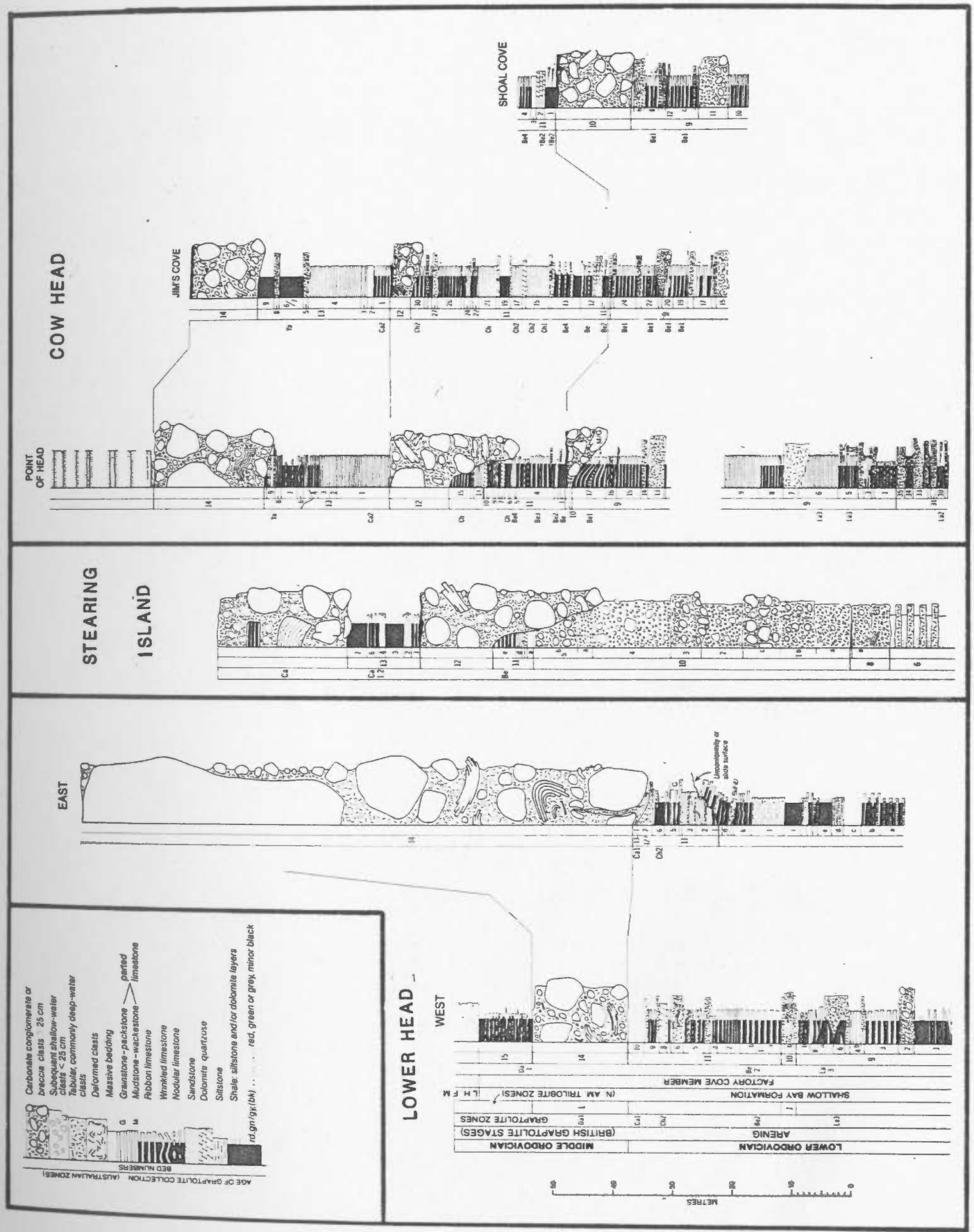


2.2. Stratigraphy

Proximal and distal facies of the Cow Head Group (hereafter commonly abbreviated to CHG) were divided into two new coeval formations by James and Stevens (1986, after lead of Williams et al., 1985). The coarse-grained facies in the northwest is termed the Shallow Bay Formation, the finer-grained shaly facies in the southeast the Green Point Formation. Both are subdivided into several members: the Shallow Bay Formation includes 1. the Downes Point Member, a 100m thick sequence of late Middle Cambrian to early Upper Cambrian conglomerates which includes beds 1-5 of Kindle and Whittington (1958); 2. the Tuckers Cove Member is a 60m thick sequence of late Cambrian age comprising quartz-rich calcarenite conglomerates, minor ribbon limestone, sandstone, siltstone and shale. It includes all of Bed 6; 3. the Stearing Island Member comprises an 80m thick succession of megaconglomerates with minor quartz-rich calcarenites and shale ranging from Late Cambrian to Early Ordovician (Tremadoc) in age. It includes beds 7 and 8; 4. the Factory Cove Member comprises a 100m thick sequence of ribbon and parted limestone and minor shale intercalated with beds of boulder and megaconglomerate, of Lower to Middle Ordovician age and including beds 9-15 (Fig. 2-6).

The Green Point Formation was subdivided into three members: 1. the Martin Point Member is a 100-150m thick sequence of green and black shale with partings and layers of ribbon limestone, minor siltstone and calcareous sandstone, and is Late Cambrian in age; 2. the Broom Point Member is an 80m thick sequence of ribbon to parted limestone of Tremadoc age; 3. the St. Pauls Member is a 130-150m thick sequence of red, green and black shale, limestone, limestone conglomerate, siltstone and dolomite of Upper Canadian to Lower Whiterock age (Fig. 2-7). Rocks of the Cow Head Group are overlain by over 1700m of green sandstone of the Lower Head Formation which represents a Middle Ordovician flysch.

Figure 2-6: Proximal sections of Arenig age of the CHG (from James and Stevens, 1986).



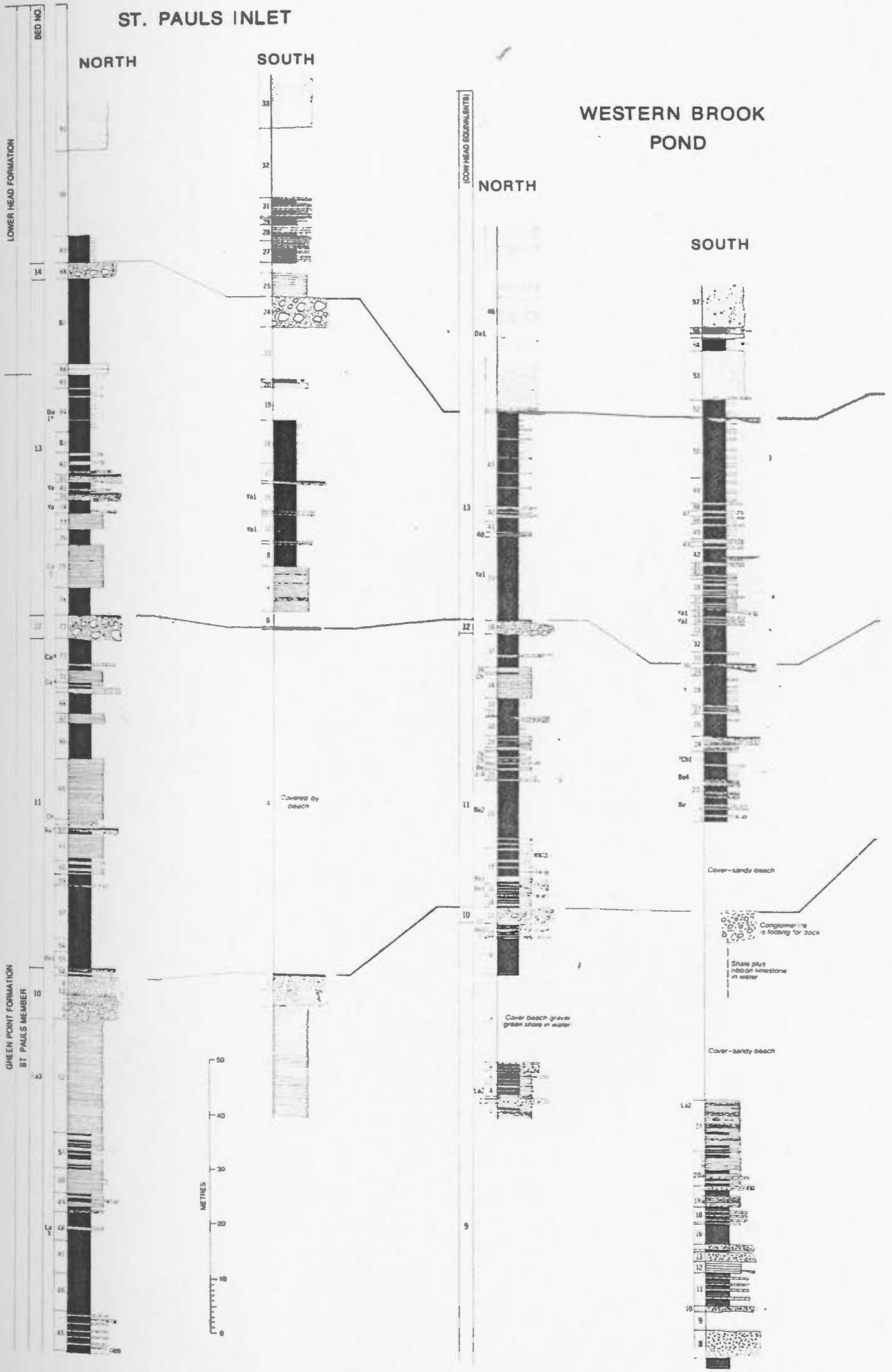
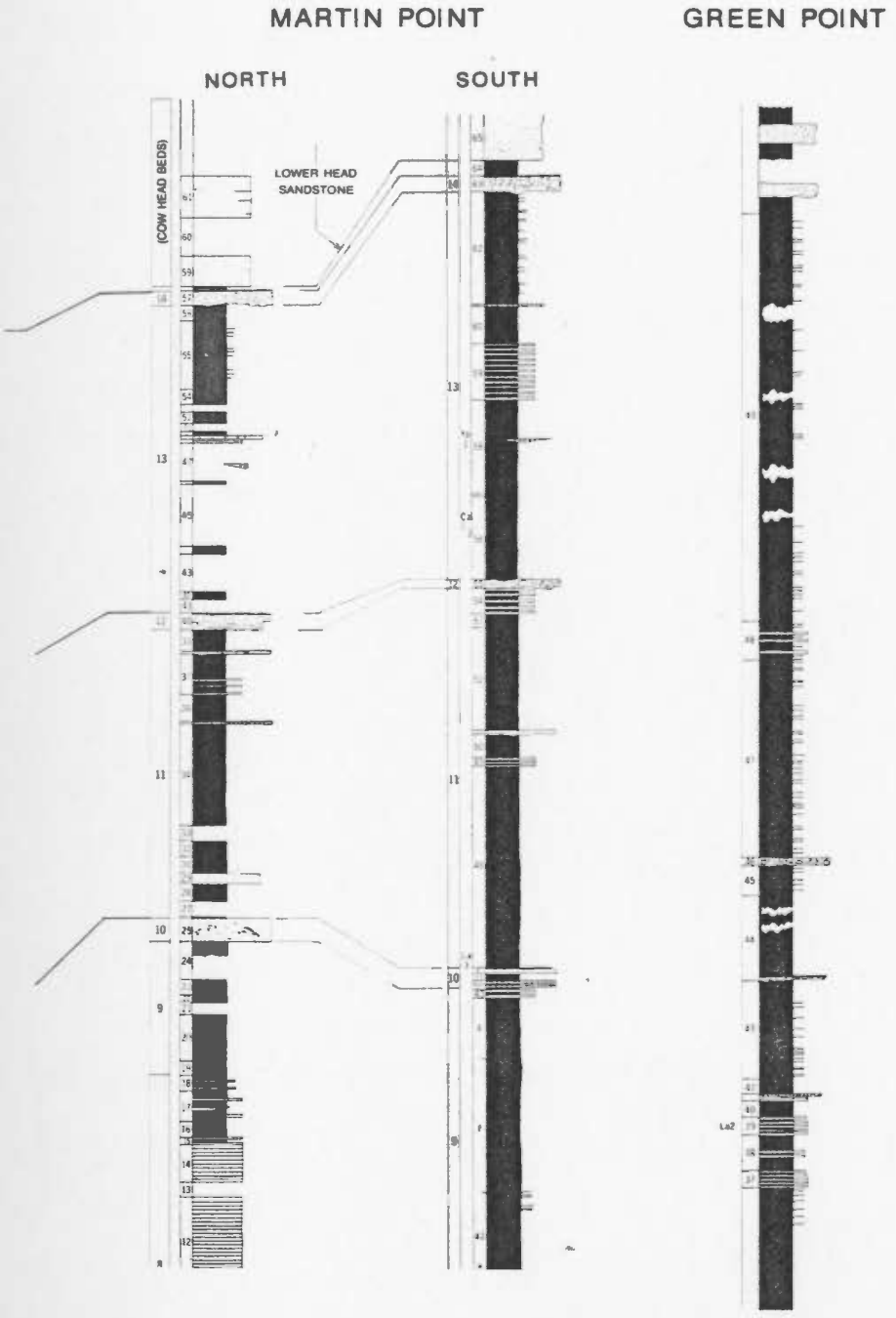

ST. PAULS INLET
NORTH
SOUTH
WESTERN BROOK POND
NORTH
SOUTH
BED NO.
LOWER HEAD FORMATION
GREEN POINT FORMATION
ST PAULS MEMBER
(COW HEAD EQUIVALENTS)
METRES
Covered by beach
Cover beach gravel green shale in water
Cover-sandy beach
Cover-sandy beach
Shale plus ribbon limestone in water

Figure 2-7: Distal sections of the Arenig part of the CHG (from James and Stevens, 1986).



2.3. Sedimentology

Sediments of the CHG are a mixture of hemipelagites and sediment gravity flows. The hemipelagites include limestone rhythmites, shales and siltstones. The shales are green, black or dark grey and were deposited under anaerobic or dysaerobic conditions or are red and bioturbated, indicating deposition in an oxygenated environment. Dolomitic siltstones are partly detrital and partly diagenetic in origin (Coniglio, 1985). The limestone rhythmites include parted to ribbon limestones composed of lime mudstone, graded calcisiltite and rippled calcarenite. The sediments lithified relatively early on the sea floor indicated by their presence as undeformed plates in the conglomerates. The conglomerates were subdivided into 5 types (Hiscott and James, 1985): 1. Graded stratified conglomerate; 2. limestone plate conglomerate; 3. limestone chip conglomerate; 4. boulder conglomerate; 5. megaconglomerate (Fig. 6-1). The last four conglomerate types were interpreted as debris flow deposits, the first type as turbidite. Chert is a diagenetic product which is found more commonly in the Ordovician part of the sequence replacing limestone rhythmites, tops of conglomerate beds and shales. Cherts were also incorporated as clasts into the conglomerates and must have formed early. The rocks of the Cow Head Group have been studied by James and Stevens (1986) and their descriptions and interpretations are summarized in the following section.

2.4. Stratigraphy of Arenig units of the slope sequence

The Arenig part of the Shallow Bay Formation consists of the Factory Cove Member with beds 9 through 15 (Fig. 2-6); in the Green Point Formation the St. Pauls Member includes rocks of this age (Fig. 2-7). The proximal strata contain the megaconglomerate horizons which are the main focus of this study (see Chapter 1).

2.4.1. Beds 9 and 10

Bed 9 (Pl. 6.1, Fig. 2) in the proximal facies is up to 50m thick and displays abundant carbonate rhythmites with evenly bedded to nodular limestone layers separated by black and green shales. Fine-grained limestone rhythmites are common in the lower part of Bed 9 while near the top calcarenites dominate. On Stearing Island welded conglomerates occur (Fig. 2-6). Equivalent deposits of the distal facies are red shale with locally interbedded green and black shale. Parted and ribbon limestones and conglomerates are rare (Fig. 2-7). Bed 10 (Pl. 6.1, fig. 2, Fig. 6-8) is a conglomerate of variable thickness that cannot be correlated easily over long distances (e.g. 10km). It represents a complex of different conglomerates referred to as the Bed 10-complex (James and Stevens, 1986).

2.4.2. Beds 11 and 12

Bed 11 varies from 10 to 35m in thickness in the Shallow Bay Member and in the lower part is dominantly composed of dark shale, silicified limestone and phosphatic conglomerate. Spiculitic and radiolarian-rich limestone is common. The top half of Bed 11 is composed of parted to ribbon limestone and green-grey to black shale. Silty buff weathering dolomite punctuates the sequence (Fig. 2-6). In the distal facies the lower part of Bed 11 is mainly composed of dark green, red and black shale with chert commonly replacing bedded and conglomeratic limestone; calcarenite and phosphatic conglomerate are common. The upper part of Bed 11 is typically red and green shale and buff weathering dolomite with variable amounts of parted limestone and conglomerate (Fig. 2-7). Bed 12 is the most persistent of the three Arenig megaconglomerates and can be recognized in almost all localities (Fig. 2-5).

2.4.3. Beds 13 and 14

Bed 13 is 15-20m thick in the proximal facies with basal calcarenite and ribbon limestone. A central conglomerate unit may be present with limestone clasts, black chert fragments and phosphate granules. The upper part is usually shale (Fig. 2-6). In the St. Pauls Member Bed 13 is thicker (50-60m) probably because the top was not eroded by the overlying conglomerate (Bed 14). The lower part of Bed 13 is green and black shale locally with basal calcarenites and chert. In the middle part limestone plate conglomerates are present in some proximal sections (i.e. St. Pauls Inlet). Red shale is abundant in the upper parts and green sandstones top the sequence in St. Pauls Inlet sections. In more distal facies red shale represents the most common lithology (Fig. 2-7). Bed 14 contains the largest boulders of all megaconglomerates and is widespread in proximal and distal facies.

2.4.4. Bed 15

Bed 15 (James and Stevens, 1986) is present on Cow Head Peninsula with a few meter thick siltstone-shale units. In distal facies it comprises red shale and chert interbedded with coarse calcarenite. It commonly grades upward into green sandstone of the Lower Head Formation (Fig. 2-7).

2.5. Stratigraphy of the Upper Canadian to Lower Whiterock part of the shelf sequence

The sedimentation of the shelf sequence is reflected in the slope deposits and the shelfedge represents a hinge zone between the two sedimentary and faunal realms. The shelf carbonates are therefore described in some detail. Fig. 2-8 shows the lithostratigraphy of the contemporaneous St. George Group. Knight and James (in press) and James et al. (in press) have conducted a detailed study of the St. George Group and their results are summarized in the following section. The Arenig part of the Cow Head Group is coeval to the upper Boat Harbour, Catoche and Aguathuna formations of the St. George Group. The St. George

Group is part of the autochthonous shelf sequence and represents a ca. 500m thick succession of carbonates deposited in shallow subtidal to intertidal environments of a low latitude shelf platform (Swett et al., 1972; Knight, 1977; 1978; Knight and James, in press). Variations in deposition during this time interval reflect fluctuation in sea level possibly in response to early stages of Taconic orogeny (Barnes, 1984; Knight and James, in press; James et al., in press).

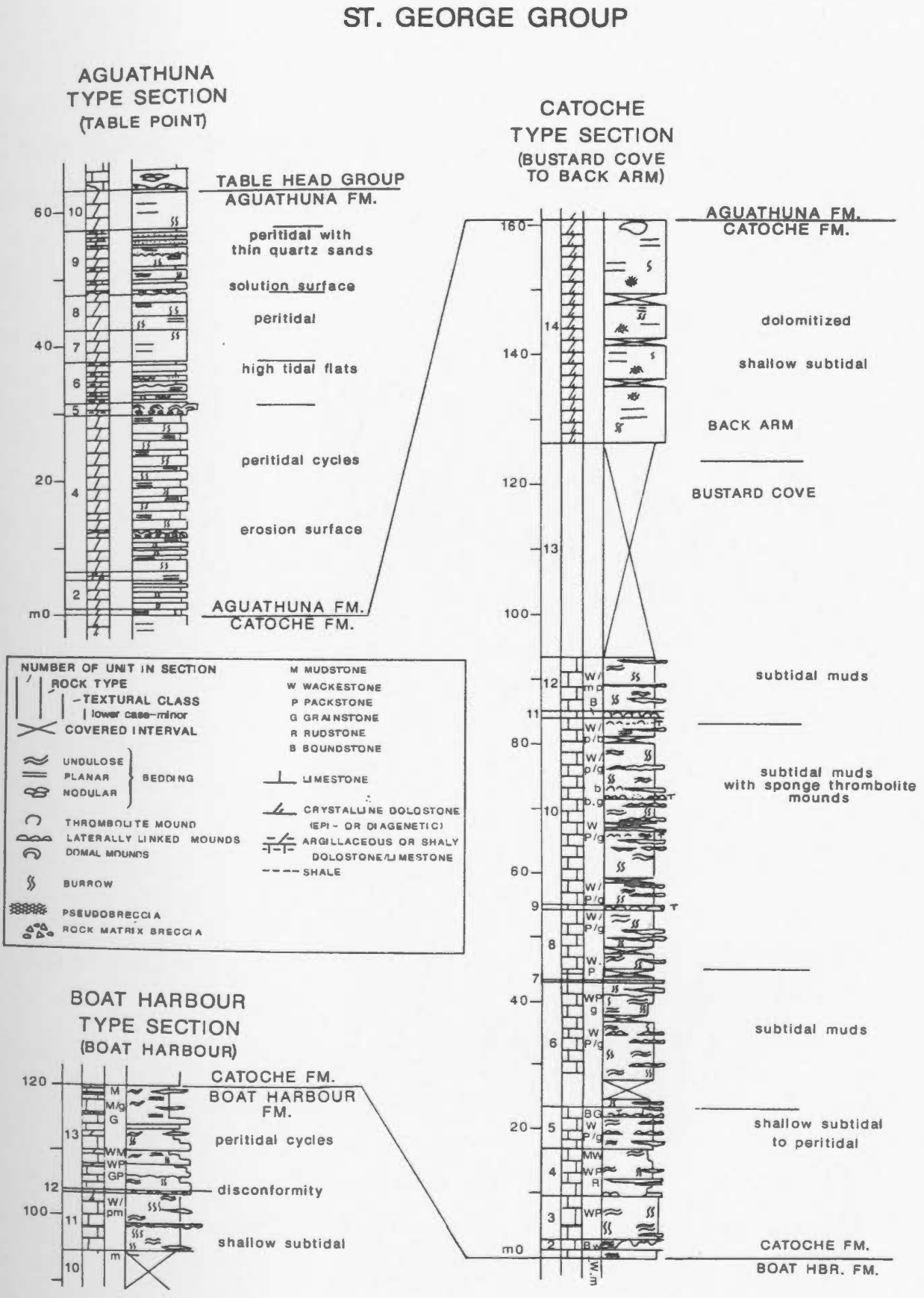
2.5.1. Boat Harbour Formation

This formation is generally older than Bed 9 of the slope sequence. Only the uppermost part, above a subaerial disconformity, contains conodonts and trilobites which suggest age equivalence with the lower part of Bed 9 (Stouge and Boyce, 1983; Stouge, 1982). Subaerial exposure is indicated by a paleokarst horizon with dolomitized and silicified solution surfaces. The overlying sediments are carbonate sands and muds deposited in a low intertidal to supratidal environment.

2.5.2. Catoche Formation

The Catoche Formation is roughly coeval to beds 9, 10 and lower 11 of the CHG (James, Williams and Boyce, 1987). It includes generally subtidal deposits, affected by extensive dolomitization in the upper part. Fossils are abundant and boundstone mounds are distributed throughout the sequence. They are various types of algal-sponge mounds (thrombolites) (Pratt and James, 1982) largely formed by *Renalcis*. Peritidal deposits dominate the lower part of the formation with units of crossbedded intraclastic rudstone (probably storm deposits) and tidal flat limestones. Higher up in the sequence burrowed mottled wackestones, intra- and bioclastic grainstones and algal mounds prevail. Near the top of the formation peloidal and fenestral limestones occur. In the upper 30-50m dolostone replaces limestone, being generally multi-genetic and the result of several episodes of dolomitization (Haywick, 1985; Haywick and James, in press).

Figure 2-8: Lithostratigraphy of the Arenig part of the St. George Group (after James and Knight, in press).



2.5.3. Aguathuna Formation

Dolostone, minor limestone and shale are characteristic of this formation which is largely equivalent to the upper part of Bed 11 and beds 12, 13 and 14 (James, Williams and Boyce, 1987). The limestones are generally mudstone to packstone and stromatolite boundstone. Breccia horizons with chert and dolostone pebbles are locally present and interpreted as erosional disconformities due to subaerial exposure, karstification and synsedimentary faulting. The shales are green, grey and red, laminated and dolomite-rich; the dolostones are peritidal deposits. Locally a prominent erosional disconformity marks the top of the St. George Group (the St. George Unconformity of James et al., in press).

2.6. Depositional setting

The depositional setting of the Cow Head slope deposits and of the platformal sequence has been evaluated in separate papers by James and Stevens (1986) and James et al. (in press) respectively. Paleozoic slope deposits reflect sea level and tectonic history as well as sedimentation on the platform to a larger degree than younger deep water deposits which have an stronger overprint of pelagic biogenic sedimentation. Mineralized pelagic organisms are generally sparse in the Lower Paleozoic and sedimentation is hemi-pelagic with carbonate derived from adjacent shelves. The autochthonous carbonate platformal sequences exposed in western Newfoundland are interpreted as outer shelf deposits in contrast to those found on the Mingan Islands of Quebec, which represent remains of the platform interior. Platform evolution extended over a time interval from Early Cambrian to Middle Ordovician and has been subdivided into four phases by James et al. (in press): PHASE 1. A pre-platform shelf with dominantly siliciclastic deposition, minor buildups of archaeocyathids and ooid shoals is followed by formation of PHASE 2, a narrow high energy platform characterized by peritidal siliciclastic-carbonate Grand Cycles. These two phases comprise the Cambrian part of the shelf sequence and are reflected in abundant conglomerates and quartz-rich carbonate turbidites in the slope sequence. PHASE 3. A wide, low energy carbonate

platform develops over the course of the Early Ordovician comprising two megacycles with subtidal and peritidal deposits (St. George Group). PHASE 4. Foundering of the platform begins with synsedimentary faulting in the Middle Ordovician followed by drowning (Table Head Group) and subsequent burial by synorogenic flysch (Mainland Sandstone).

The megacycles of Phase 3 are each comprised of a lower series of shallowing upwards cycles followed by a middle subtidal sequence and upper shallowing-upward cycles. They are thought to reflect deposition in response to eustatic sea level changes. The first megacycle corresponds roughly to the Tremadoc part of the slope sequence, the second to the Arenig units. This second megacycle comprises the upper Boat Harbour, Catoche and Aguathuna formations of the St. George Group. Time equivalent deep water deposits are represented by beds 9 through 11 of the Cow Head Group.

James and Stevens (1986) recognized 5 stages of sediment accretion in beds 1-15 of the slope sequence which respond to the phases of platform evolution outlined above. STAGE 1 is characterized by extensive debris sheets of welded conglomerates with minor limestone rhythmites comprising beds 0-5 (late Middle to Late Cambrian). During STAGE 2 a quartz-rich calcarenite sediment apron formed at the toe-of-slope interbedded with minor shales and sporadic conglomerates. An abrupt change from calcarenite to shale deposition occurs between St. Pauls Inlet and Broom Point sections suggesting that the apron ended somewhere between the two localities with distal facies prevailing farther down slope. STAGE 3 is characterized by a wide muddy carbonate sediment apron which formed during earliest Ordovician time. Proximal facies are welded conglomerates and minor calcarenites which are distally replaced by limestone rhythmites and shale. Sedimentation is thought to reflect low energy conditions on the platform corresponding to subtidal sediments of the Watts Bight Formation. STAGE 4 involves the formation of a constricted carbonate sediment apron beginning in the middle Tremadoc and continuing through the Arenig (Fig. 2-9).

It encompasses sedimentation of beds 8 through lower 13. Proximal facies comprise several megaconglomerate horizons (beds 10 and 12) which extend into distal facies where they are interbedded with limestone rhythmites and shales. The distal facies are dominantly red, green and black shale with minor limestone rhythmites. The style of sedimentation can be subdivided into three phases: 1. a lower aerobic phase, 2. a middle condensed phase and 3. an upper euxinic phase (Fig. 2-9). The lower aerobic phase is characterized by red shale deposition beginning in the upper part of Bed 8; the middle condensed phase represents lag deposition expressed in the phosphate and chert rich deposits of lower Bed 11 corresponding to the upper part of the Catoche Formation which reflects maximum transgression and possibly temporary platform drowning. The upper euxinic phase comprises limestone rhythmites as in Bed 9 but the intercalated shales in the proximal facies are all green or black and interpreted as deposited under anaerobic conditions. Red shales only occur in the most distal sections. Stage 5 with mixed carbonates and flysch encompasses the upper part of Bed 13, beds 14 and 15. These strata correspond to the upper Aguathuna Formation on the shelf which is an interval of synsedimentary faulting and episodes of subaerial exposure. A reduction of carbonate delivery to the slope is indicated in the more proximal sections which contain red shale in the lower part. The Bed 11 megaconglomerate indicates margin collapse probably as a result of tectonic activity. Onlap of flyschoid sandstones begins in the middle of Bed 13 in the distal sections but does not reach the proximal slope until Bed 15.

2.7. Paleogeography

Ordovician carbonates of the North American platform are interpreted as deposits of a low-latitude carbonate shelf and slope (Williams and Stevens, 1974; Jaanusson, 1979; Ross, 1984). The position of the shelfedge of the St. Lawrence platform has been a subject of debate. The deep water carbonates of the Cow Head Group are thought to have been transported the east. The transgression on the Grenvillian basement was from the east as indicated by the lack of Cambrian platformal rocks on the Mingan Islands and in the subsurface of Anticosti Island

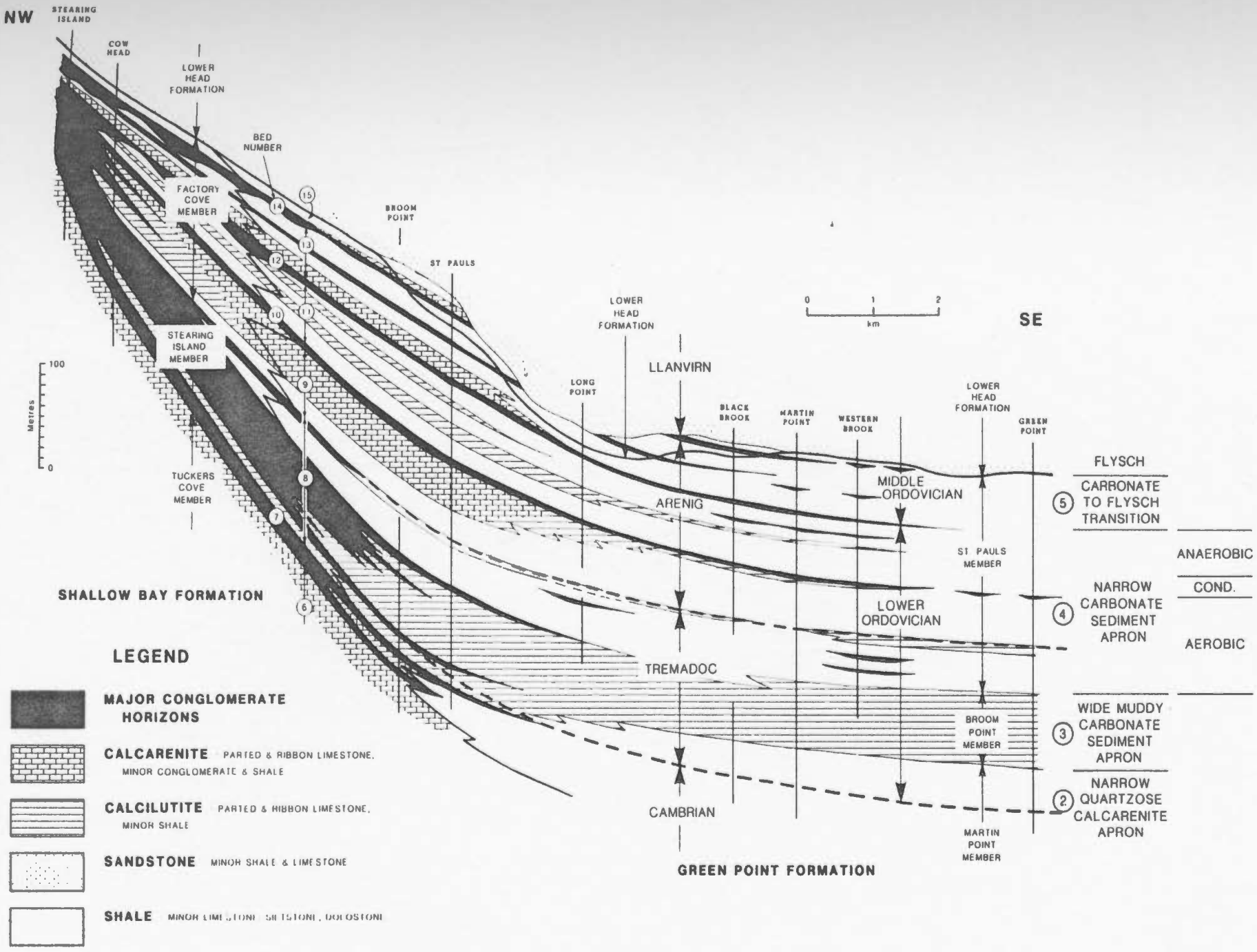


Figure 2-9: Diagram illustrating interpretive crossection of Early Ordovician Cow Head strata (from James and Stevens, 1986).

(James et al., in press). Early workers (Lock, 1972) suggested the White Bay area as root zone for the Cow Head Klippe because the region is situated at the edge of the Appalachian Miogeocline. Lock recognized about 100m of limestones and marbles (Doucers Formation of the Coney Arm Group) which he suggested to represent sediments "intermediate" between carbonate platform rocks in the west and limestone breccias of the Cow Head Group. He concluded that the breccias were derived a short distance east from the Doucers Formation.

Recent geophysical investigations suggest an even more easterly site for of the margin (Keen et al., 1986). A marine seismic reflecion line along the northern coastline of Newfoundland suggests that the Appalachian Miogeocline extends eastward under the Dunnage Zone for about 70km. The Newfoundland seismic profile thus indicates westward tectonic transport over at least 100km (Ando et al. 1986). However, Church (1987) cautioned, that the major tectonic elements cannot be unambiguously extrapolated seaward to the north, as some degree of flexure is indicated in the offshore trend. If flexure of the Baie Verte-Brompton line is considered then the eastern margin of North America would extend only 40km under the Dunnage Zone (Keen et al., 1987).

The morphology of the margin is envisaged as a Bahaman type shelfbreak with steep walls dissected by canyons (Rodgers, 1968, Stevens, 1970). This interpretation is mainly based on the presence of megaconglomerates in the Cow Head Group which are typically associated with steep walled carbonate platforms (Cook, 1970; Mountjoy et al., 1972). The nature of the clasts and boulders in Cambrian megaconglomerates has been addressed by James (1981), who concluded that they represent remains of algal mounds which grew along the shelf margin. They may have formed buildups as a result of early lithification rather than framework support but could possibly accumulate to build a steep escarpment. The present study of the nature of the clasts in the younger (Arenig) megaconglomerates is designated to aid in understanding the nature of the shelfbreak.

Chapter 3
BIOSTRATIGRAPHY

3.1. Introduction

The shelfedge derived boulders in the megaconglomerates in the Cow Head Group come from a "hinge zone" between the shallow and deep water realm and commonly contain mixed faunas which allow correlation between the different settings. A biostratigraphic framework is well established for the Cow Head Group; graptolites and conodonts from the bedded sediments have been studied from most sections, shelly fossils mainly from the conglomerates. Fossils from the adjacent shelf deposits of the St. George Group have been previously documented (e.g. Stouge, 1982; Stouge and Boyce, 1983 and others) in some detail and compositions of shelf-, shelfedge- and slope-faunas can therefore be readily compared. In order to consider the biostratigraphy and biofacies of conodonts from the different conglomerate horizons and clast lithologies and to reconstruct their original stratigraphic position in the fragmented slope and shelfbreak sequence the biostratigraphy of shelf and slope sequences is summarized herein as well as the fossil data from the conglomerates.

To study the conodont biostratigraphy and biofacies of the Arenig Cow Head megaconglomerates (beds 10, 12, 14) 256 conodont samples were collected from clasts and matrix of the conglomerate beds. Sample numbers, yields and faunal compositions are summarized in appendices 1-4. An additional 30 samples were taken from the different lithofacies of the intercalated bedded sequences, especially from strata immediately above and below the conglomerates for the purpose of comparison and stratigraphic control. Depending on the clast size,

sample weight ranged from 1 to 4 kg and averaged 2 kg. The largest number of samples was taken from the proximal facies containing the largest boulders and the highest portion of foreign clasts (i.e. clasts derived from outside of the depositional environment). The foreign clasts were sampled most thoroughly as they probably represent fragments of the upper slope and the marginal build-up facies which are the main concern of this study. Of all megaconglomerates Bed 14 was found to yield the largest variety of different lithologies and was sampled most extensively. Collecting concentrated on boulders at Lower Head and on Cow Head Peninsula. For each lithology recognized, at least two samples were taken from two different clasts to check on the identification. In more distal facies some additional lithofacies types were recognized and samples collected where clast size permitted.

At Lower Head, Bed 14 yields clasts eroded from strata as old as Late Cambrian (James and Stevens, 1986) and the number of different lithologies is so high, that despite collecting 147 samples probably not all lithofacies have been recognized. Commonly a certain lithofacies type is represented by only one clast which could not be duplicated elsewhere in the entire outcrop. The sampling of these rare lithologies was therefore random. The samples taken from the conglomerate horizons yielded a total of 12,492 elements representing 132 multi-element and form species. The colour alteration index (CAI) of all conodonts recovered is between 1.5-2 indicating low burial temperatures between 50° and 140°C (Epstein et al., 1977) and agrees with the regional values reported by Nowlan and Barnes (1987). Most conodonts are well preserved and complete. Worn and abraded conodonts occur in a few samples from clasts of bedded fine-grained lime mudstone. Conodonts derived from upper slope and shelf platform have usually a sucrose surface, indicating a diagenetic alteration. This is in contrast with specimens from the bedded sequence which are shiny and unaltered (Pl. 5.9, fig. 1). Backscatter and SEM analyses show a crystalline overgrowth composed of a calcite enriched apatite. Diagram in Appendix 5 shows the qualitative composition of the conodont surface and its overgrowth.

3.2. Previous work

Biostratigraphic work on the shelf sequence has been conducted by many workers including Fahraeus (1970), Barnes and Tuke (1970), Stouge (1982), Stouge and Boyce (1983), Stouge (1984) and Williams et al. (1987). The slope sequence has been studied, among others, by Schuchert and Dunbar (1934), Johnson (1941), Oxley (1953), Kindle and Whittington (1958), Erdtmann (1971), Nowlan (1974), Fortey et al. (1982), Johnston (1987), James and Stevens (1986), Williams and Stevens (in press) and Ross and James (1987). These studies concern different fossil groups, mainly graptolites, trilobites, brachiopods and conodonts and supply a detailed biostratigraphic framework for further studies.

3.3. Conodont provincialism

A problem for correlating conodont assemblages over great distances, or as in the case of North America, from shelf to slope deposits is the pronounced difference in faunal composition at different localities. This provincialism of Ordovician conodonts was first noted by Sweet et al. (1959) and by Sweet and Bergström (1962). The two faunal provinces distinguished for the early Ordovician, namely the North American Midcontinent Province and the North Atlantic Province have been further reviewed by Barnes et al. (1973), Sweet and Bergström (1974), Barnes and Fahraeus (1975), Lindström (1976), Bergstrom (1977) and Ethington and Repetski (1984). According to these authors conodont faunal provincialism was initiated in the Tremadoc and modified as to distinctiveness and areal extend over the course of the Ordovician (Fahraeus, 1976; Bergstrom, 1977). The Midcontinent Province is interpreted herein as a habitat of conodontophorids adapted to life in tropical shelf seas with elevated temperatures and salinities, while the North Atlantic Province was established by faunas adapted to cooler tempertures in low latitudes or deeper water and to normal salinity (Fahraeus and Barnes, 1975).

Two zonal schemes were established for the Lower and Middle Ordovician by

Ethington and Clark (1971, 1981) and (Sweet et al., 1971) for the Midcontinent and by Lindström (1971), Van Wamel (1974) and Löfgren (1978) for the North Atlantic Province. Precise correlation between these two principal conodont zonations is difficult and correlation via other faunal successions has been more successful: for example the standard graptolite zonation has been tied in with the conodont zonal schemes (Lindström, 1971; Bergström, 1971, 1973; Sweet and Bergstrom, 1976; Barnes et al., 1976).

Most conodont species in this and previous studies of the CHG are known from one or the other faunal province, some cosmopolitan forms also occur. The faunal composition is variable and obviously depended on environmental conditions which will be elaborated on in a later chapter.

3.4. Biostratigraphy of the shelf sequence

The segment of the shelf sequence roughly equivalent in age to the Arenig part of the slope sequence includes the upper part of the Boat Harbour Formation, the Catoche and Aguathuna formations of the St. George Group. Trilobites (Whittington and Kindle, 1969; Boyce, 1978; Fortey, 1979; Boyce, 1983, 1985, 1986; Williams et al, 1987), cephalopods (Flower, 1978), conodonts (Stouge, 1982; Kenna, 1986; Z. Ji, in prep.) and graptolites (Williams et al., 1987) have been reported from these formations.

3.4.1. Shelly fossils

Reference areas for North American Lower and Middle Ordovician trilobite and brachiopod biostratigraphy are in Utah and Nevada. Based on work of Ross (1951) and Hintze (1951, 1952) 12 trilobite-brachiopod zones were erected and designated letters A-L (Fig. 3-1). Shelly fossils from the upper part of the Boat Harbour Formation above the "pebble-bed", a major discontinuity surface, belong to North American shelly Zone G_2. The Catoche Formation comprises trilobites indicative of zones G_2 to I, possibly J (Williams et al., 1987). Trilobites from the top of the Aguathuna Formation belong to Zone L and possibly Zone M. The

basal part of the overlying Table Head Group (Table Point Formation) contains trilobites of Zone M.

3.4.2. Graptolites

Graptolite horizons are known from the Catoche and basal Aguathuna formations (Williams et al., 1987). They indicate that most of the Catoche Formation falls within the *Tetragraptus approximatus* Zone (Williams, 1986, Williams and Stevens, in press) and is thus equivalent to Bed 9 of the Cow Head Group. Near the top of the Catoche Formation a fauna occurs which is referable to the *Tetragraptus akzharensis* Zone and possibly the lowest part of the *Pendeograptus fruticosus* Zone suggesting correlation to the upper part of Bed 9, Bed 10 and the lowest part of Bed 11. In the lower Aguathuna Formation a large number of specimens of *Didymograptus (Expansograptus) nitidus* Hall was recovered which is restricted to the *P. fruticosus* and *D. bifidus* zones of the Cow Head Group. This indicates a lower to middle Bed 11-age.

3.4.3. Conodonts

Conodonts of the St. George Group are currently under investigation by K. Stait and Z. Ji. Stouge (1982) proposed a preliminary conodont zonation for platformal carbonates of the St. George Group on the Great Northern Peninsula. Beginning with the upper Boat Harbour Formation he recognized 6 faunas (Fauna 1-6) which he subsequently correlated to the conodont successions of North America documented by Ethington and Clark (1971) and by Sweet et al. (1971). The lowest faunas 1 and 2 of the Boat Harbour Formation below the unconformity ("pebble bed") were correlated with Fauna D and possibly C. Fauna 3 recovered from horizons above the "pebble bed" also lies within Fauna D. Fauna 4 contained elements of Fauna E and appeared at the base of the Catoche Formation ranging upward to the Laignet Point Member. The diagenetic dolostones at the top of the Catoche Formation yielded a sparse fauna (Fauna 5) suggestive of Fauna E-1. The Aguathuna Formation contained only sparse faunas

and barren intervals. Fauna 6, recovered from the top of the formation yielded elements typical of Faunas 2-3 of the North American Midcontinent succession. This fauna ranges upwards into the lowermost Table Head Group (Stouge, 1984) (Fig. 3-1).

3.5. Biostratigraphy of the slope sequence

3.5.1. Graptolites

Graptolites from bedded sediments of the Cow Head Group were first collected by Richardson and described in Logan (1863) and by Billings (1865). Subsequent collections were made by Schuchert and Dunbar (1934) and Johnson (1941); descriptions are found in Ruedemann (1947). Kindle and Whittington (1958) also collected graptolites but focussed on trilobites for biostratigraphic purposes. Erdtmann (1971) proposed a zonal scheme for the graptolite successions of the area. The most recent publications are by James and Stevens (1986), Williams (1986) and Williams and Stevens (in press). Most of the data summarized herein are derived from Williams and Stevens (in press) who proposed a new local scheme based on the Cow Head faunas and subsequently correlated these with Australian graptolite zones (as defined by Webby et al., 1981). Graptolites from Beds 9-11 of the Cow Head Group can be correlated with Australian stages Lancefieldian 3 to Darriwillian 1 (Fig. 3-1). Williams and Stevens distinguished eight different graptolite zones which can be correlated with the conodont succession determined by Fahraeus (1970), Nowlan (1974), Fahraeus and Nowlan (1978), and Johnston (1987): (1) The *Tetragraptus approximatus* Zone defined near the base of Bed 9 is mostly equivalent to Lancefieldian 3 of the Australian scheme and is suggested to define the base of the Arenig. The *T. approximatus* Zone coincides with the Baltoscandian conodont zones of *Paroistodus proteus* and *Prioniodus elegans*. (2) The *Tetragraptus akzharensis* Zone is defined at Western Brook Pond North (WBPN 18). This zone is equivalent to Bendigonian 1-2 and the upper part of the *P. elegans* Zone. Bed 10 and the upper part of Bed 9 fall in the range of this interval. (3) The *Pendeograptus fruticosus* Zone is

equivalent to most of Be3 and Be4 and is defined at the base of Bed 11 on Cow Head Peninsula. It correlates to the lower part of the *Oepikodus evae* Zone. (4) The *Didymograptus bifidus* Zone is recognized in the middle of Bed 11 on Cow Head Peninsula (at Jim's Cove). It correlates to the Chewtonian Stage of Australia and to the upper part of the *O. evae* Zone. (5) The *Isograptus victoriae lunatus* Zone is recognized at Martin Point North (MPN 36) and is equivalent to Castlemainian 1. It coincides with the change of *O. evae* dominated conodont faunas to *Periodon aculeatus* Hadding dominated faunas in the upper part of Bed 11 (Johnston, 1987). (6) The *I. victoriae victoriae* Zone is defined at Martin Point North (MPN 39) and correlates to Castlemainian 2. In distal sections this zone is found near the top of Bed 11; in proximal sections at the base of Bed 13. No change of conodont faunas coincides with the base of this interval. Fauna A.4 of Johnston (1987) is succeeded by Fauna A.5 somewhat higher in the sequence. (7) *I. victoriae maximus* Zone is defined on Cow Head Peninsula (CHP 13.6 at Jim's Cove). It correlates to Ca3 and the Yapeenian stages 1-3 and falls within the range of Bed 13. The conodont faunas have not changed in this interval or are not known to date. (8) The *Undulograptus austrodentatus* Zone is recognized at Western Brook Pond South where it occurs below the highest conglomerate horizon considered to be Bed 14 and correlates to Darriwillian 1. The zone falls within the range of upper Bed 13, beds 14 and 15. Conodont faunas from this interval are poorly known. An advanced form of *P. aculeatus* seems to be characteristic of this interval. The interval of the upper part of the *I. v. lunatus* Zone to the *U. austrodentatus* Zone is roughly equivalent to the British *Didymograptus hirundo* Zone which Löfgren (1978) correlated with the upper *Paroistus originalis* Zone, the *Microzarkodina flabellum parva* Zone and the *Eoplacognathus?-M. flabellum* Subzone in Jämtland. Williams (1986) proposed that the Arenig/Llanvirn boundary lies at the base of the *U. austrodentatus* Zone, equivalent to the boundary between the Australian Yapeenian and the Darriwillian stages. In terms of Baltoscandian conodonts this would coincide either with the boundary between the *Microzarkodina parva* Zone and the *Eoplacogathus? variabilis - M. flabellum* Subzone or that between the *E.?*

variabilis - M. flabellum and the *E.? variabilis - M. ozarkodella* subzones. In the CHG the first platform conodonts appear in the *U. austrodentatus* Zone (Llanvirn?) at Western Brook Pond. (C.R. Barnes, pers. comm., 1987) below a conglomerate horizon considered Bed 14. Conodont faunas from this conglomerate yield an advanced species of *Periodon aculeatus*. In the proximal sections Bed 14 rests on sediments with graptolites of the older *I. v. maximus* Zone.

3.5.2. Shelly fossils

Trilobites and brachiopods are dominantly known from the boulders in the conglomerates. Brachiopods have been identified and described by Billings (1865), Cooper (1956) and Ross and James (1987). Ten genera and 17 species of brachiopods have been recognized in beds 12, 13 and 14 by Ross and James (1987). Faunas from boulders in Bed 14 belong to zones K, L and lower M; those from from clasts in Bed 12 to zones L, H, J and I.

Kindle and Whittington (1958) studied trilobites from the Cow Head Group and found almost similar evidence: they assigned trilobites from beds 9 and 10 to Ross/Hintze zones G and H; Bed 12 trilobites were considered to be earliest Middle Ordovician i.e. "Whiterock Stage"; Bed 14 trilobites were considered to show affinity to those of zones M and N. In contrast to later workers the authors concluded that the boulders are equivalent in age to the middle Table Head Group.

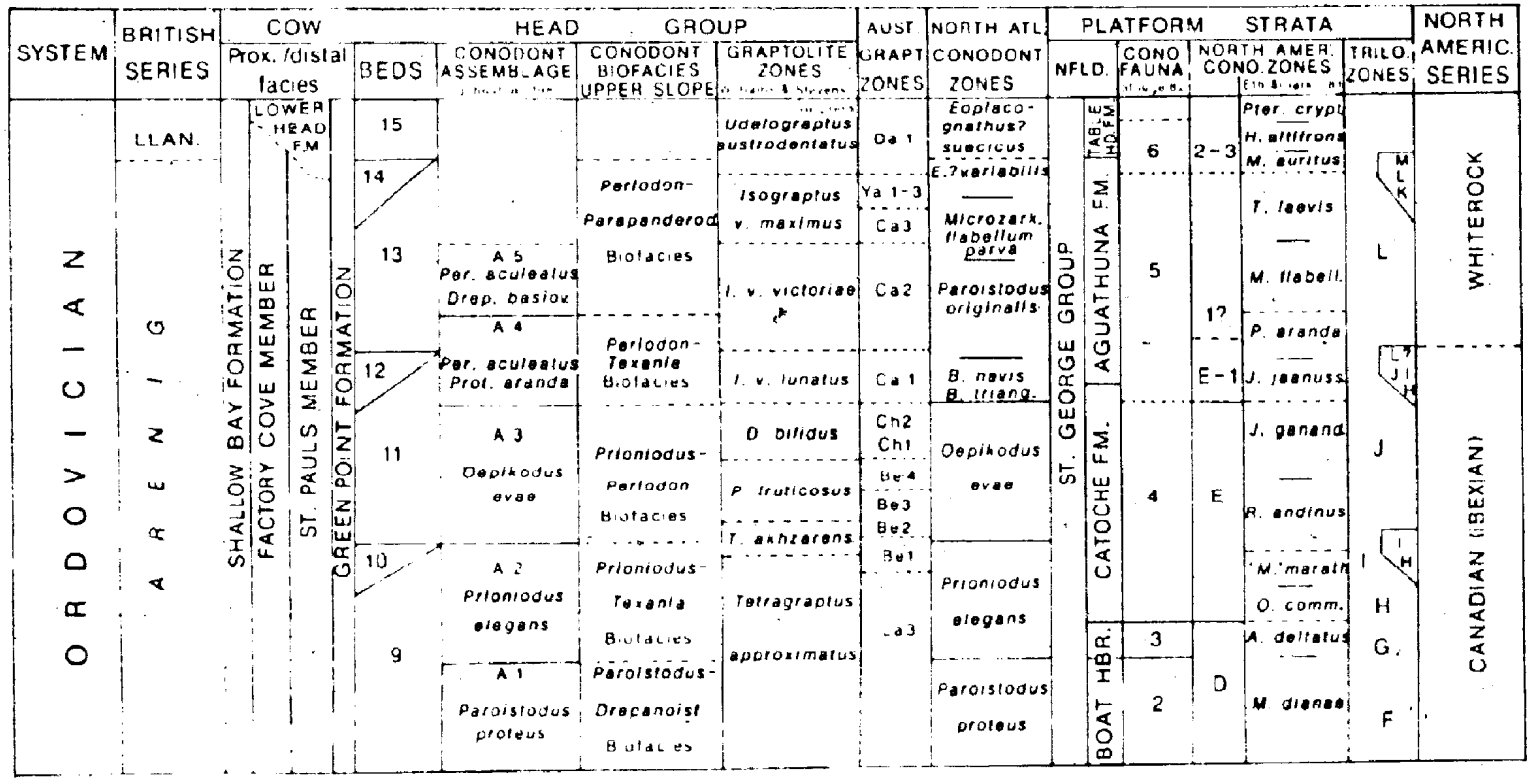
3.6. Conodont biostratigraphy of the Cow Head Group

Arenig conodonts from the CHG have been studied from Cow Head Peninsula by Nowlan (1974) and by Fahraeus and Nowlan (1978) and from the Martin Point South and St. Pauls Inlet sections by Johnston (1987). These authors recovered well preserved specimens without crystal overgrowth. Johnston reported a low CAI of 1.5 to 2.

Johnston described five faunal assemblages which have many species in common

with typical North Atlantic faunas but which also contain Midcontinent, cosmopolitan and endemic forms. Five different biofacies are recognized herein from the conglomerate clasts. They are coeval with the faunal assemblages from the bedded slope sequence. The shelf sequence is not well known as yet and correlation is problematic but a preliminary version has, however, been attempted.

Figure 3-1: Correlation chart of Cow Head conodonts with other key areas and fossil groups



SYSTEM	BRITISH SERIES	COW HEAD GROUP: Prox./distal facies	BEDS	CONODONT ASSEMBLAGE	CONODONT BIOFACIES UPPER SLOPE	GRAPTOLITE ZONES	AUST. GRAPT. ZONES	NORTH ATL. CONODONT ZONES	PLATFORM STRATA: NFLD.	CONO. FAUNA	NORTH AMER. CONO. ZONES	TRILO. ZONES	NORTH AMERIC. SERIES
ORDOVICIAN	LLAN.	SHALLOW BAY FORMATION; LOWER HEAD FM; FACTORY COVE MEMBER; ST. PAULS MEMBER; GREEN POINT FORMATION	15			*Udelograptus austrodentatus*	Da 1	*Eoplacognathus? suecicus*	ST. GEORGE GROUP; TABLE HD. FM	6	2-3	*Pter. crypt.*; *H. altifrons*; *M. auritus*	WHITEROCK
	ARENIG		14		*Periodon-Parapanderod* Biofacies	*Isograptus v. maximus*	Ya 1-3; Ca3	*E.?variabilis*; *Microzark. flabellum parva*	AGUATHUNA FM.	5	1?	*T. laevis*; *M. flabell.*	L
			13	A 5 *Per. aculeatus* *Drep. basiov.*		*I. v. victoriae*	Ca2	*Paroistodus originalis*					
				A 4 *Per. aculeatus* *Prot. aranda*	*Periodon-Texania* Biofacies	*I. v. lunatus*	Ca 1	*B. navis* *B. triang.*			E-1	*P. aranda*; *J. jaanuss.*	
			12										
			11	A 3 *Oepikodus evae*	*Prioniodus-Periodon* Biofacies	*D. bifidus*; *P. fruticosus*; *T. akhzarens*	Ch2 Ch1; Be4; Be3; Be2	*Oepikodus evae*	CATOCHE FM.	4	E	*J. ganand.*; *R. andinus*	J
			10	A 2 *Prioniodus elegans*	*Prioniodus-Texania* Biofacies	*Tetragraptus approximatus*	Be1; Ca3	*Prioniodus elegans*				*M. marath.*; *O. comm.*	I; H
			9	A 1 *Paroistodus proteus*	*Paroistodus-Drepanoist* Biofacies			*Paroistodus proteus*	BOAT HBR.	3; 2	D	*A. deltatus*; *M. dianae*	G; F

CANADIAN (IBEXIAN)

3.6.1. Bed 10 and equivalents

Above a barren shale and siltstone unit in Bed 9 assemblage A1 of Johnston (1987) occurs (50m-70m above the base of the section) with *Paroistodus proteus* Lindström and *Acodus deltatus* Lindström. This interval is probably equivalent to the Boat Harbour Formation above the pebble bed with Fauna 3 of Stouge (1982). This latter fauna is characterized by a species close to (if not identical with) *Acodus deltatus* accompanied by *Parapanderodus (=Scolopodus?) gracilis* (Ethington and Clark), *Eucharodus simplex* (Branson and Mehl), *Glyptoconus quadraplicatus* (Branson and Mehl) and *Drepanoistodus? gracilis* (Branson and Mehl).

Two clasts in Bed 10 which yielded a Fauna 3 assemblage with *Acodus deltatus* and *Paroistodus proteus* support this correlation.

The first appearance of *Oistodus elongatus* Lindström (= *O.* n.sp.1 Serpagli) and *"Oistodus"* sp. aff. *"O." cristatus* Ethington and Clark s.f. defines the lower boundary of assemblage A.2 of Johnston. It occurs in the uppermost 25m of Bed 9. *Paracordylodus gracilis* Lindström and *Prioniodus elegans* Pander are the most abundant components accompanied by *Bergstroemognathus* sp. cf. *B. extensus* Serpagli, *Protoprioniodus simplicissimus* McTavish and *Walliserodus australis* Serpagli. The *Prioniodus elegans* Zone coincides here with the first occurrence of *Oepikodus communis* (Ethington and Clark) which in the Midcontinent zonal schemes defines the base of Fauna E (Ethington and Clark, 1971) or the *Oepikodus communis - "Microzarkodina" marathonensis* interval (Ethington and Clark, 1981). In the St. George Group the base of the Catoche Formation coincides with the first appearance of *Oepikodus communis* (Fauna 4 of Stouge, 1982, 1983). Near the top of the Catoche Formation below the dolomitized interval the presence of the graptolite *Tetragraptus akhzarensis* indicates that all of Bed 9 and Bed 10 except the basal *Paroistodus proteus* interval correlate to most of the Catoche Formation (Williams et al., 1987).

Foreign lithologies in Bed 10 are generally coeval to the upper part of Bed 9 and have many species in common such as *Oistodus elongatus* Lindström, *Bergstroemognathus extensus* Serpagli, *Drepanoistodus concavus* (Branson and Mehl), *Paroistodus parallelus* Sergeeva, *Periodon? selenopsis* (Serpagli) (=*P.* sp. Löfgren), *Protoprioniodus simplicissimus* McTavish and *Walliserodus australis* Serpagli. Distinctive from Bed 9 are the lack of *Paracordylodus gracilis* and rareness of *Prioniodus elegans*. Instead *Prioniodus marginalis* n.sp., a species close to but not conspecific with *P. (P.) elegans*, dominates in all samples derived from upper slope and shelfbreak. This species is also present though less abundant in the lower slope sequence but never in shelf derived clasts of equivalent age. A possible precursor of this species is *Prioniodus serratus* n.sp. which occurs in a single sample from a conglomerate slightly older than Bed 10 at Lower Head West. Typically *P. marginalis* is accompanied by *Texania* sp. aff. *T. adentata* (McTavish), *Prioniodus papiliosus* (Van Wamel) and *Protoprioniodus simplicissimus*. Conodont samples collected from the matrix of Bed 10 also yielded *P. (P.) marginalis* and *P. (P.) elegans*.

3.6.2. Bed 12 and equivalents

Assemblage A.3 of Johnston occurs in the lower 46m of Bed 11 and is characterized by high abundance of the Scandinavian zone fossil *Prioniodus (Oepikodus) evae* Lindström. Important species introduced during this interval are *Acodus? gladiatus* Lindström, *Periodon flabellum* Lindström, *Protopanderodus rectus* Lindström, *Reutterodus andinus* Serpagli, *"Scolopodus" carlae* Repetski s.f., and species of *Juanognathus*. Many of the Argentinian species that were first described by Serpagli (1974) persist from beds 9 and 10 (i.e. *Acodus russoi, Acodus? sweeti, Walliserodus australis, Bergstroemognathus extensus* and *Periodon? selenopsis*). Some of these species such as *A.? sweeti, B. extensus* and *W. australis*, change their morphology slightly with decreasing age.

Up section, assemblage A.3 is gradually replaced by assemblage A.4 which is

dominated by *Periodon aculeatus* Hadding. Johnston defined its base by the first appearance of *Oepikodus intermedius* Serpagli which is associated with *Cordylodus* sp. cf. *C. horridus* Barnes and Poplawski, *Jumodontus gananda* Cooper, *Protoprioniodus aranda* McTavish and *Strachanognathus parvus* Rhodes. This replacement probably correlates closely to the change from the *D. bifidus* Zone to the *I. v. lunatus* Zone of Williams and Stevens (in press). In the uppermost meters of Bed 11 *Tripodus laevis* (Bradshaw) is introduced. This faunal change coincides with a change of the graptolite fauna, (the *I. v. lunatus* Zone is replaced by the *I. v. victoriae* Zone (Williams and Stevens, in press)) and probably indicates the base of the Middle Ordovician.

The conodont faunal record on the shelf is so far scanty for this interval. Based on graptolite data (Williams et al., 1987) it appears that the uppermost part of the Catoche Formation and an unknown proportion of the Aguathuna Formation are age-equivalent to beds 11 and 12. *Didymograptus (Extensograptus) extensus* is found in a shale horizon near the base of the Aguathuna Formation and suggests equivalence to the middle of Bed 11 (Williams et al., 1987). Conodonts of Canadian age are present in the lower part of the Aguathuna Fm. (Z. Ji, 1987) and those of Midcontinent Fauna 2-3 in the uppermost portion (Stouge, 1982). The exact position of the Lower/Middle Ordovician boundary is not yet known.

Clasts of Bed 12 reflect the faunal change from the *Prioniodus (O.) evae* dominated to *Periodon* dominated faunas found in the slope sequence (Fig. 3-1). The older assemblage is generally similar to that of the bedded strata and yields apart from the zone fossil *P. evae* also *Periodon flabellum* and the Argentinian species. The occurrence of *Acodus? mutatus* in some samples is of interest because these species are usually found in younger faunas (Löfgren, 1978). Younger clasts in Bed 12 contain faunas with abundant *Periodon aculeatus* accompanied by *Texania heligma* n. sp., *Protoprioniodus papiliosus*, *P. aranda* and *Strachanognathus parvus*. *Tripodus laevis* is also present as well as a few specimens of *Pteracontiodus cryptodens* (Mound). Both species are generally

considered to indicate Whiterockian age. *P. (Oepikodus) communis* is relatively rare and restricted to a few samples. The matrix of Bed 12 yielded a few broken elements of *P. (O.) evae* and *P. aculeatus* indicating that their is no significant age difference between clasts and matrix.

The recognition of coeval Scandinavian biofacies is somewhat hampered by the lack of the baltoniodan zonal index fossils in all of North America. In öland, Sweden the last occurrence of *P. (O.) evae* falls within the range of Van Wamel's (1974) *Prioniodus navis-P. crassulus* Assemblage Zone. Van Wamel did not distinguish *P. navis* from the older *P. triangularis* as did Löfgren (1978) and the older part of the *P. navis-P. crassulus* Assemblage Zone of Van Wamel may coincincide with Löfgren's *P. (B.) triangularis* Interval. The *P. (B.) navis* Zone and possibly the *Paroistodus originalis* Zone may correlate to the upper part of Bed 11. This interpretation is supported by the increased abundance of *P. originalis* in younger clasts of Bed 12.

Shelf derived clasts are scarce in Bed 12 and they are difficult to evaluate. They contain faunas similar to those described by Stouge (1982) from different levels of the Catoche Formation but yield, instead of *P. (Oepikodus communis)*, *P. (O.)* sp. aff. *minutus*, a species which is characterized by two denticulate processes in the prioniodontiform element. Similar elements occur in *Prioniodus* species from the Pogonip Group (Ethington and Clark, 1981) and the Antelope Valley Limestone (R.L. Ethington, pers. comm., 1986). Their value for biostratigraphic purposes is yet unknown.

3.7. Lower/Middle Ordovician boundary in North America

The Lower/Middle Ordovician boundary is defined biostratigraphically at the base of Ross/Hintze Zone L (Ross et al., 1982). This zone is based on trilobites from the Pogonip Group in Utah (Hintze, 1951). Cooper (1956, 1976) recognized the first early Ordovician brachiopod fauna (the *Orthidiella - Anomalorthis - Rhysostrophia* suite) in the Whiterock Series of the Monitor Range, Nevada.

Ross (1964) concluded that Zone L of Hintze is equivalent to the *Orthidiella* Zone in the Whiterock Series in Nevada. Ross et al., (1982) formally designated the base of Zone L as boundary between the Canadian (Ibex) and the Whiterock series. The top of the Ibex is time equivalent to that of the Canadian Series. The Whiterock/Ibex boundary at the Whiterock type section in Nevada has not been formally defined in terms of conodonts. Lower Ordovician conodonts from the Ninemile Formation at the type section have been described by Ethington (1972) and those from the Middle Ordovician of the Antelope Valley Formation by Harris et al. (1979). The boundary itself has only been addressed in an abstract by Harris and Repetski (1982). Thus the conodont succession accross the Ibex/Whiterock boundary is only known from the Ibex type section in the Pogonip Group in Utah (Ethington and Clark 1981). Here the base of Zone L (i.e. the first occurrence of *Orthidiella*) is near the top of the Wah Wah Formation. This coincides with the upper part of the *Protoprioniodus aranda - Juanognathus jaanussoni* Interval. No change of the conodont assemblages is associated with the change of shelly fossil composition and it has been pointed out by Ethington and Clark (1981) that Hintze's trilobite succession established at the Pogonip Group cannot be differentiated via conodonts. Fahraeus (1977) showed the problematics of using trilobite and/or brachiopod zones based on generic identifications for correlation.

The younger *Microzarkodina flabellum-Tripodus laevis* Interval begins near the top of the Wah Wah Formation somewhat above the base of Zone L. Both intervals are characteristic of Fauna E-1 of the older zonation established by Ethington and Clark (1971) and Sweet et al. (1971). The base of Zone L with the first occurrence of *Orthidiella* in Nevada coincides with the lithostratigraphic subdivisions of the Lower Ordovician Ninemile Formation and the Middle Ordovician Antelope Valley Formation. Two conodont samples taken accross the boundary (samples courtesy of C.R. Barnes) show no major change in faunal composition. The sample from the top of the Ninemile Formation contained abundant *Tripodus laevis* Bradshaw, *Oistodus lanceolatus* Pander and

"Scandodus" mysticus Barnes and Poplawski. Accessory species are represented by *Periodon aculeatus* Hadding, *Texania marathonensis* (Bradshaw), *Paroistodus originalis* Sergeeva, *Drepanodus arcuatus* Pander, *Scolopodus? peselephantis* Lindström and *Pteracontiodus cryptodens* Mound. The sample from the base of the Antelope Valley Formation also contains abundant *T. laevis* and *"S." mysticus* but lacks *O. lanceolatus*. Instead *P. aculeatus* is more abundant. New species introduced are *Paroistodus parallelus* Pander and a species related to *Ansella nevadensis* (Ethington and Schumacher) or *Ansella jemtlandica* (Löfgren). This evidence suggests that the faunas are correlative to the *T. laevis - J. jaanüssoni* Interval of Ethington and Clark (1981). *Protoprioniodus aranda* Cooper has not been observed. Based on the conodont evidence from the type section the Lower/Middle Ordovician boundary in the Cow Head Group could be either correlated to lie somewhere within Johnston's Assemblage A.4 (upper Bed 11 or lowermost Bed 13) with *P. aranda* or at the base or in the lower part of Assemblage A.5 (lower part of Bed 13) characterized by the appearance of *Acodus? robustus* (Serpagli) (= *"S." mysticus*) and *A. jemtlandica* (see below). Shelly fossils collected from the megaconglomerates of Bed 12 by Kindle and Whittington (1958) and Ross and James (1987) suggest that Whiterock faunas are present in the younger boulders of this horizon equivalent to the upper part of Bed 11. However, the conodont succession of the Whiterock type section needs further study before correlations can be evaluated.

3.7.1. Bed 13 and equivalents

Assemblage A.4 of Johnston (1987) persists from the top of Bed 11 into the basal Bed 13 where it is replaced by assemblage A.5 (between 174m and 180m above the base). The A.5-fauna is dominated by an intermediate form of *Periodon aculeatus* and defined by the first appearance of *Acodus? robustus* (Serpagli), *"Scandodus" flexuosus* Barnes and Poplawski, *Walliserodus ethingtoni* (Fahraeus) and *Drepanoistodus basiovalis* (Sergeeva). The latter occurs earlier in foreign clasts in Bed 12, (i.e. is present earlier in the upper slope sequence).

In the middle of Bed 13 a mixed fauna with late forms of *Periodon aculeatus* and *Spinodus* sp. cf. *S. spinatus* Hadding occurs. Foreign clasts from Bed 14 typically contain species of *Parapanderodus* spp., *Erraticodon* sp. cf. *E. balticus* Dzik, *Ansella jemtlandica*, *Drepanoistodus* sp. cf. *D. venustus* (Stauffer) and *Oistodus? tablepointensis* Stouge. It has many species in common with the lower and middle Table Head Formation as well as with faunas from uppermost Bed 13 and a conglomerate overlying Cow Head strata at Martin Point (basal Lower Head Formation). The co-occurrence of taxa over a wide stratigraphic range is thought to be ecologically controlled (Pohler et al., 1987 and Chapter 4). The occurrence of *Ansella jemtlandica* and *Erraticodon* sp. cf. *E. balticus* suggests latest Arenig to earliest Llanvirn age. Graptolite data are in favour of an assignment to the upper Arenig. Samples from matrix of Bed 14 conglomerates contained poorly preserved scarce specimens of the advanced form of *P. aculeatus* together with older species suggesting that the matrix is as old as the penecontemporaneous clasts.

Most of the shelf derived clasts in Bed 14 are age-equivalent to the Catoche Formation and possibly the lower Aguathuna Formation. One large synsedimentary deformed boulder at Lower Head even yields species of Fauna C of the Midcontinent zonation with *Rossodus manitouensis* Repetski and Ethington and *Loxodus bransoni* Furnish. A single clast from Lower Head East contained *Paraprioniodus costatus* (Mound) and is the only representative of Stouge's Fauna 6 from the upper Aguathuna and basal Table Head formations. This fauna contained taxa characteristic of Midcontinent faunas 2-3 which are of lower Whiterock age. This rare shelf derived clast fauna is considered to be age-equivalent to the boundstone lithologies usually found in Bed 14 with their *Periodon-Parapanderodus* dominated shelf edge faunas.

3.8. Conclusions

Of the North Atlantic conodont zonation the *Paroistodus proteus*, *Prioniodus elegans* and *Oepikodus evae* zones are recognized in bedded and conglomerate horizons ranging from the upper half of Bed 9 through beds 10, 11 and 12. The younger *Baltoniodus navis/triangularis* and *Microzarkodina flabellum parva* zones (Löfgren, 1978) are not found in the CHG and are not present elsewhere in North America. The upper part of Bed 11 and Bed 13 may correlate to this interval. The top of Bed 13 and Bed 14 probably correlate to the *Eoplacognathus? variabilis* Zone.

Of the North American Midcontinent zonation Fauna E with *Oepikodus communis* is equivalent to the *Prioniodus elegans* and *P. (O.) evae* zones in the CHG which assigns a late Canadian age to beds 9-11. This is a somewhat longer interval than has been previously observed by Ethington and Repetski (1984) who considered the *P. (O.) communis* Zone equivalent to only the *P. (O.) evae* Zone. The faunal change observed near the top of Bed 11 and in younger clasts of Bed 12 occurs at a level close to the Lower/Middle Ordovician boundary.

Chapter 4
CONODONT PALEOECOLOGY

4.1. Introduction

Conodont paleoecology is a relatively new discipline in conodont research mainly because in early studies many conodont species were interpreted to be of global distribution and of wide facies tolerance. Ideas about conodont ecology favoured planktonic mode of live (Müller, 1962; Lindström, 1964). With ongoing study evidence accumulated that many conodonts were limited to faunal provinces and that certain genera preferred distinct habitats within provinces (Merrill, 1966; Lindström, 1969; Seddon and Sweet, 1971; Barnes et al., 1973). The faunal provinces which existed during the Ordovician became known as the North Atlantic and the (North American) Midcontinent provinces (Sweet et al., 1959; Sweet and Bergström, 1974). Generally the Midcontinent Province faunas occur in a carbonate platform environment with shallow warm water and possibly raised salinities. The North Atlantic Province in contrast is developed in deep and/or temperate to cold water environments (Barnes et al., 1973; Barnes and Fahraeus, 1975). In evaluating the terminology used in context with provincialism, Lindström (1976) pointed out that provincialism has a strong geographical connotation and that the Midcontinent Province sensu strictu is confined to North America. However, many conodont assemblages are known from similar depositional settings representing faunas of Midcontinent affinity. These are referred to as subprovinces. Examples of Midcontinent subprovinces would be the Canadian Arctic (Nowlan, 1976) or the Siberian Platform (Moskalenko, 1973). The Appalachian faunas described among others by Barnes and Poplawski (1973) could be regarded as a North Atlantic subprovince. For conodont assemblages

showing strong endemicity Lindström advocated the term "fauna" named after one or more genera or species (e.g. *Amorphognathus* Fauna) without geographic connotations. Lindström (1976a) recognized several faunas in the Arenig: the Lower Arenig is characterized by a *Paroistodus* and a *quadraplicatus* Fauna. The former is named after *Paroistodus proteus* Lindström and refers to faunas of North Atlantic affinity, the latter is named after *Glyptoconus quadraplicatus* (Branson and Mehl) and refers to contemporaneous faunas of Midcontinent affinity. A younger *Paroistodus* Fauna is characterized by *Paroistodus parallelus* and is also of North Atlantic affinity. It incorporates the *Prioniodus elegans* and *P. (O.) evae* zones of Baltoscandia. No typical Midcontinent fauna was recognized for the same time interval. The Argentinian fauna of Serpagli (1974) with *Juanognathus* is regarded as a separate assemblage. Subsequent work (Bthington and Clark, 1981) has shown that elements of this fauna also occur in the Pogonip Group of Utah and Nevada which can be regarded as part of the Midcontinent Province. Serpagli's *Juanognathus* Fauna is herein referred to as the Argentinian Fauna. Younger Arenig and Llanvirn aged faunas are referred to as *Periodon* Fauna when of North Atlantic aspect and as *Histiodella* Fauna when of Midcontinent aspect. The term *Periodon* Fauna is adopted herein but extended into older strata (i.e. older than the lowest occurrence of *Histiodella*). Many of the conodonts found in the Cow head material are rare and/or cannot be assigned to an already described species (e.g. xx-form elements). They are not considered in the following discussion. Faunas as well as provinces can be subdivided into communities (Lindström, 1976) or biofacies as has been shown by several workers (Merrill, 1966; Druce, 1973). Barnes and Fahraeus (1975) in particular illustrated composition and occurrence of conodont communities of the Ordovician. Fortey and Barnes (1977) observed four communities or biofacies in Lower Ordovician shelf, shelfedge, upper slope and lower slope deposits of Spitsbergen. The different environments occur, however, in vertical succession, that is, in a deepening upward cycle. The biofacies are therefore not strictly time equivalent. This is in fact the case for most studies conducted on this topic simply because laterally correlatable outcrops of shelf/slope successions are not common in the geological

record. The Recurrent Species Associations of Bergström and Carnes (1976) as well as Stouge's (1984) biofacies and sub-biofacies are largely derived from vertical successions.

The Cow Head area where slope and shelf deposits are found in close proximity provides the opportunity to study conodont communities in their lateral distribution and composition. Correlation between shelf and slope sucessions has been outlined in Chapter 3. Conodont faunas from clasts which represent remains of the shelfedge were situated in the boundary region where shelf (Midcontinent faunas) and basin faunas (North Atlantic faunas) meet. This setting offers an opportunity to study the mechanisms of interaction between the two faunal provinces. The relationships can be demonstrated by comparing faunas reported in earlier studies from the lower slope sequence (Fahraeus, 1970; Fahraeus and Nowlan, 1978, Johnston, 1987) and from the shelf (Barnes and Tuke, 1970; Stouge, 1982, 1984) with those of the shelf edge. Ethington and Repetski (1984) as well as Stouge (1984) recognized inner shelf, outer shelf and shelfedge biofacies in Lower and Middle Ordovician rocks of the North American Midcontinent Province. Their terminology is adopted herein with the addition of a lower slope biofacies which has been recognized by Fortey and Barnes (1977).

In order to establish the biofacies of the shelfedge/upper slope environment data regarding the sedimentology of clasts, found in the three megaconglomerate horizons (beds 10, 12 and 14) has been utilized. This is elaborated on in later chapters (chapters 6-10). The clasts have been subdivided according to their origin and age into local, foreign and older lithologies and assigned the letters A, B, C respectively. Foreign clasts are interpreted as fragments of the shelfedge and upper slope (Fig. 1-2) and only conodont faunas from these lithologies are used to establish the biofacies. The conodont data are summarized in appendices 1-4. The biofacies recognized from each conglomerate horizon are compared to faunas considered contemporaneous (cf. Chapter 3) in adjacent environments (i.e. bedded lower slope deposits of the CHG and shelf deposits of the St. George Group) and

in other areas which were selected based mainly on the amount of documentation available and on the distinctiveness of the faunal composition.

Lower and Middle Ordovician faunas are described in some detail from Sweden (Van Wamel, 1974; Löfgren, 1978), the western U.S (Ethington and Clark, 1981), Australia (McTavish, 1973; McTavish and Legg, 1976; Cooper, 1981) and Argentina (Serpagli, 1974).

In Sweden faunas are described from öland (Van Wamel, 1974) and Jämtland (Löfgren, 1978). Both localities are part of the Scandinavian platform (Bruton et al., 1985) and lie within the Central Baltoscandian Confacies belt (Jaanusson, 1976) which is deepening towards the west. Jämtland is located close to the Caledonian front in the west and and its sediments were probably deposited in deeper water. Limestone deposition dominated in öland during the Arenig; limestone and shale is present in Jämtland. Scandinavia is likely to have occupied a position in high latitudes (Bruton et al., 1985).

The Pogonip Group of the Ibex area in Utah comprises a succession of thin-bedded limestone, siltstone and shale deposited on the North American craton close to the western continental margin. It can be regarded as an outer shelf sequence. The more westerly situated rocks of the Toquima, Antelope and Monitor ranges are interpreted as adjacent slope deposits (Ross, 1976).

Ordovician sediments of Australia were deposited in several sedimentary basins (e.g. Canning Basin, Amadeus Basin, Georgina Basin). These basins are the remains of a shallow epeiric sea (Larapintine Sea) which connected the Tasman Eugeosyncline with the Burmese Malayan Eugeosyncline (Webby, 1978) during the Ordovician. Australia probably occupied a position within 15-30° North of the equator during this time. Sediments and conodonts of the Canning Basin have been described by McTavish (1973) and McTavish and Legg (1976). This basin was closer to the Burmese Malayan Geosyncline than the intracratonic Amadeus Basin whose faunas were described by Cooper (1981). The Canning Basin was

probably influenced by cool 'Atlantic' currents from the geosyncline and the setting can be regarded as outer shelf in contrast to the sediments of the Amadeus Basin which lay closer to the centre of the seaway and are better described as inner shelf deposits. Burrett et al. (1984) described a Middle to Upper Ordovician shallow platform to deep basin transect from southern Tasmania. Burrett et al. (1983) found North Atlantic or cosmopolitan faunas with *Periodon* in the deep water sediments and Midcontinent faunas with *Phragmodus* in the shallow water deposits. The platform margin was inhabited by Midcontinent faunas together with elements found elsewhere in Australia (Burrett et al., 1984).

The paleogeographic situation of the San Juan Limestone in Argentina is difficult to assess because of the tectonic complexity of the Precordillera. According to Baldis (1978) along the western border of this area a shelf carbonate sequence grades into a flysch sequence during the Early Ordovician. The adjacent Famatina region is interpreted as a shelf/slope sequence. The San Juan Limestone may thus also represent an outer shelf environment.

4.2. Paroistodus - Drepanoistodus Biofacies

Three samples from clasts in Bed 10 (230, 234, 236) yielded a fauna characterized by *Paroistodus numarcuatus* and *Drepanoistodus inconstans*. Accompanying species include *Scolopodus? peselephantis*, *"Scandodus" pseudoramis* (Serpagli), *Paroistodus proteus* and *Drepanodus arcuatus*. Johnston (1987) reported a similar fauna from the base of Bed 9 and the assemblage obviously belongs to the *Paroistodus proteus* Zone of Baltoscandia. It is not further evaluated herein because of the small size of the collection.

4.3. Prioniodus - Texania Biofacies

Of the 35 samples collected from Bed 10 (clasts and matrix) 22 are from foreign penecontemporaneous lithologies and representative of the shelf edge and upper slope environment. These clasts yielded 2105 conodonts representing 56 multielement and form species (Appendix 1). Eight species are especially abundant and comprise 60% of the fauna. These are:

- *Prioniodus (P.) marginalis* n. sp., 28%,
- *Prioniodus (P.) serratus* n.sp., 16%,
- *Prioniodus (P.) elegans* Pander, 15.5%,
- *Oistodus elongatus* Lindström, 4%,
- *Drepanoistodus inconstans* (Lindström), (3.9%),
- *Drepanoistodus forceps* Lindström (3.4%),
- *Texania* sp. aff. *T. adentata* (McTavish) (2.8%).

Also significant are *Paroistodus parallelus* Pander (2.3%), *Drepanoistodus concavus* (Branson and Mehl) (2.3%) and *Drepanodus arcuatus* Pander (2.2%). The assemblage is termed *Prioniodus - Texania* Biofacies after the most abundant and the most distinct genera respectively. The fauna is distinguished by the prioniodans *Prioniodus* and *Texania*, and the simple cone genera *Oistodus, Drepanoistodus, Drepanodus* and *Paroistodus*. The prioniodans are, with the exception of *P. (P.) elegans*, endemic to the shelfedge and the upper slope. They show affinity to Australian species which have been described from the Emmanuel Formation by McTavish (1973). The dominating simple cone species are mostly cosmopolitan or of North Atlantic aspect. True cosmopolitan species are *D. arcuatus* and *P. parallelus*. Their world wide distribution has been interpreted as the result of a pelagic life style (Fortey and Barnes, 1977). *O. elongatus* is abundant in Argentinian and Baltoscandian faunas but a rare constituent of the Midcontinent (cf. Ethington and Clark, 1981); it does, however,

occur in the St. George Group (Stouge, 1982). *D. inconstans* and *D. forceps* may also be cosmopolitan but their similarity to other species of *Drepanoistodus* makes evaluation difficult. A species close to if not conspecific with *D. forceps* has been reported from the Pogonip Group (Ethington and Clark, 1981). *D. concavus* is only known from the North American Midcontinent.

Of the 56 species found in shelf edge derived clasts 20 are restricted to the Midcontinent with only sporadic occurrences reported from localities outside of North America. They comprise about 8% of the fauna (Fig. 4-1).

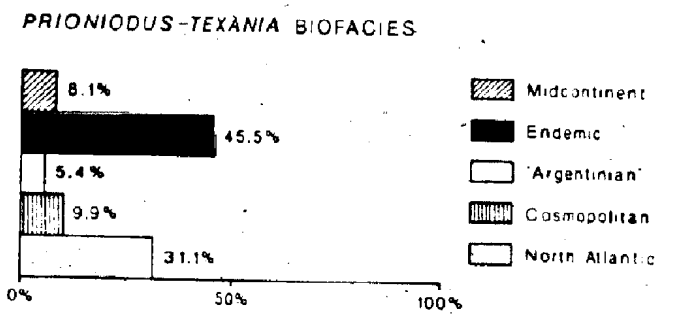


Figure 4-1: Composition of the *Prioniodus-Texania* Biofacies

Four species (5.4%) are known from Argentina but do also occur in North America in open shelf deposits . Thirteen of the species (31.1%) are largely restricted to the North Atlantic Province and 7 (9.9%) can be regarded as cosmopolitan. The remaining 12 species are endemic to the upper slope environment and are mostly of Australian affintiy or single problematic elements. This endemic group accounts for 45.5% of the biofacies.

4.4. Comparison with contemporaneous faunas from other regions

4.4.1. Lower slope deposits (Bed 9) of the Cow Head Group

Johnston (1987) studied conodonts from the bedded Arenig sequence at St Pauls Inlet and Martin Point. The Martin Point section is dominantly composed of shale and produced only small faunas, the St. Pauls Inlet section in contrast yielded large numbers of conodonts. Bed 9 here is equivalent in age to foreign clasts in Bed 10; 52 different species were recognized in Bed 9. In contrast to the prioniodid dominated shelfedge biofacies the lower slope fauna is dominated by *Paracordylodus gracilis* Lindström (25% of the total fauna) and *P. (P.) elegans* (13%). Johnston did not distinguish between *P. (P.) elegans* and *P. (P.) marginalis*. Study of his collections shows that the samples contain a mixture of both species with *P. (P.) elegans* being the more abundant species. *D. arcuatus* comprises 10% of the fauna, followed by *P. parallelus* (7%) and *Periodon? selenopsis* Serpagli (5%). *Glyptoconus quadraplicatus* (Branson and Mehl), *D. concavus* and *Diaphorodus delicatus* (Branson and Mehl) each comprise 3.5% of the fauna. Together these eight species represent 71% of the fauna. North Atlantic (*P. (P.) elegans, Periodon? selenopsis, Paracordylodus gracilis*) and cosmopolitan species (D. arcuatus, P. parallelus]) dominate the lower slope biofacies. Of the endemic shelfedge species only *P. (P.) marginalis* is present in significant numbers. As with the upper slope biofacies the fauna is highly diverse, but is not as exclusively dominated by one species. Both biofacies are quite distinct because of the different character of the dominating species.

4.4.2. Baltoscandian biofacies

Conodonts of the *P. elegans* Zone in Jämtland (Löfgren, 1978) are far less diverse than those from the Cow Head region. Of the 10 species listed from the *Prioniodus elegans* Zone *P. (P.) elegans* is most abundant followed by *D. forceps* and *Periodon?* sp. (= *P.? selenopsis*). *D. arcuatus, P. parallelus* and *Stolodus*

stola stola (Lindström) are also important. This fauna clearly shows a closer kinship to the lower slope biofacies of Bed 9 than to that of the upper slope. The dominating species, however, are different. The conodont fauna described from öland by Van Wamel (1974) is dominated by simple cone genera, i. e. *D. arcuatus, D. forceps, P. parallelus, Scolopodus? peselephantis* Lindström and *Scolopodus quadratus* Pander. *P. (P.) elegans* is present but not an important component of the fauna. *P. gracilis* occurs in both of the Scandinavian sections but is largely restricted to older sequences. In the Cow Head Group the species becomes less abundant in the upper part of Bed 9 where numbers of *P. (P.) elegans* increase.

4.4.3. Midcontinent biofacies

Rocks yielding contemporaneous conodont faunas of Midcontinent aspect are present in the Catoche Formation of the St. George Group. Stouge's (1982) Fauna 4 correlates for the most part with Fauna E (Fig. 3-1). Several of the species which Stouge reported are also present in the upper slope biofacies, including: *P. parallelus, D. concavus, D. arcuatus, O. elongatus* and *"Scandodus" pseudoramis* Serpagli. According to Stouge, *Prioniodus (Oepikodus) communis* (Ethington and Clark) represents the dominant faunal element (No species numbers are published from the St. George Group to date and the exact composition of the fauna is therefore difficult to evaluate). An Argentinian Fauna with *Bergstroemognathus extensus* Serpagli, *O. elongatus, Acodus? sweeti* Serpagli and *Scolopodus* sp. aff. *S. quadratus* Pander is present in the middle Catoche Formation in Fauna 4. This interval is interpreted as deep subtidal facies (Knight and James, in press) and it is conceivable that deeper water faunas were able to migrate onto the shelf platform.

In the Pogonip Group of Utah and Nevada rocks of the middle to upper Fillmore Formation are probably equivalent to beds 9 and 10 as well as to the Catoche Formation. A diverse fauna with more than 40 species has been reported by Ethington and Clark (1981). The Interval-zones of *Texania (=Microzarkodina?) marathonensis - Oepikodus communis* and *Jumodontus*

gananda - Reutterodus andinus (Fauna E) are dominated by eight species which comprise 60% of the fauna. The most abundant species is *Prioniodus (O.) communis* (20% of fauna), followed by the long ranging species *Acodus* sp. aff. *A. emmanuelensis* McTavish and *Acodus deltatus*. Also abundant are *Teraina marathonensis* (Bradshaw) and, surprisingly, *Paracordylodus gracilis*. A species close to *D. forceps* together with *Walliserodus comptus* and *"Scandodus"* sp. 1 Ethington and Clark (= *"S." pseudoramis*) are significant components of the fauna. It is conspicuous that species with complex acodiform and prioniodiform apparatuses dominate the Midcontinent faunas in contrast to the simple cone species which are more abundant in the Scandinavian sections during this time interval.

4.4.4. Other regions

Contempemporaneous conodonts have been described from the Emmanuel Formation of the Canning Basin by McTavish (1973). He described 20 species, 15 of which are endemic to Australia and comprise almost 80% of the fauna. About 15% of the fauna is of Midcontinent aspect and only 5% are North Atlantic forms.

Serpagli (1974) described 14 species in his Local Assemblage Zone A which can be correlated with the *P. elegans* Zone. The author did not record numbers of species recovered and percentages can therefore not be calculated. Seven of the species reported are endemic, that is, they are ubiquitous in Argentina. Most of these Argentinian species have subsequently also been found in Midcontinent sediments (Ethington and Clark, 1981), a few also in Scandinavia (*Oistodus elongatus, Periodon? selenopsis*). *P. (P.) elegans* is not present in Argentina.

4.5. Conclusions

Comparison of the upper slope/shelfbreak biofacies with age-equivalent platformal and lower slope sequences shows that during Bed 9 and Bed 10 time three strongly segregated biofacies existed: 1. a *P. (O.) communis* biofacies characterized the open shelf environment; 2. a *Prioniodus - Texania* biofacies inhabited the shelfedge and upper slope and 3. a *Paracordylodus* biofacies is found on the lower slope. Fig. 4-2 shows the distribution of the most abundant species of the three biofacies. Species are listed in order of decreasing abundance for shelfedge and lower slope.

Each of these biofacies are dominated by a species which is largely restricted to its realm (i.e. *P. (O.) communis*, *P. (P.) marginalis*, *P. gracilis*). Accompanying species are either also endemic or cosmopolitan. The strong faunal segregaton impedes correlation between the three biofacies and although an "interfingering" of the faunas can be observed this seems to be controlled by environmental factors rather than biostratigraphic ranges. Consequently a species with a relatively short range in one environment may persist for a long time in another. For the time interval of the *P. elegans* Zone the boundaries between the biofacies are rather sharp and the upper slope/shelfbreak represents a distinct independant habitat rather than a "mixing zone" between two provinces. Interestingly some of the shelfedge species show kinship to Australian faunas (i. e. faunas described by McTavish, 1973) with *P. (P.) marginalis* being close to *P. (P.) oepiki* Metavish; *P. (P.) serratus* close to *Acodus longibasis* McTavish and *T.* sp. aff. *T. adentata* close to *T. adentata* (McTavish). Another Australian species (*Protoprioniodus simplicissimus* McTavish) is also present. An exchange of biostratigraphically important species is far more common between upper and lower slope biofacies than an exchange between shelf and upper slope. Also many of the dominant species of the upper and lower slope are of North Atlantic affinity allowing correlation with other North Atlantic Province faunas rather than with those from the Midcontinent. Short ranging abundant and distinct species are not yet known from the time equivalent Midcontinent Province and although many Midcontinent species are present as minor constituents in the shelfedge biofacies they are not useful for detailed correlation.

Figure 4-2: Conodont biofacies distribution and composition during Bed 9/10 time

SHELF

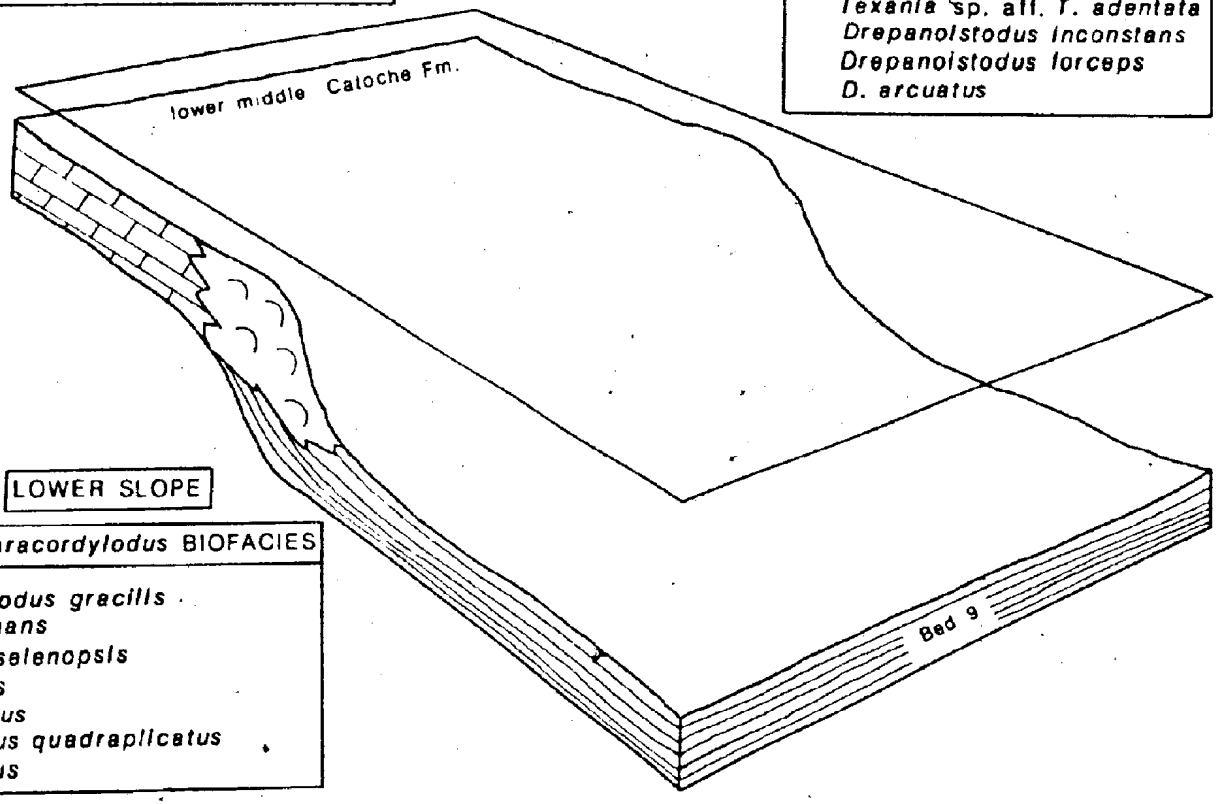
Prioniodus (Oepikodus) communis BIOFACIES

P. (O.) communis
'Scandodus' pseudoramis
Drepanoistodus concavus
Paroistodus parallelus
Drepanodus arcuatus

SHELFEDGE

Prioniodus Texania BIOFACIES

Prioniodus (P.) marginalis
P. (P.) elegans
Oistodus elongatus
Texania sp. aff. *T. adentata*
Drepanoistodus inconstans
Drepanoistodus forceps
D. arcuatus



LOWER SLOPE

Prioniodus – Paracordylodus BIOFACIES

Paracordylodus gracilis
P. (P.) elegans
Periodon? selenopsis
D. arcuatus
P. parallelus
Glyptoconus quadraplicatus
D. concavus

4.6. Prioniodus-Periodon Biofacies

Conodont samples of foreign lithologies in Bed 12 yield conodonts of two different zones derived from older (lower Bed 11-age)and younger (upper Bed 11-age) strata of the upper slope (Appendix 2). This is consistent with the biostratigraphic evidence reported from the bedded sequence of Bed 11 (Johnston, 1987) where *Prioniodus (Oepikodus) evae* occurs in the lower to middle part and *Periodon aculeatus* in the upper part of Bed 11. The middle part of the section produced faunas with about equal amounts of *P. (O.) evae* and *P. aculeatus*. Seventeen samples from Bed 12 can be recognized as older lithologies. These are dominantly lumpy wackestones which yield large numbers of the Baltoscandian zonal index fossil *Prioniodus (Oepikodus) evae*. The fauna comprises 1238 elements representing 31 multielement and form species. Only 4 species comprise 85% of the fauna:

- *P. (O.) evae*, 76%,
- *Periodon flabellum* Lindström, (6%),
- *Protopanderodus rectus* and *Drepanoistodus forceps* (1.5% each).

This association is termed the *Prioniodus-Periodon* Biofacies. Accompanying species are typically Argentinian faunal elements with *Bergstroemognathus extensus* Serpagli, *Walliserodus australis* Serpagli and *Acodus? sweeti* (Serpagli) and *Scolopodus* sp. cf. *S. quadratus* Pander. Samples of Bed 11 age from lower slope derived clasts found in beds 12 and 11 are also dominated by *P. (O.) evae* but the most abundant accompanying species, apart from *P. flabellum*, are *Bergstroemognathus extensus* and *Drepanodus arcuatus* (Johnston, 1987).

Plotting the percentages of the different species (Fig. 4-3) shows that almost 90% of the shelf edge fauna is of North Atlantic affinity, followed by cosmopolitan species (5.6%). Argentinian species comprise 1.8% of the fauna and is more common in lower slope derived clasts. Endemic and Midcontinent species are low in abundance (0.5 and 2.6% respectively).

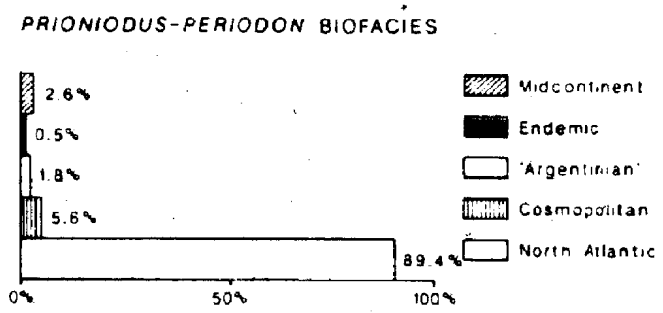


Figure 4-3: Composition of the *Prioniodus - Periodon* Biofacies

4.7. Comparison with contemporaneous faunas from other regions

4.7.1. Lower slope biofacies (lower Bed 11) of the CHG

Bedded lithologies in the lower part of Bed 11 are similar in faunal composition to those of the upper slope with the dominant species being *P. (O.) evae* and *P. flabellum* which together comprise about 80% of the total fauna. Next in abundance are *D. arcuatus*, *Protopanderodus rectus* Lindström and *Paroistodus parallelus* Pander. Argentinian faunal elements persist from Bed 9 into the *O. evae* Zone.

4.7.2. Baltoscandian biofacies

Comparison with conodonts of the *O.) evae* Zone in Baltoscandia shows a fairly similar faunal association: in Jämtland *P. (O.) evae* and *P. flabellum* dominate the fauna followed by *D. forceps* and *P. rectus* (Löfgren, 1978). Faunas from öland are more diverse and dominated by *D. forceps* and/or *P. (O.) evae*. *P. flabellum* is also an important component of the fauna together with *P. rectus*, *P. parallelus* and *D. arcuatus* (Van Wamel, 1974).

4.7.3. Midcontinent biofacies

Coeval shelf faunas in the St. George Group are probably represented by Fauna 5 of Stouge (1982) which persists throughout the upper part of the Catoche Formation and probably the lower part of he Aguathuna Formation. The faunal composition appears to be fairly similar to that of the middle Catoche Formation. The same is true for the Pogonip Group where Fauna E, dominated by *P. (O.) communis*, persists from the upper Fillmore Formation through most of the Wah Wah Formation.

4.7.4. Other regions

The lower part of the Horn Valley Siltstone in Central Australia yields *P. (O.) evae* (Cooper, 1981) and *Bergstroemognathus extensus*. The fauna is dominated by endemic species (e.g. *Trigonodus larapintinensis* (Crespin) which comprise almost 50% of the fauna, North Atlantic species comprise about 14%, Argentinan elements 13% and Midcontinent forms 24%. These numbers are derived from a small fauna (1302 elements) and give only a general impression of the composition of this biofacies.

In Argentina (Serpagli, 1974) faunas yielding the Scandinavian zonal index fossil *P. (O.) evae* are dominated by *Juanognathus variabilis* Serpagli and *Reutterodus andinus*; *W. australis*, *B. extensus*, *P. parallelus* and *P. flabellum* are also present.

4.8. Conclusions

Compared to the *Periodon-Texania* Biofacies of Bed 10 endemism during lower Bed 11 time is low and North Atlantic, cosmopolitan and Argentinian species inhabited the shelf edge as well as the lower slope (Fig. 4-4). The shelf during this time interval is invaded by Argentinian faunal elements which are interpreted as deep shelf faunas (Ethington and Repetski, 1984). The almost worldwide spread of North Atlantic faunas with *P. (O.) evae* is interpreted as the result of a eustatic sea level high (Vail et al., 1977; Barnes, 1984).

Figure 4-4: Conodont biofacies distribution and composition during lower Bed 11-time.

SHELF

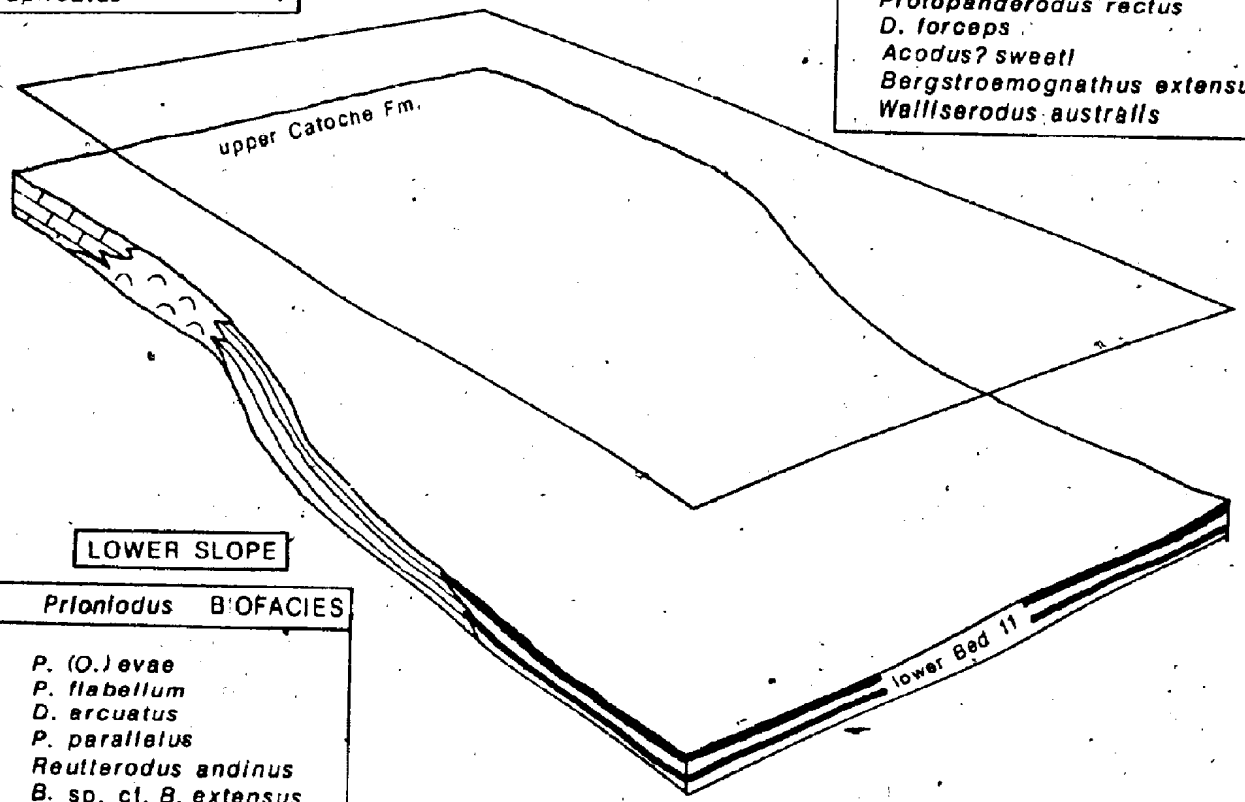
'Scandodus' - Prioniodus BIOFACIES

'S.' pseudoramis
P. (O.) communis
D. concavus
D. arcuatus
Tripodus laevis
Protoprioniodus aranda
G. quadraplicatus

SHELFEDGE

Prioniodus - Periodon BIOFACIES

Prioniodus (O.) evae
Periodon flabellum
Protopanderodus rectus
D. forceps
Acodus? sweeti
Bergstroemognathus extensus
Walliserodus australis



LOWER SLOPE

Prioniodus BIOFACIES

P. (O.) evae
P. flabellum
D. arcuatus
P. parallelus
Reutterodus andinus
B. sp. cf. B. extensus
Acodus gladiatus

4.9. Periodon-Texania biofacies

Ten samples from Bed 12 can be identified as younger lithologies based on lithological (the lumpy wackestones are missing) and faunal evidence (*P. (O.) evae* disappears). 38 species were identified (1512 elements) (Appendix 2) and the fauna is composed of

- *Periodon aculeatus* Hadding, 58.7%,
- *Texania heligma* n.sp. (15.9%),
- *Protoprioniodus papiliosus* (Van Wamel) (5.2%),
- *Strachanognathus parvus* Rhodes (3.8%),
- *Protoprioniodus aranda* Cooper (3.4%),
- *P. (O.) communis* (2.6%).

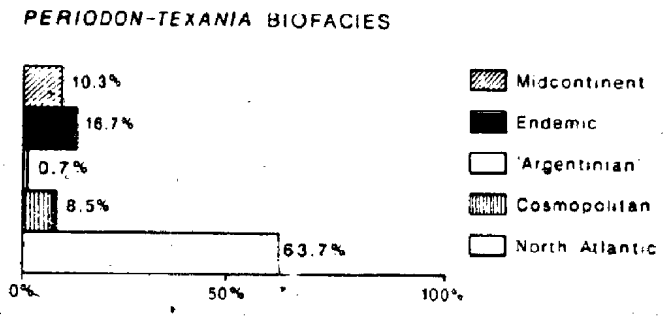


Figure 4-5: Composition of the *Periodon - Texania* Biofacies

Plotting the percentages of the different faunal components of the assemblage (Fig. 4-5) shows that species of North Atlantic affinity decreased by almost 30% in abundance compared to the *Prioniodus-Periodon* Biofacies. Endemic and Midcontinent species are more abundant here (16.7% and 10.3% repectively), while Argentinian faunas are minor components of the faunal assemblage.

4.10. Comparison with other regions of equivalent age

4.10.1. Lower slope biofacies (Bed 13) of the CHG

The faunal shift is reflected in the bedded sequence of Bed 11 (Johnston, 1987) where the upper part also contains a *P. aculeatus* dominated fauna composed of 43 different species (7147 elements). Four species comprise 90% of the fauna: *P. aculeatus* (80%) followed by *P. (O.) interrnedius* (Serpagli), *P. flabellum* and *P. parallelus*. Characteristic accessory species are *Spinodus* sp. cf. *S. horridus* (Barnes and Poplawski), *P. aranda* and *S. parvus* which are all introduced at this level. Many Argentinian elements (e.g. *Bergstroemognathus extensus*, *Acodus? sweeti*, *Walliserodus australis*) disappear in this interval.

4.10.2. Baltoscandian biofacies

The *Periodon-Texania* Biofacies probably corresponds in age largely to the *Paroistodus originalis* Zone (cf. Chapter 3) of Baltoscandia. Löfgren 1978) collected a fauna comprising 27 species, dominated by *Microzarkodina flabellum* (Lindström), *Prioniodus (Baltoniodus) navis* (Lindström) and *P. originalis*. Also abundant are *Protopanderodus rectus* and *Drepanoistodus basiovalis* (Sergeeva). The four species mentioned first comprise more than 65% of the fauna. *Protoprioniodus* sp. cf. *P. simplicissimus* McTavish occurs in this interval. Two abundant species, *P. (B.) navis* and *Scandodus brevibasis* (Sergeeva), are missing in the Cow Head sequence. *Periodon flabellum* persists and is not yet replaced by *P. aculeatus*. In öland the *P. originalis* Zone has been termed *Triangulodus brevibasis* Assemblage Zone by Van Wamel (1974) and only 12 different species are reported from the interval. Notably *P. flabellum* is rare or absent in the section and instead *Microzarkodina flabellum* is common together with *P. (B.) navis*. *S. brevibasis* occurs for the first time and *P. originalis* becomes abundant. *D. basiovalis* and *P. rectus* together with *P. (B.) navis* and *M. flabellum* dominate the fauna. It differs from the Swedish fauna mainly in the lack of *P. flabellum* and the lower diversity of species (14 at most in öland to 23 in Jämtland).

4.10.3. Midcontinent biofacies

On the shelf the lower part of the Aguathuna Formation is probably equivalent to the upper part of Bed 11. Only few species have been recovered from the dolomitized rocks to date (Stouge, 1982; Kenna, 1986; Z. Ji, pers. comm., 1987). These include *P. (O.) intermedius* and *Texania marathonensis* (Bradshaw). Also present are *P. papiliosus*, *J. variabilis*, *D. concavus*, *Semiacontiodus asymmetricus* (Barnes and Poplawski) and *Jumodontus gananda* Cooper. The faunal assemblage probably represents Fauna E-1 and persists from the upper Catoche into the lower Aguathuna Formation. In the Pogonip Group of Utah and Nevada the upper Wah Wah and Juab formations are regarded as equivalent to this interval (Chapter 3). Ethington and Clark (1981) reported 33 different species from this interval with three species comprising 60% of the fauna at section J. These are *P. (O.) communis*, ?*Acodus emmanuelensis* and *Juanognathus variabilis*. *Protoprioniodus papiliosus* and a few specimens of *Tripodus laevis* are also present. Generally the fauna becomes less abundant and diverse in the lower Juab. At the Fossil Mountain section the fauna of the upper Wah Wah and lower Juab formations comprises 27 species and is dominated by *P. aranda* together with *Texania marathonensis*, *Parapanderodus gracilis* and aff. *O. minutus*. These species comprise more than 50% of the fauna. *M. flabellum* occurs in this interval together with *T. laevis*. *O. communis* becomes rare and is replaced by aff. *O. communis*. Compared to the *Periodon-Texania* Biofacies the shelf fauna is less diverse and less dominated by just one or a few abundant species. Comparison of the two different sections (i.e. section J and Fossil Mountain) of the Pogonip Group shows that the faunal composition changes quite drastically over a relatively short distance as in the Cow Head Group.

4.10.4. Other regions

In Central Australia the interval above the last occurence of *P. (O.) evae* in the Horn Valley Siltstone (Cooper, 1981) is considered roughly contemporaneous with the *Periodon - Texania* Biofacies. This interval is characterized by endemic species (e.g. *Prioniodus amadeus, Drepanoistodus pitjanti*) which comprise 55% of the fauna; Midcontinent species comprise 43% and North Atlantic forms only 2% of the biofacies.

In Argentina Assemblage Zone C and possibly part of D of Serpagli (1974) may be correlated to the *Periodon - Texania* Biofacies. The interval is dominated by *Prioniodus (O.) intermedius* Serpagli. Most of the other species which first occur in this interval are also of Argentinian origin, many with occurrences in the Midcontinent. Of the 24 species described from Zone C and lower D only eight have occurrences in Baltoscandia.

4.11. Conclusions

The faunal change during upper Bed 11-time affected graptolite as well as conodont faunas (Fig. 3-1) and probably occurred in response to a regression on the shelf platform which is reflected in the dolomitized shallow water carbonates of the lower Aguathuna Formation. The *Periodon-Texania* Biofacies, though still dominated by North Atlantic species shows an increase of Midcontinent, endemic and cosmopolitan species at the expense of North Atlantic and Argentinian components (Fig. 4-6).

The *Periodon-Texania* biofacies differs from the lower slope biofacies in yielding higher numbers of specimens of *P. originalis, P. aranda* and *S. parvus*. The endemic species *T. heligma*, a close relative of *Texania* sp. aff. *T. adentata* from Bed 10, is rare in the bedded sequence, while *P. (O.) intermedius* is lacking in the upper slope facies. Both biofacies have in common that most of the accessory species are present in low numbers.

Figure 4-6: Conodont biofacies distribution and composition during upper Bed 11-time

SHELF

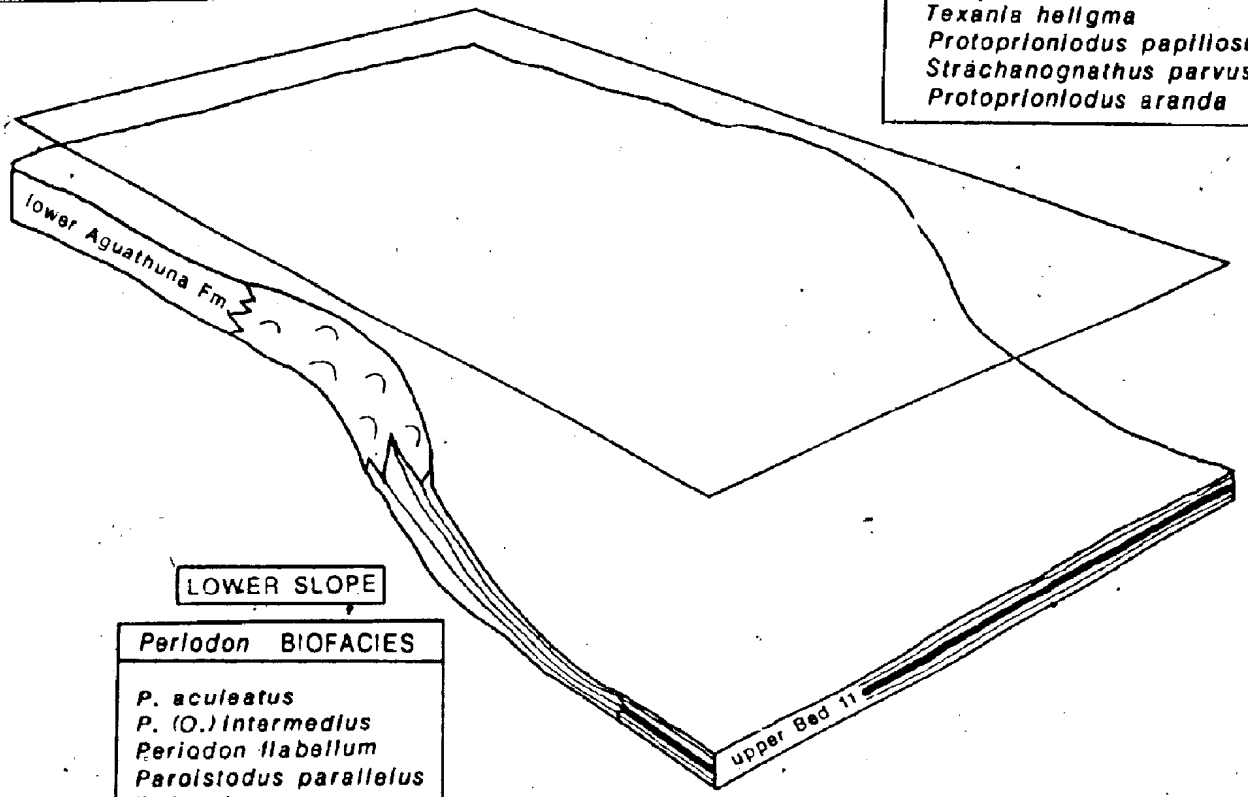
Prioniodus – Texania BIOFACIES

Prioniodus (O.) intermedius
Texania marathonensis
Tripodus laevis

SHELFEDGE

Periodon – Texania BIOFACIES

Periodon aculeatus
Texania heligma
Protoprioniodus papiliosus
Strachanognathus parvus
Protoprioniodus aranda



LOWER SLOPE

Periodon BIOFACIES

P. aculeatus
P. (O.) intermedius
Periodon flabellum
Paroistodus parallelus
T. laevis
P. aranda

4.12. Periodon-Parapanderodus Biofacies

The 65 samples collected from foreign penecontemporaneous lithologies in Bed 14 yielded 2250 conodonts representing 56 different multielement and form species (Appendix 3). Close to 90% of the fauna consists of 8 species:

- *Periodon aculeatus*, (74.7%),
- *Parapanderodus arcuatus* Stouge, (4.1%),
- *Protopanderodus rectus*, (3.2%),
- *Paroistodus parallelus*, (2.2%),
- *Oistodus lanceolatus*, (1.7%),
- *Drepanoistodus* sp. aff. *D. basiovalis* Sergeeva, 1.5%,
- *Parcistodus originalis*, 1.5%
- *Parapanderodus* sp. 1, 1.5%.

The fauna comprises in addition to the species listed above small numbers of Table Head faunal elements such as *Parapaltodus simplicissimus* Stouge, *Drepanoistodus* sp. cf. *D. venustus* (Stauffer), *Paltodus* sp. cf. *P. jemtlandicus* Löfgren, *Scolopodus oldstockensis* Stouge, *Oistodus? tablepointensis* Stouge and *Erraticodon balticus* Dzik. The above species are particularly abundant in the middle part of the Table Head Group (Stouge, 1984). This faunal assemblage, found in shelf margin derived clasts is termed *Periodon-Parapanderodus* Biofacies.

Plotting the different species according to their provincial affinity (Fig. 4-7) shows, that most are of North Atlantic aspect but a high percentage (9.1% compared to 10.3%, 2.6% and 8.1% respectively in older biofacies) is of Midcontinent affinity. Endemicity of the fauna is 3.4% and Argentinian elements are rare (0.5%). Cosmopolitan species account for 7.3% of the fauna.

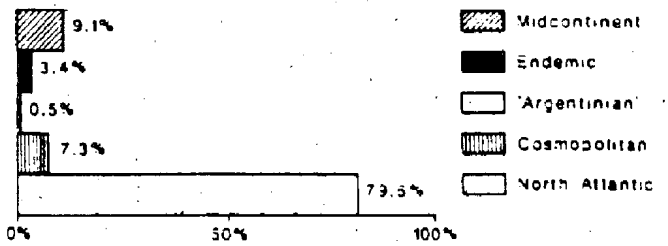


Figure 4-7: Composition of the *Periodon - Parapanderodus* Biofacies

4.13. Comparison with contemporaneous faunas from other regions

4.13.1. Lower slope biofacies

Age-equivalent lower slope deposits of Bed 13 yielded rich faunas at the St Pauls Inlet section (Johnston, 1987) with 11533 elements representing 58 different multielement and form species. As in Bed 14 the fauna is dominated by *Periodon aculeatus* which comprises 84% of the fauna. Also common are *P. flabellum*, *Protoprioniodus aranda*, *P. parallelus* and *Drepanodus arcuatus*. Comparison with the clast faunas in Bed 14 suggests that many species are restricted to the shelfedge environment at that time. These include *Ansella jemtlandica*, *D.* sp. cf *D. venustus*, *P. originalis*, *Parapanderodus* sp. 1, and many of the rare Table Head species listed earlier. *P. arcuatus* is almost absent in lower slope deposits and instead a closely related form *P.* sp. cf. *P. arcuatus* is present.

4.13.2. Baltoscandian biofacies

Beds 13 and 14 are considered to be largely age equivalent to the *M. parva* and possibly to the lower part of the *Eoplacognathus? suecicus* Zone of Scandinavia. In Jämtland faunas from the *M. flabellum parva* Zone are dominated by *Prioniodus (Baltoniodus) prevariabilis norrlandicus* (Löfgren, 1978) which comprises close to 50% of the fauna. Also abundant are *P. rectus* and *D. basiovalis*. *P. flabellum* still persists in small numbers. Species of Midcontinent affinity are scarce, such as *Protopanderodus* sp. cf. *P. varicostatus*, *Protoprioniodus* sp. cf. *P. simplicissimus*, *Parapanderodus* sp. aff. *P. gracilis*, *Pallodus?* sp. cf. *P.? mysticus* and *Drepanoistodus* sp. cf. *D. venustus*. The next younger *Eoplacognathus? variabilis* Zone is subdivided into the *Eoplacognathus? variabilis - Microzarkodina flabellum* and the *E.? variabilis - M. ozarkodella* Assemblage subzones (Löfgren, 1978). Faunas of the older zone are still dominated by elements of *Prioniodus (Baltoniodus)*. *P. rectus* sp. cf. *P. varicostatus*, *D. basiovalis* and *Scolopodus cornuformis* are next in abundance. *Scalpellodus latus* occurs in this interval together with *D.? venustus*, *Acodus? mutatus* and *Ansella jemtlandica*. In öland sections of this age are missing.

4.13.3. Midcontinent biofacies

A single clast found in Bed 14 at Lower Head contained a fauna equivalent to Fauna 6 of Stouge (1982) which occurs at the top of the Aguathuna Formation and in the lowermost Table Head Group and which is considered to be age equivalent to Fauna 2 and 3 of the Midcontinent zonation. Stouge (1982) referred to his Fauna 6 from the top of the St. George Group as a 'hyaline fauna' because of the large number of hyaline species such as *Leptochirognathus* sp. aff. *L. primus* Branson and Mehl, *Tetraprioniodus costatus* (Mound), *Multioistodus* sp. cf. *M. subdentatus* Cullison and *Trigonodus carinatus* Stouge. These faunas have hardly any species in common with shelfedge and lower slope biofacies.

4.13.4. Other regions

The Bed 13/14 biofacies have nearly age-equivalent counterparts in other areas such as the Fort Pena Formation in Texas (Bradshaw, 1969), the Levis Formation (Uyeno and Barnes, 1970) and the Mystic Conglomerate in Quebec (Barnes and Poplawski, 1973).

The Mystic Conglomerate is dominated by *Periodon aculeatus*, *Paroistodus? originalis* and *Protopanderodus cooperi*. Other significant faunal elements are *Parapanderodus arcuatus* and *Ansella jemtlandica*. Similar to the *Periodon-Parapanderodus* Biofacies there are scattered specimen of *Erraticodon balticus*, *Oistodus? tablepointensis*, *Spinodus ramosus* and *Parapaltodus simplicissimus* present. In contrast, *Spinodus horridus* which is fairly abundant in the Mystic as well as in the middle Table Head Group is almost absent in the Cow Head conglomerates.

The Levis Formation (Uyeno and Barnes, 1970) is dominated by *Periodon*, *Protopanderodus* and *Paroistodus?* and lacks *Spinodus* and *Ansella*.

The Fort Pena Formation is dominated by *Periodon*, *Protopanderodus* and *Drepanoistodus*. The association of *Periodon aculeatus* and *Protopanderodus* sp. cf. *P. varicostatus* together with a lack of *Spinodus* is similar to the Cow Head conglomerates and suggests that the two deposits are similar in age. The Mystic Conglomerate which shows more similarity to the middle Table Head Formation may be slightly younger.

In Argentina the first occurrence of *Ansella jemtlandica* (=*Bellodella* sp. A of Serpagli) in Assemblage Zone D up to Zone E probably correlates to the *Periodon-Parapanderodus* Biofacies. Only seven species were described from this interval. Three of the species are of North Atlantic affinity, one is a cosmopolitan, the others are endemic with occurrences in the Midcontinent Province.

4.14. Conclusions

The high proportion of *Periodon aculeatus* found in foreign penecontemporaneous clasts of Bed 13 age is characteristic of shelfedge facies found in allochthonous sequences along the Appalachian Orogen. The shelf edge facies is strongly segregated from coeval platform faunas which are almost exclusively of Midcontinent affinity (Fig. 4-8).

The *Periodon-Parapanderodus* Biofacies has many species in common with the middle Table Head Group (*Cordylodus?-Periodon* Biofacies of Stouge (1984)). The similarity is probably the result of deepening of the water on the shelf during middle Table Head-time as a result of foundering of the platform. This enabled the shelfedge faunas to migrate onto the platform (Pohler et al., 1987).

4.15. Summary and conclusions

Five different biofacies characterized the Arenig shelfbreak/upper slope environment. These are from old to young: (1) the *Paroistodus-Drepanoistodus* Biofacies, (2) the *Prioniodus-Texania* Biofacies, (3) the *Prioniodus-Periodon* Biofacies, (4) the *Periodon-Texania* Biofacies and (5) the *Periodon-Parapanderodus* Biofacies. The first two Biofacies occur in boulders in Bed 10 and are thus contemporaneous to Bed 9 of the bedded sequence of the CHG, Biofacies (3) and (4) are found in boulders in Bed 12, equivalent to Bed 11; Biofacies (5) is restricted to Bed 14, equivalent to Bed 13 of the lower slope. Comparison of shelfbreak/upper slope-derived faunas with those from the lower slope shows that both faunas are more closely related to the North Atlantic Province than to the Midcontinent Province and should be regarded as a Subprovince of the North Atlantic Province. The lower Arenig faunas are representative of the older and younger *Paroistodus* Fauna (sensu Lindström, 1976); upper Arenig faunas can be referred to as *Periodon* faunas. Similar faunas can be found in deep water sediments around the North American Craton. These faunas have been described from many localities, examples are: Levis (Uyeno and Barnes, 1970); the Mystic Conglomerate (Barnes and Poplawski, 1973); the

Figure 4-8: Conodont biofacies distribution and composition during Bed 13/14 time

SHELF

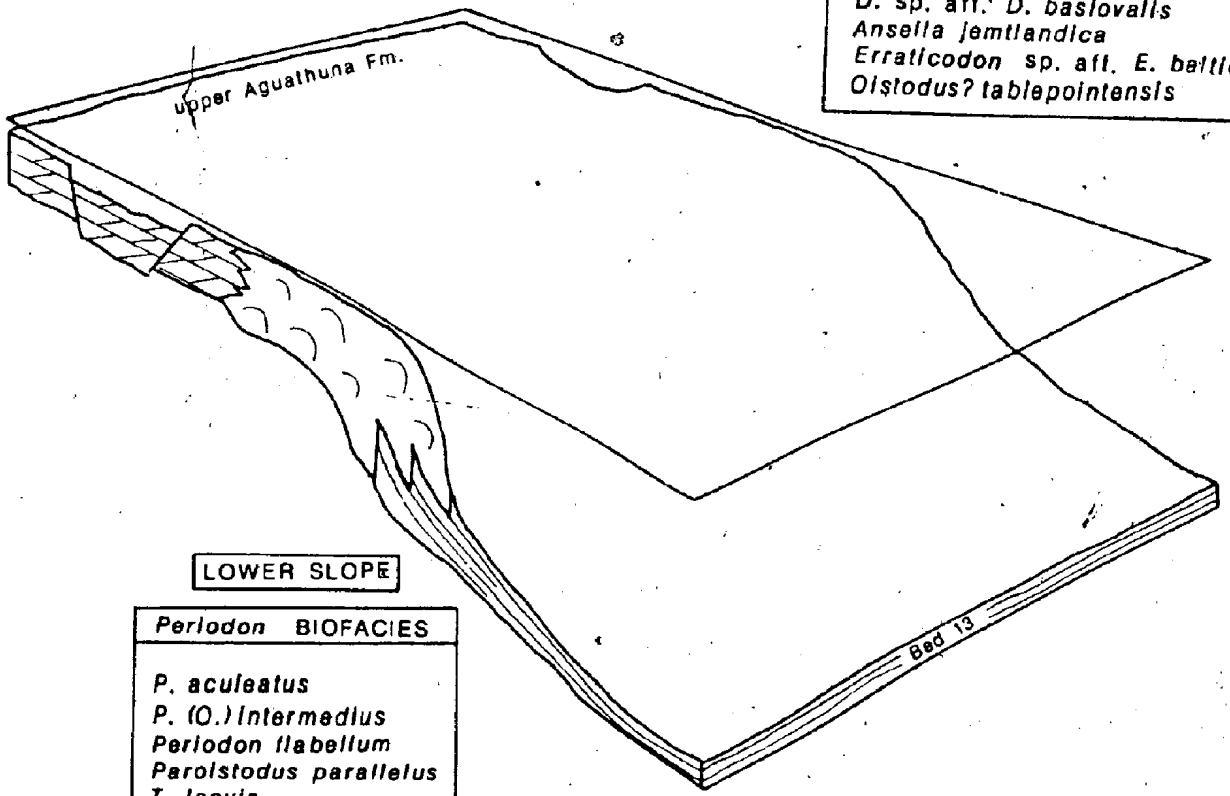
Trigonodus – Tetraprioniodus BIOFACIES

Multioistodus sp.cf. *M. subdentatus*
Trigonodus carinatus
Leptochirognathus sp. aff. *L. primus*
Tetraprioniodus costatus
Parapanderodus gracilis

SHELFEDGE

Periodon – Parapanderodus BIOFACIES

P. aculeatus
Parapanderodus arcuatus
P. rectus
Oistodus lanceolatus
P. parallelus
D. sp. aff. *D. baslovalis*
Ansella jemtlandica
Erraticodon sp. aff. *E. balticus*
Oistodus? tablepointensis



LOWER SLOPE

Periodon BIOFACIES

P. aculeatus
P. (O.) intermedius
Periodon flabellum
Paroistodus parallelus
T. laevis
P. aranda

Taconic Allochthon (Landing, 1976); the Hamburg Klippe (Bergström et al., 1972); the Ouachita Mountains (Repetski and Ethington, 1977); the Marathon Basin (Bradshaw, 1969) and the Toquima Range (Ethington, 1972; Harris et al., 1979).

Comparison of the shelfbreak/upper slope faunas with those reported from the lower slope (Johnston, 1987) of the CHG shows that the two environments are inhabited by different conodont assemblages. These are referred to as biofacies and represent communities structuring the *Paroistodus* and *Periodon* faunas across this North American margin. Except for the *Prioniodus-Texania* Biofacies of Bed 10 the biofacies of shelfbreak/upper slope and lower slope are similar with regard to the dominating species but differ in the composition of accessory species. Shelfbreak and slope faunas are strongly segregated from those reported from the shelf platform (Stouge, 1982; Stouge and Boyce, 1983) which are of North American Midcontinent aspect and which can be correlated to sections on the North American craton. The shelf and slope faunas differ in the composition of the dominating species but have some of the accessory species in common. The shelfbreak apparently represents a sharp faunal boundary between shelf and slope with only minor interaction of the conodont faunas. The presence of boulders with shelf faunas indicates that the provincial boundary was not far from the site where the debris flows originated (i.e. shelfbreak/upper slope). There is no indication of the presence of a true "mixing zone" where the dominating species of both provinces occur together in large numbers.

Provincial boundaries are not well studied in other areas. The Lower to Middle Ordovician Pogonip Group probably represents a segment of an ancient shelf margin with the outer shelf environment preserved in the Ibex area of Utah and the upper slope in the Antelope and Toquima ranges of Nevada. The faunas described from Utah (Ethington and Clark, 1981) are clearly of Midcontinent aspect with only few North Atlantic forms while those of Nevada (Ethington, 1972; Harris et al., 1979; pers. observation, 1986, 1987) are mixed faunas with many North Atlantic as well as Midcontinent forms. Ocean currents or

geographical barriers (e.g. reef barriers) may be responsible for the differences in migrational patterns.

Plotting the biofacies compositions of the shelfbreak/upper slope faunas of the CHG with respect to North Atlantic, Midcontinent, Argentinian, endemic and cosmopolitan species shows fluctuations in composition which can be related to the sealevel history of the platform (Fig. 4-9): the *Prioniodus-Texania* Biofacies was established during a transgressive phase and persisted over a relatively long period of time. It yields the highest number of endemic species and is distinct from the lower slope as well as from the shelf.

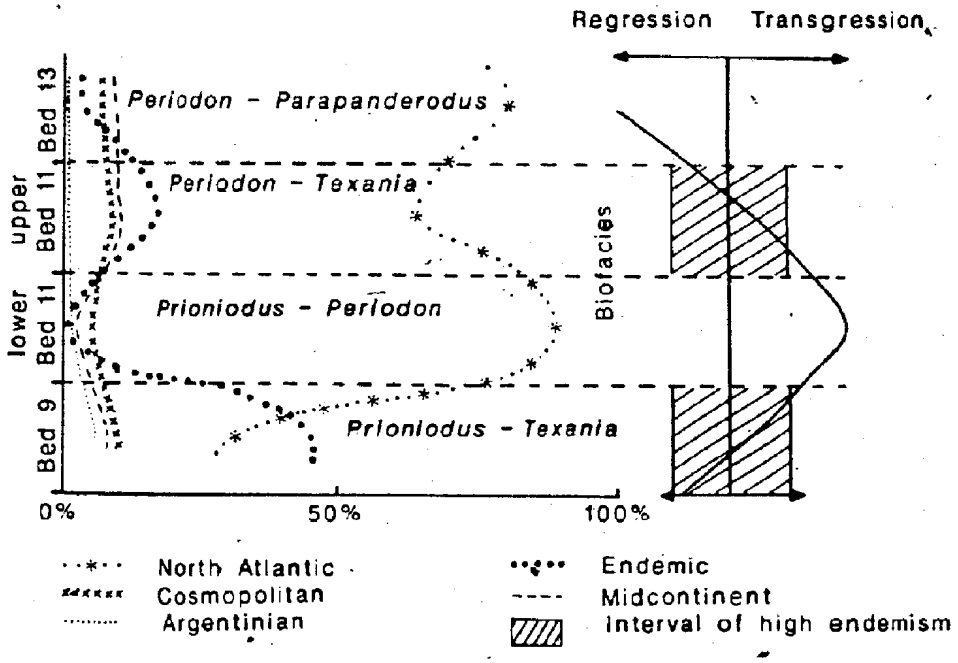


Figure 4-9: Relationship of biofacies composition and sealevel history.

The following younger *Prioniodus-Periodon* Biofacies was established during a period of high sealevel on the shelf. It yields the lowest number of endemic and Midcontinent forms and the highest number of North Atlantic species. With the onset of regression on the shelf a new fauna is established at the shelfedge, the

Periodon-Texania Biofacies with a higher number of Midcontinent and endemic species and a decreased number of North Atlantic forms. The youngest *Periodon-Parapanderodus* Biofacies responds to the lowest sea level on the shelf and records an increase of North Atlantic species, decrease of endemic forms and stable number of Midcontinent species. Argentinian and cosmopolitan species are too rare to evaluate their role in biofacies composition. The fluctuations in faunal composition suggest that at certain times endemic faunas were established. These endemic species commonly are restricted to a few samples or rare lithologies where they occur in large numbers suggesting that they evolved in response to highly specialized environmental conditions. Most of the endemic forms are related to species previously described from Australia (McTavish, 1973). High endemism in recent marine environments has been linked to several factors such as special environmental conditions (ref.) or short larval stages which prevent dispersal (ref.). In ancient sediments island faunas have been interpreted to be highly endemic (Neumann, 1984). The sporadic occurrence and relatively low number of the endemic species found, however, does not allow further speculation on their significance. Migrations of Midcontinent elements to the shelfedge are clearly related to shallowing of the water on the shelf; abundance of North Atlantic forms to relatively high sealevel on the shelf recorded in the Catoche Formation (James et al., in press).

Among the conodont faunas from other localities those from the Mystic Conglomerate appear to be closely related to the *Periodon-Parapanderodus* Biofacies (Barnes and Poplawski, 1973). Comparison of conodont faunas from the Scandinavian platform shows differences between öland and Jämtland which suggest that two different biofacies are present. Similarly faunas from different sections of the Pogonip Group show different compositions suggesting, that different biofacies are present. The Argentinian faunas (Serpagli, 1974) contain dominantly endemic and Midcontinent species which warrant to assign them to an Argentinian Subprovince of the Midcontinent Province. Australian faunas are highly endemic and should be regarded as an Australian Province rather than a Midcontinent Subprovince.

Comparison of conodont faunas from the CHG with those from other areas confirm a few consistent trends: Midcontinent faunas are present in shallow tropical or subtropical waters. In North America the interior shelf is inhabited by Midcontinent faunas while the outer shelf with presumably deeper water is inhabited by a mixture of Midcontinent, Australian and/or Argentinian faunas. The shelfbreak/upper slope is dominated either by Midcontinent or by North Atlantic faunas depending on locality. Incursions from North Atlantic faunas on the shelves are related to deepening (cooling?) of the water; excursions of Midcontinent faunas to the shelf edge or upper slope to shallowing (warming?) of water (Fig. 4-9).

The reasons for the strong segregation of provincial faunas are difficult to evaluate because (a) few studies have dealt in detail with this problem, (b) the life style of the conodont animal is not clear and (c) the apparatus of many conodont species has not yet been established which causes problems for understanding distributions of the species. Study of recent oceans suggests that the shelf/slope break represents a fundamental boundary for marine life as was demonstrated for isopod crustacean faunas northwestern Atlantic (Taylor, 1977). Cook and Taylor (1975) speculated on the role of the thermocline for the observed patterns of trilobite biofacies distribution. They suggested that water temperature is a leading factor in restricting universal spread of trilobites. This may apply for conodonts as well. Other causes for the faunal seggregation may be bottom water aeration, different life and feeding styles of different genera and larval dispersal. A variety of factors is most likely the cause for the ambiguous evidence.

Chapter 5
TAXONOMY

5.1. Introduction

This investigation concentrates on biostratigraphy and conodont-biofacies, hence the systematic part has been restricted to the taxonomic treatment of a those species which add new information to the knowledge of Lower Ordovician conodonts.

All species recovered are illustrated (Plates 5.1-5.9) and tabulated (Table 5-1). Most are also found in rocks from the bedded sequence of the Cow Head Formation and the reader is referred to these reports (Fahraeus & Nowlan, 1978, Johnston, 1987).

Multielement taxonomy is employed where an apparatus has already been defined or the writer is confident that it can be reconstructed from the material at hand. Form-taxa are distinguished by the abbreviation s.f. (following Barnes & Poplawski, 1973). Tentative generic designations are enclosed in quotation marks.

For tabulation of specimens available compositional elements which are part of a symmetry-transition series are summarized under inclusive terms (eg. ramiform elements of *Acodus*).

The synonymy lists for species that are only discussed as "Remarks" are restricted to:

- the original author;

- authors who contributed significantly to the knowledge of the species;
- authors who provided a detailed synonymy;
- authors whose identification is questioned or rejected.

Specimens figured are deposited in the type collections of the Geological Survey of Canada. Species recovered from conglomerate horizons are listed in alphabetical order in Table 5-1. Species described in the text are marked '*'. The column caption "species ID" refers to A = Argentinian faunal elements, meaning species which were first described by Serpagli (1974); C = cosmopolitan species (refers to species which occur in both, Midcontinent and North Atlantic deposits); E = endemic species (only known from foreign lithologies in the Cow Head conglomerates); M = Midcontinent species (described from the North American craton); N = North Atlantic species (described from Baltoscandia); and U = unidentified species. Plate and figure numbers where specimens are illustrated are given in the third column of the table.

FAUNAL LIST		
Species	Species ID	Pl./fig. #
Acodus deltatus Lindström.	N	5.1, 1-4.
A. gladiatus Lindström	N	5.1, 5.
A.? mutatus Branson & Mehl	M	5.1, 6.
**A.? sweeti* (Serpagli)	A	5.1, 8-9.
*Acodontiform element 1	U	5.1, 10.
*Acodontiform element 2	U	5.1, 7
Acontiodus reclinatus Lindström	N	5.1, 11-12.
A. iowensis Furnish	M	5.1, 18.
**A.* sp. aff. *A. latus* Pander	U	5.1, 14.
**A.* sp. 2 Barnes & Tuke	M	5.1, 13.
Ansella jemtlandica (Löfgren)	N	5.1, 15-17.
**Bergstroemognathus extensus* Serpagli.	A	5.1, 19-22.
Cristodus loxoides Repetski.	M	5.1, 23-24.
Coelocerodontus bicostatus Van Wamel	N	5.1, 25.
Cordylodus caboti Bagnoli et al.	C	5.1, 27.
C. proavus Müller.	C	5.1, 26.
Cornuodus longibasis Lindström	N	5.1, 28-29.
**Drepanodus arcuatus* Pander	C	5.2, 1-7.
**D.* ? *toomeyi* Ethington & Clark	M	5.2, 8.
Drepanodus sp. 2 Ethington & Clark	M	5.2, 10.
D. sp. 4 Repetski	M	5.2, 9.
D. sp. 4 Serpagli	A	5.2, 11.
**D.?* sp. 1 s.f.	U	5.2, 18.
**D.* sp. 2 s.f.	U	5.2, 19.
*Drepanodontiform element 1	U	5.2, 12.
*Drepanodontiform element 2	U	5.2, 13.
**Drepanoistodus concavus* (Branson&Mehl)	M	5.2, 20-23.
D. forceps Lindström	C	5.2, 24-26.
**D.* sp. aff. *D. basiovalis* (Sergeeva)	C	5.2, 16-17.

FAUNAL LIST		
Species	Species ID	Pl./fig. #
D. aff. *basiovalis* sensu Eth.&Clark.	M	5.2, 14-15.
D. inaequalis (Pander)	N	5.2, 27.
D. inconstans (Lindström).	N	5.2, 28-31.
**D.* cf. *venustus* (Stauffer).	M	5.3, 1.
Eoconodontus notchpeakensis Miller	C	5.3, 2.
**Erraticodon* sp. aff. *E. balticus* Dzik	M	5.3, 3-5.
Eucharodus parallelus (Branson & Mehl)	M	5.3, 6.
Fryxellodontus? corbatoi Serpagli	A	5.3, 8-10.
F.? ruedemanni Landing	M	5.3, 11.
**F.?* sp.	U	5.3, 12.
Glyptoconus quadraplicatus (Branson&Mehl)	M	5.3, 7.
Juanognathus jaanussoni Serpagli	A	5.3, 13.
J. variabilis Serpagli	A	5.3, 14.
Jumodontus gananda Cooper	M	5.3, 15-16.
Loxodus bransoni Furnish	M	5.3, 17.
**Oistodus elongatus* Lindström	A	5.3, 18-22.
**O. lanceolatus* Pander	N	5.3, 23-26.
O. aff. *inaequalis* Ethington & Clark	M	5.3, 27.
O. cf. *venustus* (Stauffer)	C	5.3, 31.
O.? tablepointensis Stouge	M	5.3, 28.
O.? triangularis Furnish	M	5.3, 29.
**O.* sp. 1 s.f.	U	5.3, 30.
*Oistodontoform element 1	U	5.3, 32.
*Oistodontiform element 2	U	5.3, 33.
*Oistodontiform element 3	U	5.3, 34.
Oneotodus costatus Brand & Ethington	M	5.4, 1.
**Paltodus* sp. cf. *P. jemtlandicus* Löfgren	E	5.4, 2.
**P.?* sp. s.f.	U	5.4, 3.

FAUNAL LIST		
Species	Species ID	Pl./fig. #
Paracordylodus gracilis Lindström	N	5.4, 4-6.
Parapaltodus simplicissimus Stouge	M	5.4, 7.
**P.* sp.	U	5.4, 8-9.
**Parapanderodus arcuatus* Stouge	M	5.4, 10.
P. gracilis (Ethington & Clark)	M	5.4, 11.
**P.* sp. 1	E	5.4, 12.
Paraprioniodus costatus (Mound)	M	5.4,13-15.
Paroistodus numarcuatus Lindström	N	5.4, 16-17.
P. originalis Sergeeva	N	5.4, 18-19.
**P. parallelus* Pander	C	5.4, 20-21.
P. proteus Lindström	N	5.4, 22-23.
P. sp. B Stouge	M	5.4, 24.
**Periodon aculeatus* Hadding	N	5.4, 25-27,31-32.
**P. flabellum* (Lindström)	N	5.4, 28-29,33-34.
**P.? selenopsis* (Serpagli)	N	5.5, 1-3.
**Prion. (Oepikodus) communis* Ethington & Clark	M	5.5, 4-6.
P. (O.) evae Lindström	N	5.5, 7-9.
**P. (O.)* aff. *minutus* McTavish	E	5.5, 10-12.
**Prioniodus (Prioniodus) elegans* Pander	N	5.5, 13-16.
**P. (P.) marginalis* n.sp.	E	5.5, 17-20.
**P. (P.) serratus* n.sp.	E	5.5, 21-25.
**P.* sp.	U	5.5, 26-30.
*Prioniodontiform element 1	U	5.6, 1.
Proconodontus muelleri Miller	C	5.6, 2.
Protopanderodus elongatus Serpagli	A	5.6, 3-4.
P. gradatus Serpagli	A	5.6, 5.
**P. rectus* Lindström	N	5.6, 6-8.
**P.* cf. *varicostatus* Sweet & Bergström	C	5.6,9.
**Protoprioniodus aranda* Cooper	M	5.6, 10-12.
**P. papiliosus* (Van Wamel)	C	5.6, 13-14, 20.
P. simplicissimus McTavish	M	5.6, 15-16.

FAUNAL LIST		
Species	Species ID	Pl./fig. #
**P.* sp. 1 S.F.	U	5.6, 17.
Pteracontiodus cryptodens (Mound)	M	5.6,18-19, 21-23.
Ptiloncodus simplex Harris	M	5.6, 24.
**Rossodus manitouensis* Repetski & Ethington	M	5.6, 25.
**Scalpellodus* sp. 1	E	5.6, 26-29.
Scandodus furnishi Lindström	N	5.6, 30-31.
** "S." mysticus* Barnes & Poplawski	M	5.6, 32-34.
** "S" pseudoramis* (Serpagli)	M	5.6, 35-37.
*Scandodontiform element 1	U	5.8, 38-39.
*Scandodontiform element 2	U	5.7, 1.
Scolopodus carlae Repetski	M	5.9, 2A-B.
S. paracornuformis Ethington & Clark	M	5.7, 6.
S. emarginatus Barnes & Tuke	M	5.7, 2.
"S." giganteus Sweet & Bergström	M	5.7, 3.
**S. multicostatus* Barnes and Tuke	M	5.7, 4.
S. oldstockensis Stouge	M	5.7, 5.
**S.? peselephantis* Lindström	N	5.7, 8.
S. quadratus Pander	N	5.7, 7.
S. aff. *filosus* Eth. & Clark	M	5.7, 9.
**?Scolopodus* sp. Ethington & Clark	M	5.7, 10.
** "Scolopodus"* sp.	U	5.7, 12.
*Scolopodontiform element 1	U	5.7, 11.
**Semiacontiodus asymmetricus* Barnes & Poplawski	M	5.7,13.
**Serratognathus dougli* n.sp.	M	5.7, 14-16.
Spinodus horridus Barnes & Poplawski	M	5.8, 1.
S. ramosus Hadding	M	5.8, 2.
**Strachanognathus parvus* Rhodes	M	5.8, 3.
Stolodus n.sp. 1 Serpagli	A	5.8, 4-5.
Teridontus nakamurai (Nogami)	M	5.8, 6.

FAUNAL LIST		
Species	Species ID	Pl./fig. #
**Texania heligma* n.gen n.sp.	E	5.8, 11-15.
**T. marathonensis* (Bradshaw)	M	5.8, 16-20.
**T.* sp. aff. *T. adentata* (McTavish)	E	5.8, 7-10.
**T.* sp.	U	5.8, 21-25.
Tripodus laevis Bradshaw	M	5.8, 26.
**T. aff. laevis* Bradshaw	E	5.8, 27-31.
T. subtilis (Van Wamel)	N	5.8, 34-35.
**T.* sp.	U	5.8, 32-33.
?U. wisconsinensis Furnish	M	5.7, 17.
Variabiloconus aff. *bassleri* (Furnish)	U	5.7,18-19.
Walliserodus ethingloni Fahraeus	N	5.7, 20.
**W. australis* Serpagli	A	5.7, 21-22.
**W. aff. australis* Serpagli	U	5.7, 23-24.
Westergaardodina sp.	U	5.7. 25.
*New genus A new species 1	U	5.7, 29.
*New gen. A n. sp. 2	U	5.7, 27-28.
*New genus B sp. 1	U	5.7, 30.
*New genus C sp. 1	U	5.7, 26.

Genus *Acodus* Pander, 1856

Type species. *A. erectus* Ulrich and Bassler, 1926.

ACODUS? SWEETI Serpagli
Pl. 1, figs. 8-9

"Paltodus" sweeti SERPAGLI, 1974, p.58, Pl.14, figs. 13a-14a; Pl.24, figs. 8-10, Text-fig. 12.

"Scandodus" americanus SERPAGLI, 1974, p.83, Pl. 16, figs. 6a-7b; figs. 16-17; Pl.30, fig.10, Text-fig. 22.

Remarks.- Prioniodontiform and oistodontiform elements assigned to *"Paltodus" sweeti* and *"Scandodus" americanus* by Serpagli (1974) are placed in *Acodus? sweeti* as suggested by Lindström (1977).

The prioniodontiform element agrees most closely with *"Paltodus"? sweeti* s.f.. Serpagli (1974) pointed out that the elements are variable in their basal outline. Forms recognized herein to belong to *"P." sweeti* s.f. show a variable length of the oral margin of the base. The margin can be short (as in Serpagli's specimens), or reach almost the same length as the lateral process.

The oistodontiform elements of *A. sweeti* have been described as *"Scandodus" americanus* s.f. by Serpagli (1974) who suspected that they belong in an apparatus with *"P." sweeti* s.f.. Lindström (1977) suggested that *Walliserodus australis* Serpagli also belongs into the apparatus representing acodiform elements of *Acodus? sweeti*. With regard to the apparatus composition of related genera (e.g. *Tripodus*, *Prioniodus*) this is possible but has to await further study

Occurrence.- Beds 10 and 12.

Material.- 53 elements.

Repository.- Hypotypes: GSC 90310-90311.

Acodontiform element 1
Pl. 5.1, fig. 10; Fig. 5-1

Description.- A hyaline acodontiform element with a reclined cusp. Upper part of cusp is slightly twisted with a lenticular cross section. Both lateral faces are smooth. In lower part cusp develops a triangular cross section by gradually widening anterior margin to form a flat anterior face. Cross section of base is triangular with lateral faces forming long sides of triangle. Basal cavity is subtriangular in lateral view with its apex near anterior margin.

Occurrence.- Bed 12.

Material.- 1 specimen.

Repository.- Figured specimen: GSC 90312.



Figure 5-1: Lateral views of acodontiform element 1. X100.

Acodontiform element 2
Pl. 5.1, fig. 7; Fig. 5-2

Description.- Ramiform elements with a relatively large basal region compared to size of cusp. Basal region is triangular in lateral view with aboral margin forming longest side. Anterior and oral margin are both sharply keeled.

Cusp is inclined at shallow angle (100 -110°) to oral edge of base, flexed sideways and somewhat twisted. Posterior and anterior margins of cusp are sharp-edged and cross section is lenticular. Inner side bears typically a sharp-edged carina which develops into a lateral bulge situated posteriorly from midline of lateral face. This inflation produces sinuous outline of aboral margin with largest downward extension marking highest point of bulge. Outer lateral face is convex and smooth. Below outer side, basal cavity is only weakly expanded and aboral margin is evenly curved. Basal cavity is triangular with its apex situated near anterior margin. Cusp is albid.

Remarks.- The rather generalized kind of element described above is represented in several other genera (e.g. drepanodontiform element of *Tripodus*). Since no accompanying elements of *Acodus*? sp. have been found, the generic assignment is tentative.

Occurence.- Clast of Bed 10-age in Bed 14.

Material.- 6 specimens

Repository.- Figured specimen: 90309.

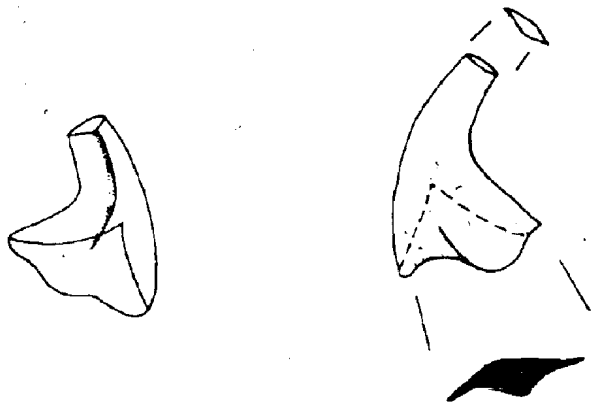


Figure 5-2: Lateral views of acodontiform element 2. X80.

Genus *Acontiodus* Pander, 1886 s.f.

Type species. *A. latus* s.f. Pander, 1856.

ACONTIODUS sp. aff. A. LATUS Pander s.f.
Pl. 5.1, fig. 14; Fig. 5-3

Description.- Recurved to reclined simple cone with asymmetrical triangular shape in posterior view. Element is flattened antero-posteriorly with sharp lateral edges and medium carina. Basal opening when viewed from below is triangular with tip of triangle on posterior side laterally from midline. This lateral displacement results in asymmetry of the element; another cause is the oblique aboral margin.

Remarks.- The form differs from *Acontiodus latus* Pander in being asymmetrical. A. sp. aff. *A. latus* may, however, represent an element in the apparatus of the former species. Ethington and Clark reported symmetrical costate forms somewhat similar to the ones found in the Cow Head material.

Occurrence.- Clasts of Bed 9-age in Bed 11.

Material.- 2 specimens.

Repository.- Hypotype: GSC 90316.

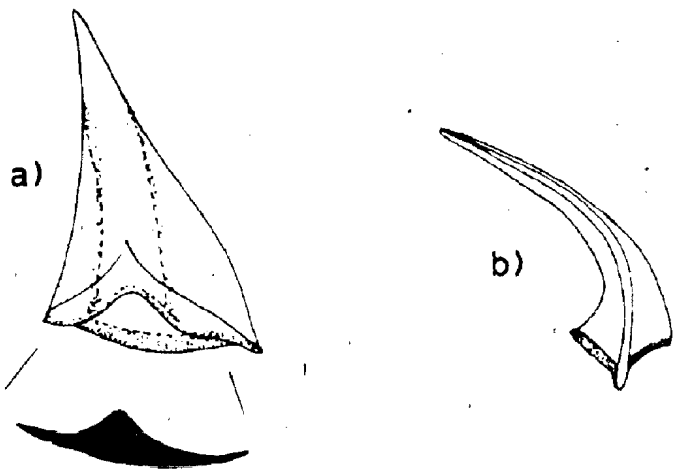


Figure 5-3: a) Posterior, b) lateral view of element of *A.* sp. aff. *A. latus*. X75

ACONTIODUS sp. 2 Uyeno and Barnes
Pl. 5.1, fig. 13; Fig. 5-4

ACONTIODUS **sp. 2 Uyeno and Barnes, 1970, p. 104, Pl. 21, figs. 4,5.**

Description.- Robust multicostate cone with erect to slightly recurved cusp and basal cavity opening to one side. Cusp is flexed laterally. Inner lateral face is smooth, outer face bears several weak costae on lower portion of cusp which grow stronger basally and disappear distally. Anterior margin is sharp-edged and forms laterally deflected keel in basal region on outer side of cusp. Posterior margin of cusp is developed as median ridge flanked by two deep grooves which are bordered by two costae higher than ridge. Cross section of cusp is wedge-shaped. Basal cavity opens to inner side and is of moderate depth; oral margin is rounded. Anterior part of basal margin is sharply sigmoidal in aboral view and strongly deflected sideways, posterior portion is wider and less deflected. Outline of basal cavity thus resembles a keyhole with narrow top (anterior) and wide bottom. (posterior). Cusp is albid.

Remarks.- The element is reported under the name *Acontiodus* in the form sense. Robustness and size suggests that the element is a gerontic form of a species which may usually occur in a different morphology.

Occurrence.- Clasts in beds 10, 12 and clasts of Bed 11-age in Bed 14.

Material.- 5 specimens.

Repository.- Hypotype: 90315.

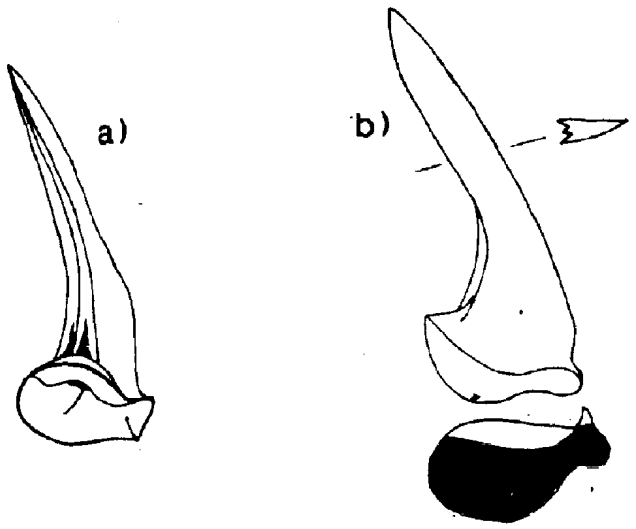


Figure 5-4: a) Posterior and b) lateral view of *Acontiodus* sp. 2 showing cross section of cusp and outline of basal cavity. X45.

Genus *Bergstroemognathus* Serpagli, 1974

Type species. *Oistodus extensus* Graves and Ellison, 1926.

BERGSTROEMOGNATHUS EXTENSUS (Graves & Ellison)

Pl. 5.1, figs. 19-22

Oistodus extensus GRAVES & ELLISON, 1941, p.13, Pl. 1, figs. 16-28.

Bergstroemognathus extensus (Graves & Ellison) Serpagli, 1974, p.40, Pl. 9 ,figs.1a-8c, Pl. 21, figs.1-7, Text-fig.7;

Bergstroemognathus sp. cf. *B. extensus* (Graves & Ellison). Landing, 1976, p.630, Pl.1, 1-6, 9, 10.

Remarks.- All three elements comprising the apparatus of *Bergstroemognathus extensus* have been recovered from boulders in Beds 10 and 12. The falodiform elements agree well with Serpagli's (1974) description. The trichonodelliform elements all lack the anterior depression along the midline of the aboral margin. They thus resemble more closely the specimens figured by Landing (1976, Pl. 1, figs. 5,9). Prioniodontiform elements from Bed 10 possess strongly inward deflected denticles and a curved aboral margin while younger forms from Bed 12 have almost straight denticles and aboral margin.

Occurrence.- Beds 10 and 12, old clasts in Bed 14.

Material.- 197 elements.

Repository.- Hypotypes: GSC 90321-90324.

Genus *Drepanodus* Pander, 1856

Type species. *Drepanodus arcuatus* Pander, 1856.

DREPANODUS ARCUATUS Pander

Pl. 5.2, figs. 1-7

Drepanodus arcuatus PANDER, 1856, p.20, Pl.1, figs. 2, 4, 5, 17, ?Pl.2, figs. 30, 31; LINDSTROM, 1955a, p. 558, Pl.2, figs. 30-33, Text-fig. 3J; LINDSTROM, 1971, p. 41, figs.4, 8; SERPAGLI, 1974, p. 43, Pl.8, figs. 8a-10b, Pl.20, figs. 13-15; VAN WAMEL, 1974, p.61, Pl.1, figs. 10-13; LANDING, 1976, p. 632, Pl.1, figs. 16-19, 21-23; FAHRAEUS & NOWLAN, 1978, p.458, Pl.2, figs. 1,2,8; LOFGREN, 1978, p.51, Pl.2, figs.1-8, (includes synonymy through 1977); ETHINGTON & CLARK, 1981, p.36, Pl.3, figs. 4-8, 12.

Drepanodus cf. *arcuatus* (Pander) LINDSTROM, 1955a, p.560, Pl.2, figs. 45-46, Text-fig. 4c.

Drepanodus flexuosus PANDER, 1856, p.20, Pl.1, figs. 6,7,8.

Scandodus pipa LINDSTROM, 1955a, p. 593, Pl.IV, figs. 38-42, Fig. 3D.

Drepanodus sculponea LINDSTROM, 1955a, p.567, Pl. 2, fig. 40, Fig. 3L.

Drepanodus gracilis (Branson & Mehl), LINDSTROM, 1955a, p. 562, Pl.IV, fig. 44.

Acontiodus arcuatus LINDSTROM, 1955a, p.547, Pl.2, figs. 1-4, Fig. 3A.

Remarks.- Three variants of *Drepanodus arcuatus* can be distinguished in the Cow Head material. The most abundant forms agree with Lindström's (1955a)

description. They occur mainly in samples from clasts in beds 10 and 12 derived from bedded sequences.

Older boulders from the upper slope in Bed 10 produced *D. arcuatus* that resemble those illustrated by Serpagli (1974). They are probably conspecific with *D.* sp. cf. *D. arcuatus* Lindström. The elements possess a basal cavity with an undulating margin especially developed in the oistodontiform elements. Like Serpagli's specimens they commonly possess an anterior keel basally. This keel is sometimes deflected in specimens which approach the arcuatiform morphology. Many of the elements are carinate and some have a costa developed on the outer side of the cusp. The drepanodontiform element, found by Serpagli (1974), has been illustrated by Ethington & Clark (1981, Pl. 3, Fig. 4) and is also present in the Cow Head material. It is characterized by lacking an antero-basal corner. An indentation is developed instead. The forms with undulating margins co-occur with "normal" *D. arcuatus*

A third variant of *D. arcuatus* occurs in two samples from phosphorite-rich clasts in Bed 14. The clasts contain *Prioniodus evae* (indicating Bed 12-age) together with a robust costate form of *D. arcuatus*. Landing (1976) reported similar types from the same stratigraphic interval (i. e. *P. evae Zone*) in the Taconic Allochthon. Hunter (1978) found exclusively costate forms in the Middle Ordovician Cobb's Arm Fm.. He considered them derivatives of *D. arcuatus* implying that development of costation is an evolutionary trend. This idea cannot be evaluated from the material at hand because the costate forms occur in abundance only in samples from phosphorite-rich clasts suggesting an ecologic rather than stratigraphic control. The one element found in stratigraphically younger sequences (Bed 14) is, however, also costate. The majority of the costate *D. arcuatus* elements are oistodontiform accompanied by a few graciliform and one costate drepanodontiform element. The only occurrence of *"Scolopodus" giganteus* Sweet & Bergström in the Cow Head material is in association with these costate forms. Bergström (in Landing, 1976) suspected that *"S." giganteus* is

a gerontic variant of *Protopanderodus robustus*. The evidence at hand suggests that it may be a variant of *D. arcuatus*. Löfgren (1978) considered the costate forms a geographical variant of the Scandinavian species because the former have been reported to date exclusively from North America.

Occurrence.- Beds 10, 12 and 14.

Material.- 177 elements.

Repository.- Hypotypes: GSC 90332-90338.

DREPANODUS? sp. 1

Pl. 5.2, fig. 18; Fig. 5-5

Description.- Recurved simple cones with two costae dissecting both sides of the element or only the outer lateral face. Symmetrical element has shallow basal cavity with apex centrally situated. Aboral margin is convex, oral margin is short and sharp. Posterior and anterior margins are sharp-edged. Both sides are convex and bicostate. One costa dissects lateral face medially, the other is more anteriorly situated. Asymmetrical element has laterally flexed cusp and two costae are present only on outer lateral face. Aboral margin is straight; basal cavity flares to inner side. All elements have a hyaline base and an albid cusp.

Remarks.- All elements are of small size. *Drepanodus*? sp. 1 may, however be closely related to *D.* sp. cf. *D. venustus* (Stauffer), but differs in possessing a shallower basal cavity and shorter aboral margin.

Occurrence.- Bed 10.

Material.- 2 specimens.

Repository.- Figured specimen: GSC 90349.

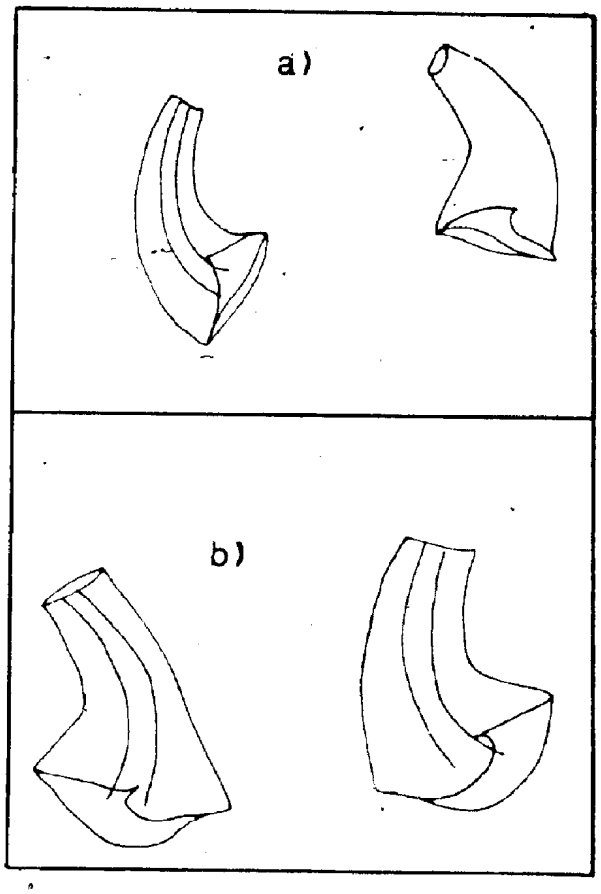


Figure 5-6: Lateral views of a) asymmetrical and b) symmetrical elements of *Drepanodus*? sp. 1. X85

DREPANODUS sp. 2
Pl. 5.2, fig. 19

Remarks.- Hyaline cones with recurved cusp. Lateral faces are smoothly convex and posterior and anterior margins are sharp. Base flares widely and has subcircular to subquadratic outline. Basal cavity is shallow with its apex situated slightly anterior of midline. White matter is confined to growth axis.

Occurrence.- Clasts in beds 10 and 12 and clasts of Bed 11-age in Bed 14.

Material.- 6 specimens.

Repository.- Figured specimen: GSC 90350.

Drepanodontiform element 1
Pl. 5.2, fig. 12; Fig. 5-6

Description.- Reclined to recurved element with small basal cavity and antero-posteriorly compressed cusp. Cusp is slightly twisted and develops lateral flange on inner side beginning shortly above base. Flange declines into merely a sharp edge in upper half of cusp and a broad median carina occurs from this point distally. Thus cross section changes from lanceolate with anterior extension in lower part to lenticular in upper part of cusp. Lateral faces of cusp are smoothly convex. Basal cavity is dark brown and of moderate depth. Its apex reaches point of greatest curvature of cusp. Cross section of basal cavity resembles triangle with rounded edges; its longest side is anteriorly situated. Surface of cone is finely striated and element is albid.

Occurence.- Bed 10.

Material.- 1 specimen.

Repository.- Figured specimen: GSC 90313.

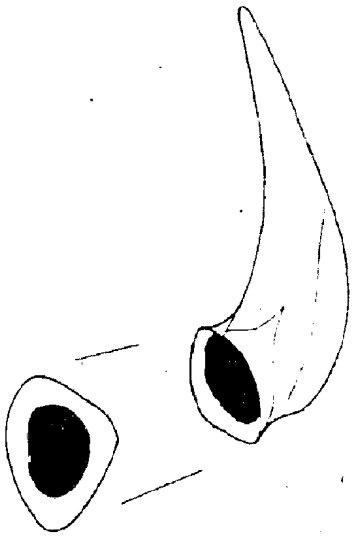


Figure 5-6: Sketch of drepanodontiform element 1 showing cross sections of cusp and outline of basal cavity. X75

Drepanodontiform element 2
Pl. 2, fig. 13

Description.- Simple cone with strongly reclined cusp and groove on inner side of element. Short base whose oral edge forms about 20° degree angle with cusp. Basal cavity is shallow. Cusp is erect but sharply recurved distally. Anterior and posterior margins are rounded. Groove reaches aboral margin and causes depression in otherwise oval cross section of base. Elements are albid with dark brown base.

Occurrence.- Beds 11 and 12.

Material.- 6 elements.

Repository.- Figured specimen: GSC 90311.

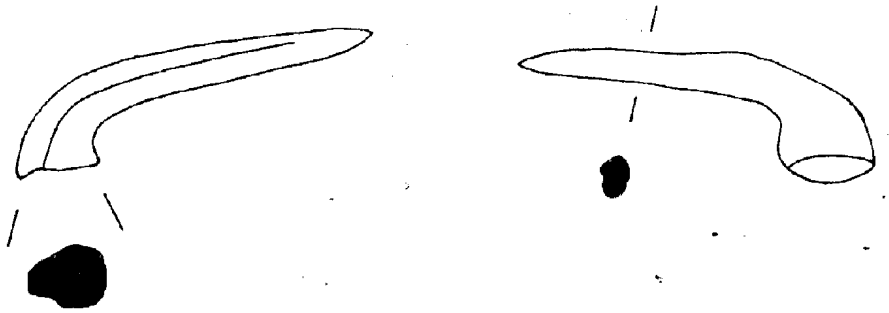


Figure 5-7: Lateral views of drepanodontiform element 2 X80.

Genus {Drepanoistodus} Lindstrom, 1971

Type species. *Oistodus forceps* Lindstrom, 1955.

DREPANOISTODUS CONCAVUS (Branson and Mehl)
Pl. 2, figs. 20-23

Oistodus concavus BRANSON & MEHL, 1933, p.59, Pl.4, figs. 6, 16, 17.

Oistodus gracilis BRANSON & MEHL, 1933, p.60, Pl.4, fig. 20. FAHRAEUS & NOWLAN, 1978, p.459, Pl.2, figs. 13, 18, 19.

Oistodus pandus BRANSON & MEHL, 1933, p.61, Pl.4, figs. 21, 22.

Drepanodus concavus (Branson & Mehl). KENNEDY, 1980, p.55, Pl.1, figs.26-34, (includes synonymy through 1979).

Remarks.- The apparatus includes oistodontiform, suberectiform and homocurvatiform elements and is therefore assigned to the genus *Drepanoistodus*. The elements are usually large with a hyaline base and lower cusp and an albid upper cusp. The amount of white matter in the cusp is variable and usually least in the oistodontiform elements. *Oistodus gracilis* s.f. is similar to *Oistodus parallelus* (Lindström, 1955a, Pl. IV, figs. 27-29) in its morphology but differs by being hyaline.

The homocurvatiform elements are highly variable and the wide range of different morphologies led Kennedy (1980) to assign them to *Drepanodus*. His "sculponeaform" elements (= *Drepanodus pandus* (Branson and Mehl)) is part of a transition series. A gradual change from the "sculponeaform" element, with a straight anterior part of the aboral margin and a low keel on the oral margin, to a more typical homocurvatiform element with a shorter curved aboral margin and a

pronounced keel on the oral margin. This latter element has a more recurved cusp and it resembles *Drepanodus amoenus* Lindström. Van Wamel (1974) included *Drepanodus amoenus* in *Drepanoistodus* and reported homocurvatiform elements with an open anterior stretch of a widely flaring base, similar to that occurring in *D. concavus*. Both, *D. concavus* s.f. and the suberectiform elements are rare in the Cow Head material. The latter possess a thin keel on the oral margin which reaches the postero-basal corner. This keel is characteristic for the species and important for distinguishing *D. concavus* from *D. basiovalis* (Sergeeva). *D. concavus* is abundant in Bed 10. It declines higher in the sequence, both in abundance and size. The composition of the apparatus has been previously recognized by Nowlan (1976) in collections from the Lower Ordovician Eleanor River Formation (Canadian Arctic Islands).

Occurrence.- Beds 10 and 12, reworked clasts in Bed 14.

Material.- 200 elements.

Repository.- Hypotypes: GSC 90351-90354.

DREPANOISTODUS sp. aff. D. BASIOVALIS (Sergeeva)

Pl. 5.2, figs. 16-17

Oistodus basiovalis SERGEEVA, 1963, p.96, Pl.7, figs. 6,7, Textfig. 3.

aff. *Drepanoistodus basiovalis* (Sergeeva). LINDSTROM, 1971, p.43, figs. 6,8; LOFGREN, 1978, p. 55-56, Pl. 1, figs. 11-17, text-fig. 26B, C.

aff. *Drepanoistodus basiovalis* (Sergeeva). BARNES and POPLAWSKI, 1973, p.775, Pl.4, figs. 3,4,7.

Remarks.- Homocurvatiform, suberectiform and oistodontiform elements which agree with the description of *Drepanoistodus basiovalis* (Sergeeva) by Barnes and Poplawski (1973) are herein referred to *D.* sp. aff. *D. basiovalis*. Compared to elements described by Sergeeva (1963), Lindström (1971) and Löfgren (1978), the Cow Head specimens resemble more closely corresponding elements of *Drepanoistodus concavus* (Branson and Mehl). They are, however, albid and generally smaller than the latter. In homocurvatiform elements, the basal cavity is deeper and the oral margin longer and more curved than in *D. basiovalis*. Furthermore, only a few of the Cow Head specimens show the extended antero-basal corner and/or the flexed inward anterior margin typical for that species. The oistodontiform elements possess the inward curvature of the aboral margin below the cusp which is also typical for *D. concavus*. Because of these distinguishing features the species is assigned to *D.* sp. aff. *D. basiovalis* rather than *D. basiovalis*.

Occurrence.- Beds 12 and 14.

Material.- 86 specimens.

Repository.- Hypotypes: 90347-90348.

DREPANOISTODUS? sp. cf. D. VENUSTUS (Stauffer)

Pl. 5.3, fig. 1

cf. *Oistodus venustus* **STAUFFER, 1935, pp.146, 159, Pl.12, fig. 12.**

Drepanoistodus? **cf.** *venustus* **(Stauffer) STOUGE, 1984, p.55, Pl.4, figs. 18-25.**

Remarks.- Costate and weakly costate homocurvatiform and oistodontiform elements are herein included in the apparatus of *Drepanoistodus venustus* following Stouge's (1984) suggestion. No suberectiform elements were found. A transition from costate to acostate elements may be present but acostate elements would be indistinguishable from other homocurvatiform elements of accompanying *Drepanoistodus* species. Therefore, only the costate forms are included in *D.*? sp. cf. *D. venustus*.

Occurrence.- Bed 14.

Material.- 3 elements.

Repository.- Hypotype: GSC 90363.

Genus *Erraticodon* Dzik, 1978

Type species. *E. balticus* Dzik, 1978

ERRATICODON sp. aff. E. BALTICUS Dzik
Pl. 5.3, figs. 3-5

aff. *Erraticodon balticus* DZIK, 1978, p.66, Pl.15, figs. 1-3, 5, 6.

aff. ?*Erraticodon* sp. LOFGREN, 1985, p.126, Fig.4,AT-AY.

Erraticodon balticus Dzik. STOUGE, 1984, p. 84-85, Pl. 17, figs. 9-19.

Remarks.- The few elements recovered are nearly all incomplete and difficult to evaluate. The neoprioniodiform element has a straighter cusp than the type specimen figured by Dzik (1978) but resembles the corresponding element described by Löfgren (1985). The trichonodelliform element has a shorter secondary cusp which is not flanked by lateral denticles as in *E. balticus*; these may, however, be broken. Cusp and denticles of the elements appear to be albid and the specimens are therefore only tentatively assigned to the hyaline species.

Occurrence.- Bed 14.

Material.- 4 elements.

Repository.- Hypotypes: GSC 90365-90367.

Genus *Fryxellodontus* Miller, 1969.

Type species *F. inornatus* Miller, 1969.

FRYXELLODONTUS sp.
Pl. 5.3, fig. 12

Remarks.- Bilaterally symmetrical elements, triangular in posterior view with pointed tip of cusp. Surface is ornamented with "girdles" which traverse the element from side to side, terminating in nodes aligned along sharp lateral margins. Basal cavity is deep. Basal outline is lenticular flaring slightly off-center on posterior as well as anterior side.

Occurrence.- Bed 10, clasts of Bed 9-age in Bed 12.

Material.- 5 elements.

Repository.- Figured specimen: GSC 90374.

Genus *Oistodus* Pander, 1856

Type species. *O. lanceolatus* Ulrich and Bassler, 1926.

OISTODUS ELONGATUS Lindstrom
Pl. 5.3, figs. 18-22

Oistodus elongatus LINDSTROMa, 1955, p. 574, Pl.4, figs. 32,33, Text-fig. 5b.

Oelandodus elongatus (LINDSTROM), Van Wamel, 1974, p.71, Pl.7, figs. 1,2,4, non fig.3;

Oistodus n.sp.1 SERPAGLI, 1974, p.53, Pl.12, figs. 1a-3c; Pl.24, figs. 1-4; Text-fig. 11.

Oelandodus cf. *O. elongatus* (Lindstrom). REPETSKI, 1982, p.29, Pl. 10, fig. 11; Pl. 11, fig.2, ?fig.1.; Fig. 5, T,V,?U.

Description.- *Ostodus elongatus* has been thoroughly described by the authors listed in the synonymy list and does not need further description with the exception of an additional laterally compressed element. Element is characterized by a large spatulate or leaf-shaped cusp and a smaller elongate base. Cusp is strongly reclined, anterior margin forms smooth curve with concavity at distal end. Faint medial carina may be developed on one side. Base extends three quarters of length of cusp. Basal outline is lanceolate, base widest at midlength. Oral margin is short and curved, aboral margin is convex downwards. Elements are albid.

Remarks.- Study of Van Wamel's type collection showed that the triangulariform element figured on Pl.7, fig.3 (Van Wamel, 1974) belongs to *Protoprioniodus* as do all the specimens of *Oelandodus costatus* Van Wamel (cf. Cooper, 1981). Repetski (1982) included a different triangulariform element in his

description of *Oelandodus* cf. *O. elongatus*. This element has not been found in the Cow Head material, but may well be part of the apparatus of *O. elongatus*.

Occurrence.- Bed 10.

Material.- 114 elements.

Repository.- Hypotypes: GSC 90380-90381.

OISTODUS LANCEOLATUS Pander

Pl. 5.3, figs. 23-25

Oistodus lanceolatus PANDER, 1856, p.27, Pl.2, figs. 17-19.

Oistodus lanceolatus (Pander) LINDSTROM, 1955a, p.577, Pl.III, figs. 58-60.

Oistodus triangularis LINDSTROM, 1955a, p.581, Pl. IV, figs. 14-18.

Oistodus delta LINDSTROM, 1955a, p.573, Pl. III, figs.3-9.

Oistodus multicorrugatus Harris SERPAGLI, 1974, p. 52, Pl. 23, figs. 13-16, text-fig. 10.

Oistodus? striolatus SERPAGLI, 1974, p.57, Pl.12, figs.5a-9b; Pl.27,figs. 5-7; Pl.30, figs.7a-8.

Oistodus sp. 1 ETHINGTON & CLARK, 1981, p. 71, Pl. 7, figs. 16, 19-21; fig. 17.

Oistodus cf. *O. lanceolatus* (Pander). REPETSKI, 1982, p.33, Pl.11, fig. 13; Pl. 12, figs. 2,4,6-8.

Remarks.- The elements recovered from boulders in beds 10, 12 and 14 are similar to those figured and described by Repetski (1982) as *O.* sp. cf. *O lanceolatus*. They differ from *O. lanceolatus* as defined by Lindström (1971) in possessing fine surface ornamentation near the base of the cusp and minor costae in addition to the main costa. These features are characteristic of *O.? striolatus* Serpagli. In the Cow Head material *O.? striolatus* is associated with elements of *O. lanceolatus* with abundant transitional forms. It is therefore considered to be conspecific with the latter species. The close relationship of *O.?striolatus* to *O. multicorrugatus* was noted by Serpagli (1974). So far the former species is only known from North and South America and may represent a geogfaphical variant of *O. lanceolatus*.

Occurrence.- Beds 10, 12 and 14.

Material.- 108 elements.

Repository.- Hypotypes: GSC 90385-90388.



OISTODUS sp. 1
Pl. 5.3, fig. 30; Fig. 5-8

Description.- Reclined element with carinate lateral faces. Anterior and posterior edges of cusp are sharp. Oral margin of base is keeled and curved, aboral margin is slightly sinuous or almost straight. Basal cavity is shallow. Basal region is dark brown; cusp is albid. This form resembles oistodontiform elements of *Acodus emmanuelensis* McTavish but lacks the flare of the basal cavity and is more reclined. Furthermore, no accompanying elements have been found.

Occurrence.- Bed 12.

Material.- 9 elements.

Repository.- Hypotype: GSC 90392.



Figure 5-8: Lateral views of two different specimens of *Oistodus* sp. 1. X85.

Oistodontiform element 1
Pl. 5.3, fig. 32

Description.- Oistodontiform element with broad reclined cusp. Cusp is deflected sideways; posterior and anterior margins are sharp. Lateral faces are swollen and cross section of cusp is lenticular. Basal cavity is of moderate depth with its apex situated anterior of midline. Base flares slightly to inner side and is smoothly convex on outer side. Aboral margin is almost straight and outlined by a dark coloured band. Cusp is albid. Oral margin is short and keeled.

Occurrence.- Bed 14.

Material.- 2 specimens.

Repository.- Figured specimen: GSC 90391.

Oistodontiform element 2
Pl. 5.3, fig. 33; Fig. 5-9

Description.- Flat element with broad, slightly reclined cusp. Inner face is smooth, outer side bears poorly defined median costa. Posterior and anterior margins are sharp. Cross section of cusp is lenticular. Basal cavity is shallow and apex situated centrally. Junction between oral margin and cusp is curved and forms an angle of about 90°. Entire element is extremely compressed laterally.

Occurrence.- Beds 12 and 14.

Material.- 3 elements.

Repository.- Figured specimen: GSC 90395.



Figure 5-9: Lateral views of oistodontiform-element 2. X80.

Oistodontiform element 3
Pl. 5.3, fig. 34; Fig. 5-10

Description.- Compressed oistodontiform element with strongly reclined cusp and curved anterior margin. Cusp is flexed inwards and possesses poorly developed costa on both lateral faces. Basal cavity is moderately deep with apex situated centrally. Outline of aboral margin is sinuous and base flares slightly to outer side. Aboral margin is long and curved with a shallow ledge running parallel to it. A short expansion of the base extends downwards past the junction of keel and base on posterior and anterior sides. Elements are albid with dark stained cavities. The morphology is similar to oistodontiform elements of *Protoprioniodus* but as accompanying elements are absent the oistodontiform elements are treated in open taxonomy.

Occurrence.- Beds 10 and 11.

Material.- 9 elements.

Repository.- Figured specimen: GSC 90396

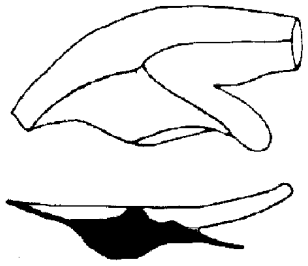


Figure 5-10: Aboral and lateral views of oistodontiform element 3. X70

Genus *Paltodus* Pander, 1856.

Type species. *P. subaequalis* Ulrich and Bassler, 1926.

PALTODUS sp. cf. P. JEMTLANDICUS Löfgren
Pl. 5.4, fig. 2

cf. *Paltodus? jemtlandicus* LOFGREN, 1978, p.65, Pl.4, figs. 1-3, 6-10.

Paltodus? cf. jemtlandicus (Lofgren) STOUGE 1984, p.56, Pl.4, figs. 26-33.

Remarks.- The specimens recovered are all oistodontiform with the typical dark brown colour noted by Stouge (1984). Their aboral outline is variable and most of the specimens lack the anterior extension of the base. Fahraeus and Hunter (1985) assigned the species to the genus *Paltodus* and the questionmark is thus not necessary.

Occurrence.- Bed 14.

Material.- 2 elements.

Repository.- Hypotype: GSC 00398.

PALTODUS? sp. s.f.
Pl. 5.4, figs. 3; Fig. 5-11

Description.- A form-species of *Paltodus* with a stout, acostate recurved cusp. Basal cavity is shallow, its apex is situated close to anterior margin. Inner side of cusp may be weakly carinate. Carina is situated at a variable distance from anterior margin and develops into a basal flare. Anterior margin is keeled; keel tapers out near base and anterior basal edge is rounded. Aboral margin is slightly arched. It may show undulation on outer side near antero - basal corner.

Remarks.- The elements show some variation in the basal flaring, the basal outline and the curvature of the cusp. No oistodontiform elements have been found which could be part of the apparatus of *Paltodus?* sp. A. The forms described above are not typical drepanodontiform elements of *Paltodus* but have been assigned to that genus because of the superficial similarity to *Paltodus? sweeti* s.f. Serpagli. It is possible that they represent a new genus.

Occurrence.- Reworked clast in Bed 14.

Material.- 6 elements.

Repository.- Figured specimen: GSC 90399.

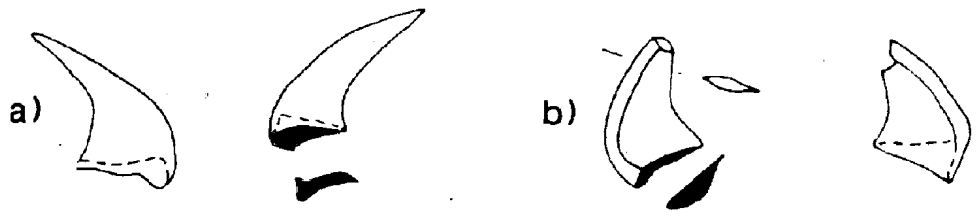


Figure 5-11: A) Acostate and b) costate elements of *Paltodus?* sp. s.f. X60.

Genus *Parapaltodus* Stouge, 1984

Type species. *P. simplicissimus* Stouge, 1984.

PARAPALTODUS sp.
Pl. 5.4, figs. 8-9

Remarks.- A species of *Parapaltodus* with almost hyaline elements which show fine surface striations. Elements are laterally compressed with sharp anterior and posterior margins. Basal cavity is triangular and its tip almost reaches anterior margin. A faint groove extends from aboral margin laterally along the anterior margin but looses its definition in the lower third of the cusp.In scandodontiform elements cusp is flexed inwards and inner side of base is slightly flared.

Occurrence.- Beds 10, 12 and 14.

Material.- 20 elements.

Repository.- Figured specimens: GSC 90404-90405.

Genus *Parapanderodus* Stouge, 1984

Type species. *Parapanderodus arcuatus* Stouge, 1984.

PARAPANDERODUS ARCUATUS Stouge

Pl. 5.4, fig. 10

Scolopodus cf. S. quadraplicatus (Branson & Mehl), BRADSHAW, 1969, p.1163, Pl.132, fig.8-9, text-fig. 4E-F.

Scolopodus gracilis (Ethington & Clark), BARNES & POPLAWSKI, 1973, p.786, Pl.3, figs.8,8a only, text-fig.H.

?*Panderodus sp.* ETHINGTON & CLARK, 1981, p.76, Pl.8, figs.17,18.

Parapanderodus arcuatus STOUGE, 1984, p. 65-66, Pl. 9, figs. 10-15.

Remarks.- Stouge (1984) described two element types composing the apparatus of *P. arcuatus*. Type I are costate elements and type II are almost symmetrical forms with a median groove. The symmetrical elements outnumber by far the costate ones, suggesting that costation is indeed a gerontic feature as implied by Stouge (1984).

Occurrence.- Bed 14.

Material.- 98 elements (5 costate forms).

Repository.- Hypotype: GSC 90406.

PARAPANDERODUS GRACILIS (Ethington & Clark)

Pl. 5.4, fig. 11

Scolopodus gracilis ETHINGTON & CLARK, 1964, p. 699, Pl.115, figs.2-4,8,9.

Scolpodus triangularis ETHINGTON & CLARK, 1964, p.700, Pl.115, figs.6,11,13,17.

"*Scolopodus gracilis*" Ethington & Clark. ETHINGTON & CLARK, 1981, p.100, figs.27,28, (contains synonymy through 1979).

non "*Scolopodus gracilis*" (Ethington & Clark). LOFGREN, 1985, p.124, fig.4AG-AK.

non *Sclopodus gracilis* (Ethington & Clark). BARNES & POPLAWSKI, 1973, p.786, Pl.3, figs.8,8A only, text-fig. H.

Remarks.- *Parapanderodus gracilis* occurs in moderate abundance in clasts from the lower part of the studied sequence. The elements are hyaline and striated although overgrowth or abrasion of the surfaces may obliterate these features. Forms with a slightly expanded base (= mature elements according to Ethington & Clark, 1964) co-occur with evenly curved elements.

The triangulariform elements which have been included in the apparatus by Barnes and Poplawski (1973) are rare but occur in the same stratigraphic interval as the graciliform elements.

The elements assigned herein to *Parapanderodus gracilis* show considerable variations in size and curvature but all possess the typical posterior groove and straight aboral margin which together set them apart from *Parapanderodus arcuatus*. Some forms are laterally flattened, a feature also noted by Ethington & Clark (1964).

Bergström (1979) and Löfgren (1985) included elements resembling *P. gracilis*,

P. paracornuformis s.f. Ethington & Clark and *Semiacontiodus asymmetricus* Barnes & Poplawski in the same apparatus. The forms assigned by the above authors to *"Scolopodus gracilis"* and *"Scolopodus" sp.* respectively seem to possess a nonstriated aboral margin which according to Stouge (1984) is characteristic of *Parapanderodus elegans*. Further information is needed to evaluate the relationships of the three different form species.

P. gracilis is a common constituent of Lower Ordovician conodont faunas in North America. The specimens reported from Norway (Bergstrom, 1979) probably belong to another species (i.e. *P. arcuatus* Stouge).

Occurrence.- Beds 10, 12 and 11.

Material.- 47 elements.

Repository.- Hypotype: GSC 90407.

PARAPANDERODUS sp. 1
Pl. 5.4, fig. 12; Fig. 5-12

Description.- Simple cones with a deep basal cavity which occupies the lower two thirds of the cusp. Lower part of cusp is straight. Curvature begins gradually in lower third of element or slightly higher. Apex of basal cavity lies near anterior margin at point of greatest curvature which is usually in upper third of cone.

Anterior margin of cusp has blunt edge, posterior margin bears a faint groove bordered by two weak postero-lateral costae. Outline of basal cavity is a blunt-edged rectangle, whereas cross section of cusp is more triangular due to distal sharpening of anterior margin. Aboral margin is straight or a short tongue-like extension of oral edge downwards gives it concave outline in lateral view. This extension together with a posterior groove is typical for *Parapanderodus*. Cusp is albid and entire element is striated including basal rim.

Remarks.- The elements display a weak curvature transition from forms with more to those with less curved cusps. The species resembles *Parapanderodus elegans* Stouge in possessing a deep basal cavity but lacks the non-striated rim and is larger in size.

Occurrence.- Bed 14.

Material.- 11 specimens.

Repository.- Figured specimen: GSC 90408.

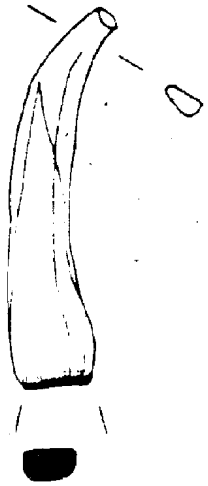


Figure 5-12: Lateral view of *Parapanderodus* sp. 1 illustrating deep basal cavity, cross section of cusp and outline of basal cavity. X70.

Genus *Paroistodus* Lindström, 1971

Type species. *Oistodus parallelus* Pander, 1856.

Several species of *Paroistodus* occur in the Cow Head material among them *P. parallelus* Pander; *P. originalis* Sergeeva, and *P. proteus* Lindström. Although all three forms are well known they are difficult to distinguish because many transitional drepanodontiform elements co-occur and the oistodontiform elements of *P. parallelus* and *P. proteus* seem to be indistinguishable.

Landing (1976) and Serpagli (1974) who both reported mixed faunas of *P. parallelus* and *P. originalis* refer all all their specimens to *P. parallelus*. Although this mixing occurs in the Cow Head material, especially in samples from Bed 10, in most cases it is possible to distinguish between the two species. *P. proteus* is restricted in its occurrence to bed 10 (or clasts of that age in other beds).

PAROISTODUS PARALLELUS Lindström

Pl. 5.4, figs. 20-21

Oistodus parallelus PANDER, 1856, p.27, Pl.2, fig.30.

Acodus expansus GRAVES & ELLISON, 1941, p.8, Pl.1, fig.6; LINDSTROM, 1955a, p.655, Pl.IV, figs. 13-17, Text-figs. 2g-i.

Paroistodus parallelus LINDSTROM, 1971, p.68, Pl.1, figs. 18-21.

Remarks.- Two drepanodontiform elements of *P. parallelus* can be distinguished which have a different stratigraphic range.

The drepanodontiform elements from clasts in Bed 10 (*Prioniodus elegans* Zone) are typically costate with short often curved aboral margins. The anterior keel

usually begins high above the base of the cusp thus leaving a gap where the antero-basal edge normally occurs.

Stratigraphically younger drepanodontiform elements display features transitional to *P. originalis*. They are only weakly costate to carinate, the aboral margin is straight or slightly curved and typically longer than in the older forms. The basal cavity is separated from the anterior keel which passes around the antero-basal corner forming a rounded edge. The curved oral margin and the more costate than carinate sides justify an assignment to *P. parallelus* rather than *P. originalis*.

The oistodontiform elements appear to be conservative and show carinate sides even in samples with strongly costate drepanodontiform elements.

Only a few elements occur in samples from Bed 12 (*Prioniodus evae* Zone). These drepanodontiform elements are transitional to *P. originalis* with a curved oral margin and smooth or carinate sides. Also elements with a laterally deflected keel or a flexed cusp are herein included in *P. originalis*. These variants may represent an undescribed different species of *Paroistodus*. Their occurrence in the Cow Head material is however too scattered to confirm this possibility.

Occurrence.- Beds 10, 12, 14.

Material.- 211 elements.

Repository.- Hypotypes: GSC 90116-90117.

Genus *Periodon* Hadding, 1913,

Type species. *P. aculeatus* Hadding, 1913.

PERIODON ACULEATUS Hadding
Pl. 5.4, figs. 25-27, 30-32

Periodon aculeatus HADDING, 1913, p.33, Pl.1, fig. 14; LOFGREN, 1978, p.74, Pl.10, figs. 1A-B, Pl.11, figs. 12-26, Fig.29 (includes synonymy through 1976).

Lorognathus flabellata GRAVES & ELLISON, 1941, p.12, Pl.2, figs. 29, 32.

Oistodus prodentatus GRAVES & ELLISON, 1941, p.13, Pl.2, figs. 6,22,23.

Ozarkodina macrodentata GRAVES & ELLISON, 1941, p.14, Pl.2, figs. 33,35,36.

Periodon aculeatus zgierzensis DZIK, 1976, p.424, Pl.44, figs.5,6, Fig.34e-k; STOUGE, 1984, p. 82-83, Pl.16, figs. 1-15.

Remarks.- For the description of the different elements comprising the apparatus of *Periodon aculeatus* the terminology of Lindström (1981, in Klapper et al.) is adapted.

The trend towards increasing denticulation in *Periodon* in general and in *P. aculeatus* in particular can be observed in the Cow Head material. The transition from *P. flabellum* to *P. aculeatus* is applied following Löfgren's (1978) numerical definition for ramiform elements (i.e. the number of small denticles between the cusp and the biggest denticle exceeds four in more than half of the elements). The rule cannot be employed for oistodontiform and prioniodiniform elements. The former are commonly represented with a higher mean number of denticulated

forms (1-3 denticles) per sample than in the Scandinavian collections. Prioniodiniform elements with only one denticle in front of the cusp commonly occur associated with otherwise fairly advanced forms of *P. aculeatus*.

Stouge (1984) observed that the angle formed between anterior and posterior processes of oulodontiform elements is larger in *P. flabellum* (between 130 and 170 degrees) than in *P. aculeatus* (between 130 and 90 degrees). This relationship is not verified in the Cow Head material. The change in the ratio of cusp length to oral margin length (1:1 or 4:3 in *P. aculeatus*; 2:1 in *P. flabellum*) noted by Stouge (1984) seems to be a more valid criterion to distinguish between the two species. It is, however, difficult to employ because many cusps are broken.

Two stages in the evolution of *P. aculeatus* can be distinguished in collections from clasts in Bed 14: the early forms possess a sparse denticulation and restricted basal cavities. Advanced forms carry between three and five denticles on the basal anterior margin of oistodontiform and prioniodiniform elements (with a mean number of four). The ramiform elements bear between four and six denticles between the cusp and largest denticle. Also typical is the lack of trichonodelliform elements already noted by Uyeno & Barnes (1970) and the return of large basal cavities. These advanced forms are conspecific with *P. aculeatus zgierzensis* Dzik.

Occurrence.- Youngest clasts in Bed 12; Bed 14

Material.- 3415 elements.

Repository.- Hypotypes: GSC 81354-81359.

PERIODON FLABELLUM (Lindström)

Pl. 4, figs. 28-29, 33-34

Oistodus selene LINDSTROM, 1955a, p.508, Pl. IV, figs. 19-20.

Prioniodina? deflexa LINDSTROM, 1955a, p.586, Pl.IV, figs. 31-35.

Prioniodina inflata LINDSTROM, 1955a, p.588, Pl.IV, figs. 26,27.

Trichonodella flabellum LINDSTROM, 1955a, p. 559, Pl.IV, figs. 28-30.

Oistodus selenopsis SERPAGLI, 1974, p.56, Pl. 13, figs. 4a-6b, Pl.23, figs. 8,9.

Periodon flabellum (Lindstrom), LINDSTROM, 1971, p.57, Fig.18; SERPAGLI, 1974, p.63, Pl.14, figs. 1a-7b, Pl. 25, figs. 7-12, Fig.14; LOFGREN, 1978, p.72, Pl.11, figs. 1-11, Fig. 29 (includes synonymy through 1978).

Remarks.- Early forms of *Periodon flabellum* are characterized by possessing large basal cavities and fewer denticles on all elements than *P. aculeatus*. The outline of the aboral margin of the ozarkodiniform elements is typically triangular. The oistodontiform elements possess a short aboral margin which is straight or slightly sinuous in lateral view. The anterior margin is adentate or carries up to three (usually two) short fused denticles.

The evolutionary trend towards higher numbers of denticles has been demonstrated by several workers (Van Wamel, 1974; Serpagli, 1974) and, most systematically, by Löfgren (1978). Serpagli (1974) found *P. flabellum* with a high percentage of denticulated oistodontiform elements at approximately the same stratigraphic level at which undenticulated forms occur in Scandinavia. The Argentinian species resembles closely the late form of *P. flabellum* found in the Cow Head material. The suggestion of Lindström (1981, in Klapper et al.) to use

a low number of denticulated oistodontiform elements as a criterion to recognize *P. flabellum* is considered invalid. (See discussion under *P. aculeatus*).

Occurrence.- Bed 12, clasts of Bed 11-age in Bed 14.

Material.- 572 elements.

Repository.- Hypotypes: GSC 90121-90124.

PERIODON? SELENOPSIS (Serpagli)

Pl. 5.5, figs. 1-3

Gen. nov. A n. sp. 1 (SERPAGLI), 1974, p.92, Pl.19, figs. 1a-3c, Pl.29, figs. 1-3, Text-fig. 25.

Oistodus selenopsis SERPAGLI, 1974, p.56, Pl 13, figs. 4a-6b; Pl. 23, figs. 8,9.

Periodon flabellum (Lindstrom), VAN WAMEL, 1974, p.80, Pl. 4, figs. 14, 15, 18 only.

Periodon? oistodontiform element LOFGREN, 1978, p.71, Pl. 10, fig.7.

Periodon? prioniodiniform element A, LOFGREN, 1978, p.72, Pl. 10, figs. 8,9.

Periodon? prioniodontiform element A, LOFGREN, 1978, p.72, Pl.10, figs. 4,6.

Remarks.- Oistodontiform elements which resemble those of *Periodon flabellum* occur in samples from Bed 10 (*Prioniodus elegans* Zone).They are not associated with denticulated ramiform or ozarkodiniform elements but with adentate *Acodus*-like forms all of which have been considered to represent an early form of *Periodon* by Van Wamel (1974) and Löfgren (1978).

The oistodontiform element of *Periodon? selenopsis* (Serpagli) can be distinguished from the corresponding elements of *P. flabellum* by the lateral deflexion of the cusp and the commonly shorter aboral margin of the former. *"Oistodus" selenopsis* Serpagli has been considered to be conspecific with *P. flabellum*. The stratigraphically oldest sample from the Argentinian collection does, however, not contain *"O." selenopsis* together with *P. flabellum* nor with the acodontiform elements (= Gen. nov. A n. sp. 1 of Serpagli, 1974) which is herein considered to belong in the apparatus. Oistodontiform and acodontiform elements all co-occur in the Cow Head material.

The prioniodiniform element has been previously described by Van Wamel (1974) and subsequently discussed by Löfgren (1978).

A prioniodiniform element with two reclined denticles,a sharp edged basal cavity, and a rounded anterior margin occurs in one sample together with very early forms of *P. flabellum* and a ramiform element of *P.?* sp. It resembles closely the cyrtoniodontiform elements described and illustrated by Serpagli (1974, p.93, Pl. 29, fig. 3) as part of his Gen. nov. A n. sp. 1. Landing (1976) interpreted the forms as juveniles of *P. flabellum* and included them in his synonymy of the species. The lack of these "juveniles" in other samples rich in *P. flabellum* suggests that they indeed represent an early evolutionary stage of *Periodon*? rather than part of an ontogenetic series. The acodontiform and drepanodontiform elements of Gen. nov. A n.sp. 1 Serpagli are probably conspecific with *P.? selenopsis*.

The few prioniodontiform elements recovered from boulders differ from those illustrated by Löfgren (1978) in possessing a basal cavity with the tip closer to the anterior margin. The inner lateral costa originates from the tip pointing in lateral or anterior direction.

The single ramiform element recovered is broken and has been tentatively assigned to *P.? selenopsis*.

Occurrence.- Bed 10, older clasts in beds 12 and 14.

Material.- 34 elements.

Repository.- Hypotypes: GSC 90125-90127.

Genus *Prioniodus* Pander, 1856

Type species. *Prioniodus elegans* Pander, 1856.

Relationships between *Prioniodus* and other genera with more or less similar apparatuses (i.e. *Baltoniodus*, *Gothodus*, *Oepikodus*) have been discussed by several workers (e. g. Bergström, 1971; Lindström, 1971; McTavish, 1973; van Wamel, 1974; Serpagli, 1974). Serpagli subdivided *Prioniodus* into subgenera (eg. *Baltoniodus*, *Oepikodus*, *Prioniodus*), as opposed to establishing three different genera. Löfgren (1978) followed this suggestion. His solution is followed herein because in all three taxa the structure of the apparatus is basically similar. Fahraeus and Nowlan (1978) advocated to assign the forms to separate genera rather than a sub-genus. Because of the close relationship of the genera Serpagli's approach is followed herein.

Sub-Genus *Prioniodus (Oepikodus)* (Lindström), 1955

Type species. *Prioniodus evae* Lindström, 1955.

PRIONIODUS (OEPIKODUS) COMMUNIS (Ethington & Clark), 1964
Pl. 5.5, figs. 4-6

Gothodus communis Ethington & Clark, 1964, p.690, 692, Pl.114, figs.6,14.

Oepikodus communis (Ethington & Clark) ETHINGTON & CLARK, 1981, p.61, Pl. 6,figs. 18,22,25 (includes synonymy through 1980).

Oepikodus communis (Ethington & Clark) STOUGE, 1982, p.38, Pl.4, figs. 9-12.

Oepikodus sp. cf. *O. communis* (Ethington & Clark)
STOUGE, 1982, p.40, Pl.6, figs.17-20.

Remarks.- All three elements within the apparatus of *Prioniodus (Oepikodus) communis* have been found exclusively in boulders of Bed 12. Most of the prioniodontiform elements resemble closely those described as *P. (Oepikodus) intermedius* (Serpagli,1974) but the evidence to regard *P. (Oepikodus) intermedius* and *P. (Oepikodus) communis* as conspecific presented by (Ethington & Clark, 1981) is convincing and this concept is followed herein. The oepikodontiform element shows all stages of the symmetry transition observed by Ethington & Clark (1981), i.e. symmetrical costate, asymmetrical costate and acostate oepikodiform elements with the acostate element being most abundant. The oistodontiform element is rare and usually broken. The evidence cited by Stouge (1982) to distinguish between *O. communis* and a succeeding *O.* sp. cf. *O. communis* (with only asymmetrical oepikodontiform elements) is difficult to evaluate because the number of specimens was not reported.

Occurrence.- Bed 12.

Material.- 41 elements.

Repository.- Hypotypes: GSC 90128-90130.

PRIONIODUS (OEPIKODUS) sp. aff. P. (O.) MINUTUS (McTavish)
Pl. 5.5, figs. 10-12

aff. *Baltoniodus minutus* McTAVISH, 1973, p.42, Pl.3, figs. 3, 14, 17 (non fig. 8? = Prioniodus sp. nov. B McTavish, 1973).

aff. *Oepikodus minutus* (McTavish), ETHINGTON & CLARK, 1981, p.62, Pl.6, figs. 19, 23, 24, 26-28, (includes synonymy through 1973).

Remarks.- The species from the Cow Head Group agrees in its overall morphology with the description of aff. *Oepikodus minutus* given by Ethington & Clark (1981). It differs from that form, however, in several respects: The oistodontiform element assigned to the species by Ethington & Clark is not present in the Cow Head material. Instead a form similar to the oistodontiform element of *Oepikodus communis* Ethington & Clark, but with a shorter anterior process occurs associated with *Prioniodus (Oepikodus)* sp. aff. *P. (O.) minutus* in stratigraphically younger samples. This element is not present in assemblages from rocks lower in the sequence; here the prioniodontiform and oepikodontiform elements co-occur with a falodontiform element with a laterally deflected, denticulated anterior process. The low number of specimens, however, does not allow further speculation on the elemental composition. The oepikodontiform elements show the lateral deflexion and the twisting of the posterior process described by Ethington & Clark (1981). A transition series from symmetrical costate, asymmetrical costate to acostate elements is developed. The trichonodelliform elements illustrated by Ethington & Clark have not been found. The denticles seem to be more slender and longer in the Cow Head specimens compared to the robust forms from the Pogonip Group.

The prioniodontiform elements are characterized by always possessing two denticulated processes, a feature that sets them clearly apart from *P. (O.) communis*. Two types of prioniodontiform elements are developed: type I is a compact form with a deep basal cavity and a short posterior process. It

corresponds to the specimens described by McTavish (1973) and Ethington & Clark (1981). Type II possesses a long posterior process and short lateral processes one of which is denticulated. The posterior process is commonly laterally deflected and twisted. The basal cavity is shallow due to the lack of connecting basal sheaths. The presence of two different prioniodontiform elements might justify an assignment of the species to the subgenus *Baltoniodus* but the similarity to *P. (O.) communis* is a convincing argument for the inclusion in *Oepikodus*. Furthermore, the development of two types of prioniodontiform elements seems to be a characteristic of most prioniodids.

Occurrence.- Beds 10 and 12, older clasts (Bed 9-age) in Bed 14.

Material.- 90 elements.

Repository.- Hypotypes: GSC 90434-90436.

Subgenus *Prioniodus (Prioniodus)* Pander, 1856.

Type species. *P. elegans* Pander, 1856.

PRIONIODUS (PRIONIODUS) ELEGANS Pander

Pl. 5.5, figs. 13-16

Prioniodus elegans PANDER, 1856, Pl.2, figs.22, 23; FAHRAEUS & NOWLAN, 1978, p.464, Pl.3, figs. 19, 23-24 (only).

Prioniodus (Prioniodus) elegans (Pander) LOFGREN, 1978, p.78, Pl.9, fig.1-6 (includes synonymy through 1977).

Remarks.- The specimens of *Prioniodus (Prioniodus) elegans* recovered from boulders in Bed 10 agree in most respects with the descriptions given by Fahraeus and Nowlan (1978) for the specimens listed in the synonymy herein. Some of the elements illustrated by Fahraeus and Nowlan belong to *Prioniodus (P.) marginalis* n.sp..

The above authors noted the presence of two prioniodontiform elements: one type with an angle of about 90 degrees between the steeply inclined anterior and lateral processes (the ambalodontiform element), the other type with less inclined processes and an angle of 100 to 145 degrees between the two processes (the amorphognathodiform element). This apparatus structure, which is related to the *Baltoniodus* apparatus, occurs also in *P.(P.) elegans* from clasts in Bed 10.

The belodontiform elements illustrated by Fahraeus & Nowlan (1978, Pl.3, fig. 23) possess denticulated anterior processes which is also typical for *P. (P.) elegans* found in Bed 10. Undenticulated processes in the Cow Head material are characteristic of *P. (P.) marginalis*. Lindström (1955a, p.569) described *Gothodus costulatus* s.f. without denticles on the posterior process. Van Wamel, (1974,

p.87, Pl.6, fig.2) included an additional prioniodiniform element in the apparatus of *P. elegans* which has denticles on the anterior process and was found higher in the sequence than his undenticulated forms.

Whether this lack of denticulation in the Baltoscandian species is a sign of environmental or stratigraphic control or indicative of the presence of a different species of *Prioniodus* (such as *P. (P.) marginalis*) cannot be decided. The general trend towards development of denticles which has been demonstrated by McTavish (1973) suggests, however, that the denticulated belodontiform elements of *P. elegans* are more advanced than the undenticulated forms.

Occurrence.- Bed 10, reworked clasts in Bed 14.

Material.- 547 elements.

Repository.- Hypotypes: GSC 90437-90440.

PRIONIODUS (PRIONIODUS) MARGINALIS n. sp.

Pl. 5.5, figs. 17-20

?Falodus sp. A FAHRAEUS & NOWLAN, 1978, p. 466, Pl.3, fig. 18.

Prioniodus elegans Pander. FAHRAEUS & NOWLAN, 1978, p. 464, Pl. 3, figs. 20, 25.

Derivation of name.- From *margin* to indicate the environment of occurrence of this species.

Diagnosis.- A multielement species with prioniodontiform, tetraprioniodiform, belodontiform and oistodontiform elements.

Description.- All elements are characterized by their relatively small size and slender appearance. Prioniodontiform element has three denticulate processes and a relatively long stout cusp. No basal sheaths have been observed. Processes are rather short and straight or project downwards. Basal cavity is shallow and continues along the processes. Denticles are short and separate, they are round to slightly flattened in cross section. Cusp is suberect thin with sharp margins. It may be weakly costate at the side where the lateral process branches off.

Tetraprioniodiform element possesses two denticulate processes and two undenticulate processes. Denticulate processes are usually long and project downwards; they are oriented postero-laterally. Angle between them is never larger than 50°. Denticles are thin and separate, round to slightly flattened in crossection. Cusp is long, slender and curved. Costae arise from continuation of anterior processes to cusp. Shallow basal cavity continues into processes.

Belodontiform element possesses long slender cusp, and posterior process of similar length. Cusp is slightly curved and continues downward into a short, undenticulated anterior anticusp. Outer side of cusp may be costate. Posterior process points downwards, forming angle larger than 90° and smaller than 130° with cusp. Denticles are isolated, short and thin, sometimes almost hyaline.

Oistodontiform element is most distinct element in apparatus. It is characterized by a posterior process which is longer tha.. the cusp with small denticles at the distal end. Small denticles also adorn the anterior process. Element has been described in detail by Fahraeus and Nowlan (1978) and needs no further explanation. All elements are albid.

Remarks.- *P. (P.) marginalis* differs in several ways from *P. (P.) elegans* Pander: generally all elements of *P. (P.) marginalis* are smaller and less robust. Their denticles are smaller and as a rule not fused. There are also less denticles present, particularly in the tetraprioniodiform and the belodontiform elements. The oistodontiform element is so obviously different, it needs no further comment. It is likely that the species has been found before but has been lumped together with *P. (P.) elegans* because in mixed faunas transitional elements occur which make distinction somewhat difficult.

Occurrence.- Bed 10.

Material.- 718 elements.

Repository.- Holotype: GSC 90111; paratypes: GSC 90112-90111.

PRIONIODUS (PRIONIODUS) SERRATUS n. sp.
Pl. 5.5, figs. 21-25

Derivation of name.- Referring to the minute denticles on the posterior process of the ramiform elements.

Diagnosis.- A species of *Prioniodus* with oistodontiform, prioniodontiform, tetraprioniodontiform and belodontiform elements, in which the processes of the ramiform elements bear miaute denticles.

Description.- Prioniodontiform elements resemble those described by McTavish (1973) as part of the apparatus of *A. deltatus longibasis*. Ramiform elements of *P. (P.) serratus* are characterized by a posterior process which carries minute denticles in well preserved specimens. Denticles increase in size towards middle part of process and decrease again distally. Ratio between denticulated and undenticulated forms is difficult to determine because crystalline overgrowth easily obliterates delicate denticles but is approximately 1:1.

In tetraprioniodontiform and trichonodelliform elements, lateral processes are more prominent and always longer than anterior process but shorter than posterior process.

In cordylodontiform elements curvature of cusp and angle of basal opening are quite variable. A large divergence of anterior and posterior processes usually coincides with a more strongly proclined cusp.

Oistodontiform element has straight reclined cusp and a posterior process which reaches about three quarters of cusp length. Cusp and process show slight lateral deflection with opposed orientations. Short anterior process is slightly curved upwards and bears three to four minute denticles only visible on well preserved specimens. Incipient denticulation is also visible on prioniodontiform elements.

Remarks.- *P. (P.) serratus* n. sp. probably presents an advanced form of *A.*

deltatus longibasis. The denticulation and elemental composition imply an assignment to *Prioniodus*. The species seems to be a relative or even precursor of *Prioniodus (P.) elegans*. *Prioniodus (P.) serratus* n. sp. is distinguished from *Acodus deltatus longibasis* McTavish by the presence of denticulation, the different angles between cusp and processes and the shorter posterior process of the ramiform elements.

In the Emmanuel Formation this stage of development of *A. deltatus longibasis* is missing maybe due to a sampling or depositional gap or because of disfavourable environmental parameters.

Occurrence.- Bed 10.

Material.- 345 elements.

Repository.- Holotypes: GSC 90446; paratypes: GSC 90445, 90447-90449.

PRIONIODUS sp.
Pl. 5.5, figs. 26-30

Description.- Oistodontiform and belodontiform elements with thin-walled deep basal cavities, short cusps and small denticles (on the belodontiform element only). Oistodontiform element is characterized by an extremely short blunt cusp and a large deep basal cavity. Virtually the entire element is hollow except for a short apical portion. Cusp is sharply reclined at about mid-length creating a bend in the anterior margin of about 110-120°. Straight anterior margin of base is keeled and grades smoothly into lower part of cusp. Oral margin of base is keeled as well; portion proximal to cusp runs subparallel to aboral margin, at about mid-length it bends down sharply and forms about 80° angle with antero-basal corner. Aboral margin of base is partly broken and its excact outline can therefore not be determined. Base flares to one side, with tip situated anteriorly.

Belodontiform elements are acostate and flexed sideways with varying degrees of twisting of cusp with respect to base. Anterior and oral margins of base carry numerous small denticles. Denticles are short with blunt tips. They are laterally compressed and fused. Denticles on anterior side are smaller than posterior and decrease in size distally. Large basal cavity is thin-walled and in some elements a lateral flare is developed which extends from base of cusp to middle of aboral margin. Cusp is reclined and short. The tip of the basal cavity is situated close to the anterior margin.

Remarks.- Collections of D. Johnston (1987) from Bed 9 contained a tetraprioniodontiform element together with other specimens of *Prioniodus* sp.. This evidence justifies the assignment of the form to *Prioniodus*.

Occurrence.- Clast of Bed 9-age in Bed 12.

Material.- 11 elements.

Repository.- Figured specimens: GSC 90450-90454.

Prioniodontiform element
Pl. 5.6, fig. 1

Description.- A single fragmentary specimen with long cusp and three denticulated processes. Cusp is slender and reclined with lenticular crossection. Costae may have been obliterated as the specimen is abraded. Two to three denticles on each process are curved and not fused but spaced apart. Basal sheaths connect the three processes creating a large basal cavity. Specimen is hyaline.

Occurrence.- Bed 14

Material.- 1 element.

Repository.- Figured specimens: GSC 90455.

Genus *Protopanderodus* Lindström, 1971

Type species. *Acontiodus rectus* Lindström, 1955a.

Lindström (1971) in his definition of *Protopanderodus* accepted panderodids with subcircular, comma-shaped, lanceolate or *Acontiodus*-like crossections of the cusp in the genus. The apparatus comprises symmetrical and asymmetrical elements forming a transition series. Löfgren (1978) restricted this rather wide framed definition in excluding elements with conspicuous striations and/or antero-posteriorly directed compression. This definition excludes for example *Protopanderodus asymmetricus* Barnes & Poplawski from the genus.

PROTOPANDERODUS RECTUS Lindström

Pl. 5.6, figs. 6-8

Acontiodus rectus n.sp. LINDSTROM, 1955a, p. 549, Pl. II, figs. 3B, 7-11.

Acontiodus rectus n. sp. var. *sulcatus* nov. LINDSTROM, 1955a, p. 550, Pl. II, figs. 12, 13, 3D.

Scandodus rectus n. sp. LINDSTROM, 1955a, p. 593, Pl. IV, figs. 21-25, 3K.

Protopanderodus rectus Lindstrom. LOFGREN, 1978, p. 90, Pl. 3, figs. 1-7, 36A-B, 31A-C (includes synonymy through 1970.

Remarks.- Most of the elements assigned herein to *Protopanderodus rectus* agree with the description of *Acontiodus rectus* var. *sulcatus* by Lindstrom (1955a). Scandodontiform elements are scarce. Some of the better preserved specimens from bed 12 contain only little white matter along the growth axis and the surfaces are finely striated. Acontiodontiform elements often possess a dark basal funnel.

Occurrence.- Beds 10, 12 and 14.

Material.- 189 elements.

Repository.- Hypotypes: GSC 90460-90462.

PROTOPANDERODUS sp. cf. P. VARICOSTATUS (Sweet & Bergström)

Pl. 5.6, fig. 9

Cf. *Scolopodus varicostatus* n. sp. SWEET & BERGSTROM, 1962, p. 1247, Pl.168, figs. 4-9, Text-fig 1A, C, K.

Protopanderodus cf. *varicostatus* (Sweet & Bergstrom), LOFGREN, 1978, p. 91, Pl. 3, figs. 26-31 (includes synonymy through 1974).

Remarks.- Most of the forms included in this species show close morphological similarity to *P. rectus*. The acontiodontiform elements however differ from *P. rectus* in possessing wider furrows grooving the cusp and a longer oral margin of the base. With these they resemble the specimens figured by Löfgren (1978, Pl. 3, figs. 26-31).

Three types of acontiodontiform elements are herein included in *P.* cf. *varicostatus*: a) specimens similar to the ones figured by Löfgren (1978; see above); b) some of the stratigraphically younger elements which could possibly be assigned to *P. cooperi* Sweet & Bergström, but they are rare and they lack the "fluted" posterior keel typical for that species. They may represent gerontic forms of *P.* cf. *varicostatus* and Stouge's (1984) approach to include them in the latter species is followed herein. c) The third type differs from *P. rectus* in possessing more pronounced costae, a less reclined cusp and a hooked anterior margin. In lateral view the elements resemble a horse's foot. It occurs typically in the stratigraphically youngest rocks of the sequence. Fahraeus and Hunter(1985) reconstructed the apparatus of *P. varicostatus* and their suggestions probably also apply to *P.* sp. cf. *P. varicostatus*.

Occurrence.- Beds 12 and 14.

Material.- 27 acontiodontiform elements.

Repository.- Hypotype: GSC 90463.

Genus *Protoprioniodus* McTavish, 1973

Type species. *Protoprioniodus simplicissimus* McTavish, 1973.

PROTOPRIONIODUS ARANDA Cooper, emend. Ethington & Clark
Pl. 5.6, figs. 10-12

Protoprioniodus aranda COOPER, 1981, p.175, Pl.30, figs. 2,6,7,10,12.

Protoprioniodus yapu COOPER, p.178, Pl.30, figs. 3,4,8, (non 5,9,11,13).

Protoprioniodus nyinti COOPER, p.176, Pl.29, figs. 1-8, 11,12.

Protoprioniodus aranda Cooper, ETHINGTON & CLARK, 1981, p.86, Pl.9, figs.24-30.

Protoprioniodus sp. A STOUGE, 1982, p.42, Pl.5, figs. 5 and 7.

Protoprioniodus sp. B STOUGE, 1982, p.42, Pl.6, fig.9.

Remarks.- *Protoprioniodus aranda* is a very distinctive species which can be readily identified in a faunal assemblage. The exact elemental composition of the apparatus is difficult to determine because a wide range of different element morphologies exists.

Ethington & Clark (1981) included *P. nyinti* in their synonymy of *P. aranda*. In the Cow Head material a few ramiform elements of *P. nyinti* occur associated with *P. aranda* but not with the oistodontiform element assigned to the apparatus by Cooper (1981). A few elements resembling his oistodontiform elements do occur isolated or together with *P. aranda* in certain samples. Because of this disjunct occurrence , the relationship between the two forms cannot be evaluated

from the material at hand. Because of the morphologic similarities they are herein accepted to belong to *P. aranda*.

Another species, *P. yapu* was established by Cooper (1981). An M element and a costate S element which lacks an anterior process have been assigned to the species (Pl. 30, figs. 3, 4, 8). These elements are regularly associated with *P. aranda* in the Cow Head material. Because of their morphologic similarity with the latter they are herein included in *P. aranda*. The prioniodontiform (P) and ramiform (S) elements of *P. yapu* have been considered to be part of *Teraniа marathonensis* (Bradshaw) by Ethington & Clark (1981). They are found together with this species in the Cow Head material. The obvious weakness of this reconstruction is that Cooper (1981), who worked with a large fauna, did not find this relationship.

Occurrence.- Beds 12 and 14.

Material.- 96 elements.

Repository.- Hypotypes: GSC 90464-90466.

PROTOPRIONIODUS PAPILIOSUS (Van Wamel)

Pl. 5.6, figs. 13-14, 20

Oistodus papiliosus VAN WAMEL, 1974, p.76, Pl.I, figs.18-20.

Gen. nov. B sp. 1 SERPAGLI, 1974, p.93, Pl.19, figs. 4a,b, Pl.29, figs.4,5, text-fig. 26.

Protoprioniodus papiliosus (Van Wamel), ETHINGTON & CLARK, 1981, p.87, Pl. 10, fig.3.

Remarks.- Ethington & Clark (1981) assigned *Oistodus papiliosus* to the genus *Protoprioniodus*. The apparatus contains oistodontiform and ramiform elements all of which have been recognized by Van Wamel (1974).

A symmetry transition series from asymmetrical to symmetrical forms characterizes the ramiform elements. All the elements constituing the apparatus show varying degrees of flexure of cusps and bases.

The asymmetrical ramiform elements are similar to the specimens figured by Serpagli (1974, p.93, text-fig. 26). A lateral ridge continues below the level of the aboral margin forming a short lateral process of variable prominence. This lateral process and the anterior margin of the cusp become more laterally positioned to produce the symmetrical element. Additional shortening of the posterior process results in the formation of Van Wamel's (1974) deltaform element. Another trend observed in the ramiform elements is the increase in length and recurvature of the triangular keel on the posterior process. These elements may be either laterally flexed or straight.

The oistodontiform elements are all laterally bowed. The outer side of the cusp is costate. The forms conform closely with Van Wamel's (1974) original description.

All elements are filled completely with white matter except for a dark

translucent band which runs parallel to the aboral margin; a feature typical for *Protoprioniodus*.

Occurrence.- Beds 10 and 12, older clasts in Bed 14.

Material.- 117 elements.

Repository.- Hypotypes: GSC 90467-90469.

PROTOPRIONIODUS sp. 1 s.f.
Pl. 5.6, figs. 17, Fig. 5-13

Description.- Cordylodontiform elements with slender continuously curved cusp, long posterior process and short anticusp. Lateral faces of cusp are somewhat swollen with a poorly defined median costa. Anterior and posterior margins are sharp. Posterior process is blade-like, long and curved; curvature increases from the proximal to distal portion and tip points downward. Process meets cusp in 90°-100° angle. A short anticusp projects downwards in extension of cusp. All processes are undenticulated. The element is albid and shows crystalline overgrowth. Designation to *Protoprioniodus* is based on the similarity to ramiform elements of *P. aranda*.

Occurrence.- Bed 12, clast of Bed 11-age in Bed 14.

Material.- 2 specimen

Repository.- Figured specimen: GSC 90472.

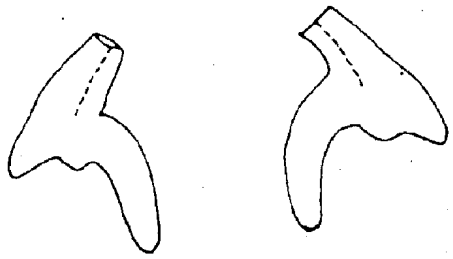


Figure 5-13: Lateral views of *Protoprioniodus* sp. 1.
X90

Genus *Rossodus* Repetski and Ethington, 1983

Type species. *R. manitouensis* Repetski and Ethington, 1983.

ROSSODUS MANITOUENSIS Repetski & Ethington
Pl. 5.6, fig. 25

Acodus oneotensis Furnish. MULLER, 1964, p. 95, Pl. 13, figs. 1a,b, 8; MULLER, 1973, p.26, Pl.7, figs. 1, 3-8.

"Acodus" oneotensis (Furnish). AN et al. 1983, p., Pl. 10, figs. 1-8, Pl.15, fig.5.

Rossodus manitouensis REPETSKI & ETHINGTON, 1983, p. 293, figs. 1-3 (contains synonymy through 1981).

Remarks.- Repetski & Ethington (1983) noted that *Acodus oneotensis* illustrated by Müller (1973) does not agree with the definition of the form species by Furnish (1938) who described a more costate form. The specimens from the Cow Head Group appear to be conspecific with those illustrated by Müller (1973) and An (1983) and are assigned to *Rossodus manitouensis*. The oistodontiform elements described by Repetski & Ethington (1983) are not present, only coniform elements occur. As noted by Müller (1973), the elements are highly variable in morphology especially the basal outline, the size of the basal cavity, the curvature of the cusp and the twisting relative to the base.

All elements are albid with dark hyaline bases. Fine striations seem to be present but the surface texture is obliterated by crystalline overgrowth.

Occurrence.- Old clast in Bed 14.

Material.- 13 coniform elements.

Repository.- Hypotype: GSC 90479.

Genus *Scalpellodus* Dzik, 1976

Type species.- *Protopanderodus latus* Van Wamel, 1974

SCALPELLODUS sp. 1
Pl. 5.6, figs. 26-29, Fig. 5-14

Description.- *Scalpellodus* sp. 1 includes transition series of recurved symmetrical and asymmetrical drepanodontiform and scandodontiform elements. Scandodontiform elements are more or less recurved with shallow costae anterior from mid-line of lateral face. Costae reach aboral margin. Basal cavity is of moderate depth with apex near anterior margin. Anterior side of cusp is gently convex, posterior margin is rounded. Cross section of cusp is sub-triangular. Asymmetrical acontiodontiform elements show transition from forms with two costae to those with only one costa. The former possess a weakly developed posteriorly directed costa on one side and a pronounced costa on other which resulted from displacement of anterior edge sideways. In unicostate forms only the antero-lateral costa is strongly developed and extends downwards below aboral margin; the other side is acostate and concave. Cross section of cusp is roughly comma shaped in forms with two weak costae and triangular with round edges in forms with one costa. Acostate lateral face of the latter forms a concave short side of the triangle. Drepanodontiform element is more laterally compressed than the unicostate drepanodontiform element and acostate lateral face is convex to flat. Posterior margin is bluntly rounded and postero-basal corner is extended thus widening basal cavity in posterior-anterior plane. All elements are albid and show curvature transition.

Remarks.- The unicostate scandodontiform elements resemble forms of *Juanognathus jaanussoni* Serpagli in possessing a basally extended costa. They lack, however, the characteristic twisting of the cusp. Furthermore the

accompanying scandodontiform elements suggest assignment of the species to *Scalpellodus*. Some of the asymmetrical scandodontiform elements resemble the scandodontiform element B of *Scolopodus cornuformis* Sergeeva described by Löfgren (1978, p.106) but *Scalpellodus* sp. 1 lacks the flange-like extension of the cusp, the basal cavity is shallower and the costae are more pronounced. Stouge (1984) described several species of *Scalpellodus* from the Table Head Group none of which seems to be conspecific with *Scalpellodus* sp. 1.

Occurrence.- Bed 14.

Material.- 40 elements.

Repository.- Figured specimens: 90480-90483.

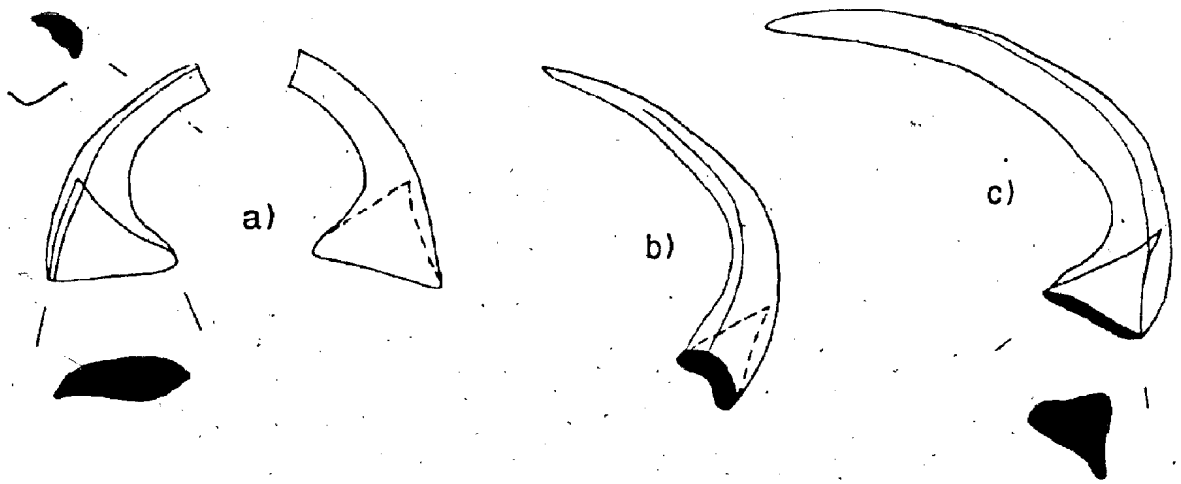


Figure 5-14: Illustrations of a) drepanodontiform, b) bicostate and c) unicostate scandodontiform elements of *Scalpellodus* sp 1. a)X70, b) X85. c) X100. All lateral views.

Genus *Scandodus* Lindström, 1955

Type species. *S. furnishi* Lindström, 1955.

"SCANDODUS" MYSTICUS Barnes and Poplawski
Pl. 5.6, figs. 32-34

Scandodus mysticus BARNES AND POPLAWSKI, 1973, p.786, Pl. 4, figs 1-2, Fig. 2K.

Paltodus? cf. *mysticus* (Barnes and Poplawski). LOFGREN, 1978, p. 64, Pl. 4, figs. 4-5, 11.

aff. *"Scandodus" flexuosus* Barnes and Poplawski. ETHINGTON AND CLARK, 1981, p. 93, Pl. 10, figs. 20-22, Fig. 21, (includes synonymy through 1981).

Remarks.- Like *Scandodus" pseudoramis* Serpagli *"S." mysticus* shows transition from acostate to costate acodontiform elements and these in turn are associated with elements resembling *"Scandodus" robustus* Serpagli. This same association has been reported by Johnston (1987) and Ethington and Clark (1981). An oistodontiform element as in *"S." pseudoramis* could not be determined but may be present in the small collection. The generic assignment to *"Scandodus"* is tentative and has to await clarification of the apparatus composition.

Occurrence.- Beds 10 to 14.

Material.- 31 elements.

Repository.- Hypotypes: GSC 90486-90488.

"SCANDODUS" PSEUDORAMIS Serpagli
Pl. 5.6, figs. 35-37; Fig. 5-15

Distomodus kentuckyensis Branson & Branson. LEE, 1970, p. 317, Pl. 7, figs. 11, 12.

Acodus deltatus Lindstrom. VIIRA, 1974, p.41, Pl.2, fig. 28.

?*"Drepanodus"* sp. 4 SERPAGLI, 1974, p. 46, Pl. 13, figs. 11a-c.

"Oistodus" pseudoramis SERPAGLI, 1974, p. 55, Pl.13, figs. 7a-10b; Pl. 23, figs. 10-12.

"Scandodus" sp. 1 s.f. ETHINGTON & CLARK, 1981, p. 96, Pl. 11, figs. 6,7; fig. 22.

Triangulodus changshanensis AN et al., 1983, p. 159, Pl.15, figs. 7-9, text-figs. p.169, 18, 20.

Remarks.- The scandodontiform element agrees with the description given by Ethington & Clark (1981) for *"Scandodus"* sp. 1. The oistodontiform element which is herein interpreted to belong in the apparatus of *"Scandodus"* sp. 1 is probably conspecific with *"Oistodus" pseudoramis* Serpagli and has been thoroughly described by this author (Serpagli, 1974).

Acodiform element has been previously described as *Acodus deltatus* Lindstrom by Viira (1974), as *Distomodus kentuckyensis* Branson & Branson by Lee (1970) and as the oistodontiform element of *Triangulodus changshanensis* by An et al. (1983). Ethington & Clark (1981) tentatively included the first two in their synonymy list for *"Scandodus"* sp. 1. The acodiform element is reclined with the cusp forming an angle of 110° or larger with the oral margin. The cusp is straight with sharp edges; one lateral face is smoothly convex, the other has a broad median swelling which continues aborally to form a basal flare. The other side of base is weakly inflated or flat. The lateral deflection of lower stretch of anterior margin is absent or weakly developed in typical acodiform elements but

transitional forms to scandodontiform elements are present. All elements are albid and therefore cannot belong to *Scandodus* as defined by Lindström (1971). Also the acodiform element is not typical for *Scandodus*. Distacodiform elements which, for example, exist in *Scandodus brevibasis* have not been identified in *"S." pseudoramis* so far but the similarity of the species to corresponding elements in *Scandodus robustus* Serpagli which has been assigned to *Acodus* by Johnston (1987) suggests a relationship between the two taxa and also implies that not all elements have been recognized yet in either species.

Occurrence.- Bed 10, clasts of Bed 9-age in beds 12 and 14.

Material.- 34 elements.

Repository.- Hypotypes: GSC 90489-90491.

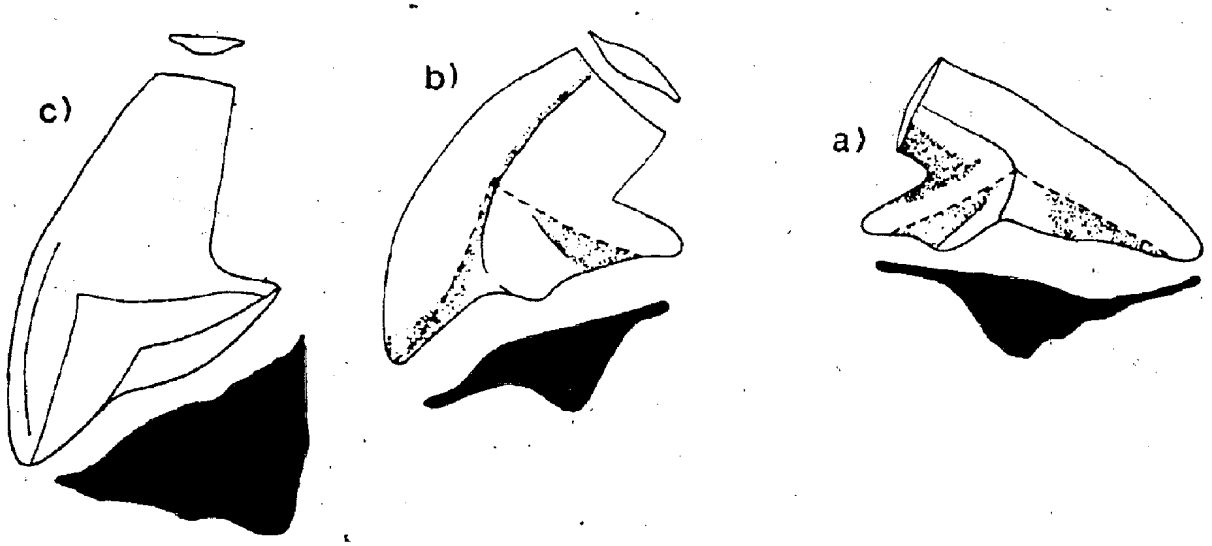


Figure 5-15: Elements of *"Scandodus" pseudoramis*. a) Oistodontiform element (X85), b) costate acodontiform element (X100), c) acostate acodontiform element (X100).

Scandodontiform element 1
Pl. 5.6, figs. 38-39; Fig. 5-16

Description.- Elements whose cusp is flexed and twisted so that base opens to one side. Both sides of cusp are regularly convex (Fig. 5-16-1) or bear a faint costa (Fig. 5-16-2). Cross section of cusp is lanceolate. Anterior and posterior edges are sharp. Base flares strongly to one side and basal cavity is shallow with irregularly lanceolate outline in aboral view. Dark brown hyaline band is developed adjacent to basal margin, otherwise specimens are albid. Elements are fragmentary.

Material.- 2 specimens.

Occurrence.- Older clast (Bed 9-age) in Bed 14.

Repository.- Figured specimens: GSC 90492-90493.

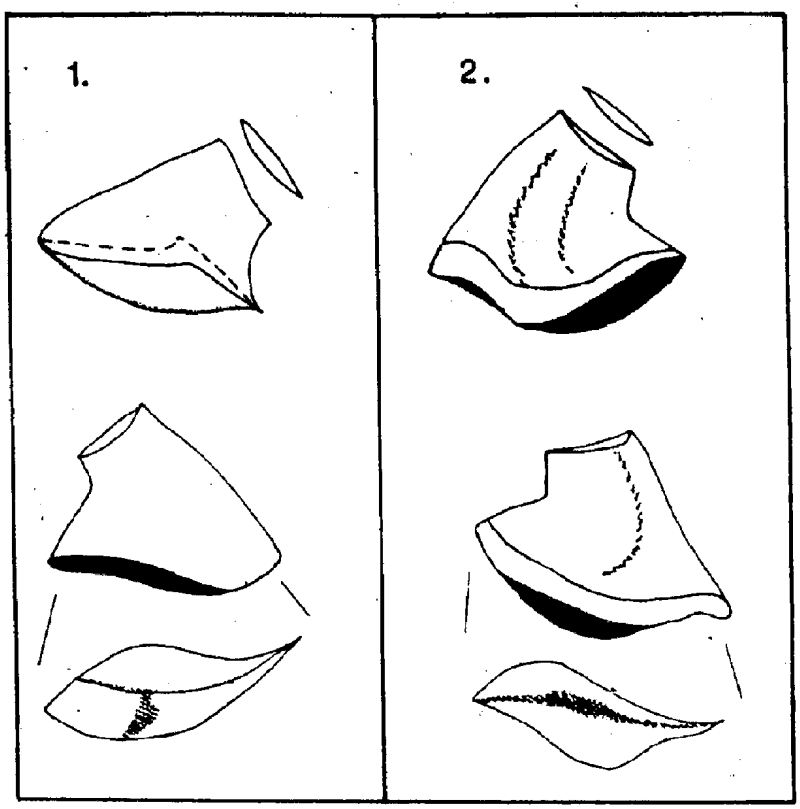


Figure 5-16: 1) Costate and 2) acostate element types of scandodontiform element 1. X70 and X80 respectively.

Scandodontiform element 2
Pl. 5.7, fig. 1; Fig. 5-17

Description.- Hyaline elements with weakly reclined and laterally flexed cusp. Long cusp is slightly twisted with respect to base with sharp anterior and posterior edges. Basal cavity flares widely especially on inner side. Basal margin extends from anterior to posterior edge in S-shape on inner side, on outer side it forms downward extension near rounded antero-basal corner.

Occurrence.- Beds 10 and 12, older clasts in Bed 14.

Material.- 4 specimens.

Repository.- Figured specimen: GSC 90494.

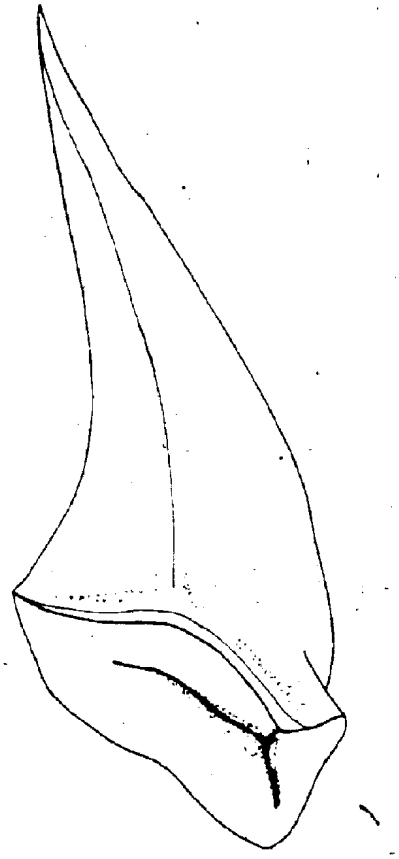


Figure 5-17: Lateral view of scandodontiform element 2. X100.

Genus *Scolopodus* Pander, 1856

Type species. *S. sublaevis* Pander, 1856.

SCOLOPODUS MULTICOSTATUS Barnes & Tuke
Pl. 5.7, fig. 4; Fig. 5-18.

Scolopodus multicostatus **BARNES & TUKE, 1970, p. 92-93, Pl. 18, figs. 5,9,15,16,, text-fig. 6D. ETHINGTON & CLARK, 1981, p. 101-102, Pl. 11, figs. 19,20.**

Remarks.- Simple cones with erect slightly curved cusp and wide basal cavity. Cusp is covered with narrowly spaced costae which decline in strength distally and basally. Cross section of cusp is round. Basal cavity flares widely and is of dark brown colour with a smooth rim. It is of moderate depth with its apex situated near anterior margin. Basal outline is round to subtriangular with the anterior side being almost flat.

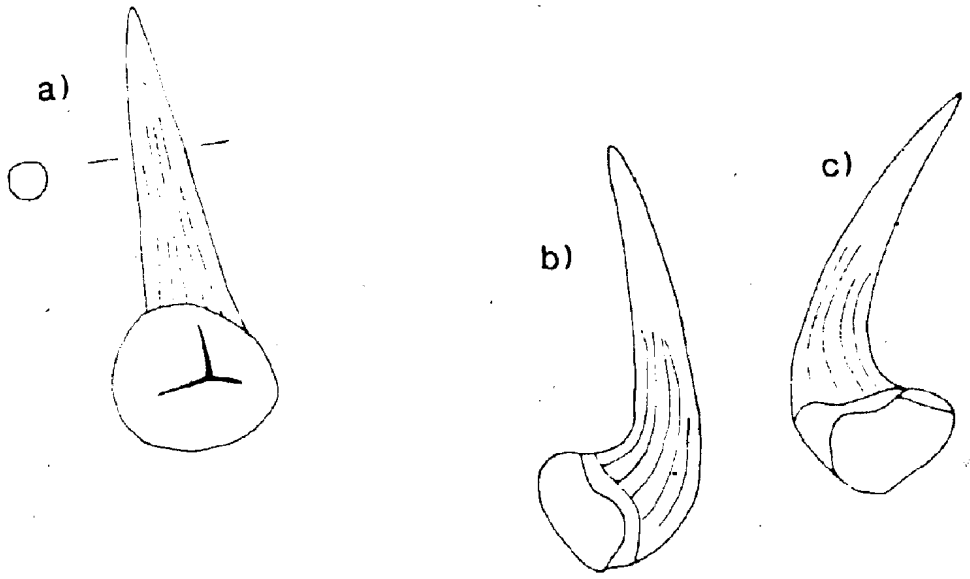
The character of the costation resembles that of *Scolopodus quadratus* but the shape and outline of the basal cavity are quite distinct from that species. Whether the cusp is albid cannot be determined because the elements are stained red, slightly abraded and show crystalline overgrowth.

Occurrence.- Bed 10, older clast (Bed 9-age) in Bed 14.

Material.- 3 specimens.

Repository.- Hypotye: GSC 90197.

Figure 5-18: Posterior (a) and lateral (b, c) views of *Scolopodus multicostatus*. X60



SCOLOPODUS? PESELEPHANTIS Lindstrom

Pl. 5.7, fig. 8

Scolopodus? peselephantis **LINDSTROM, 1955a p. 595, Pl. II, figs. 19, 20, 3Q.**

Scolopodus? peselephantis **(Lindstrom), VAN WAMEL, 1974, p. 94, Pl. 5, figs. 16, 17; LOFGREN, 1978, p. 108, Pl. 4, figs. 43-47 (includes synonymy through 1978).**

Remarks.- Löfgren (1978) observed a gradual change from older forms with a rounded cross section and minor costae towards laterally compressed elements with more prominent costae. This trend can be observed in the Cow Head material as well. Elements with a subrounded cross section of the cusp occur in samples from Bed 10, while compressed elements predominate in samples from Bed 12. The use for stratigraphic evaluation is, however, hampered because overgrowth on the element surface commonly obliterates the critical features. The older elements in the Cow Head material are commonly evenly curved in addition to the other primitive characteristics described above. This curvature of the cusp is in contrast with the almost erect younger forms with reclined cusps. In the more abundant younger forms a simple curvature transition from more to less reclined forms can be observed.

Occurrence.- Beds 10 and 12, older clasts in Bed 14.

Material.- 56 elements.

Repository.- Hypotype: GSC 90501.

?SCOLOPODUS sp. Ethington and Clark
Pl. 5.7, fig. 10; Fig. 5-19

?Scolopodus sp. ETHINGTON & CLARK, 1981, p. 106, Pl. 12, figs. 9-11.

Description.- Recurved simple cone with deep groove dissecting posterior face. Element is antero-posteriorly compressed with oval cross section of cusp and basal cavity. Basal area is dark coloured and restricted to lower quarter of cone. A thick walled rim surrounds and constricts basal opening. Depth and shape of basal cavity are not visible. Element surface is covered with coarse striae with exception of the smooth basal rim. The form maybe hyaline but crystalline overgrowth creates an opaque "milky" surface. Ethington and Clark (1981) reported the species from the upper Fillmore Formation (Pogonip Group), Utah

Occurrence.- Bed 10.

Material.- 1 specimen.

Repository.- Hypotype: GSC 90503.

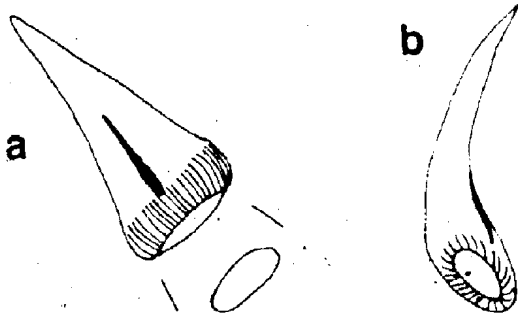


Figure 5-19: a) Posterior and b) aboral-lateral views of *?Scolopodus* sp. X45.

"SCOLOPODUS" sp.
Pl. 5.7, fig. 12

Description.- Finely striated simple cone with constricted basal cavity. Elements are spear-shaped in posterior view, slight curvature is visible in lateral view. Maximum width is attained in lower third of cusp, which then tapers towards the tip. Cross section of cusp is lenticular with sharp lateral edges. Basal opening is strongly constricted and basal cavity is shallow.

Occurrence.- Bed 12.

Material.- 1 element.

Repository.- Figured specimen: GSC 90505.

Scolopodontiform element 1
Pl. 5.7, fig. 11; Fig. 5-20

Remarks.- A coniform element, recurved with greatest curvature in upper third of cusp. Form is laterally compressed with a deep groove adjacent to anterior margin on one lateral face and a shallower groove near posterior margin on other face. Cusp is albid and is slightly twisted with respect to base. Basal cavity extends one third of cusp length. The basal region of the element is broken and the shape of the basal cavity is obscured. The elements have some features in common with *Juanognathus* Serpagli but lack the characteristic short basal processes.

Occurrence.- Beds 12 and 14.

Material.- 3 specimens.

Repository.- Figured specimen: GSC 90504.

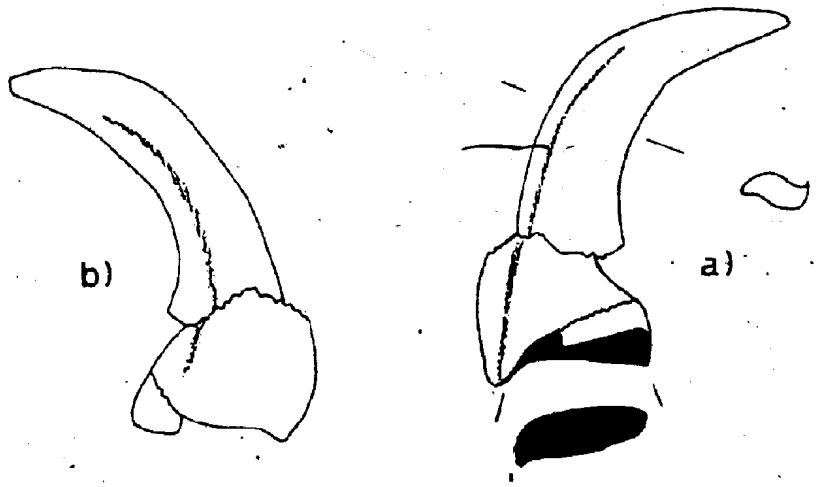


Figure 5-20: a) Postero- and b) antero-lateral views of scolopodontiform element 1. X80.

Genus *Semiacontiodus* Miller, 1969

Type species.- *Acontiodus (Semiacontiodus) nogami* Miller, 1969.

SEMIACONTIODUS ASYMMETRICUS (Barnes & Poplawski)
Pl. 5.7, fig. 13

Protopanderodus asymmetricus BARNES & POPLAWSKI, 1973, p.781,Pl.1, figs.12,12A, text-fig. 2a; ETHINGTON & CLARK, 1981, p.83, Pl.9, figs. 11,12,14,19.

Semiacontiodus asymmetricus (Barnes & Poplawski). STOUGE, 1984, p. 68, Pl. 10, figs. 5-10,15.

?*Scolopodus paracornuformis* ETHINGTON & CLARK, 1981, p.102, Pl.11, fig. 21, text-fig.25.

Remarks.- The asymmetrical elements have been adequately described by Barnes & Poplawski (1973) and Ethington & Clark (1981). Stouge (1984) and Löfgren (1985) included symmetrical elements in the apparatus which are probably conspecific with *Scolopodus paracornuformis* Ethington & Clark or a species of *Parapanderodus* Stouge.

S. paracornuformis co-occurs with *Semiacontiodus asymmetricus* in the Cow Head material and may belong in the apparatus because of the apparent morphological similarity to *S. asymmetricus*. The presence of asymmetrical antero- posteriorly compressed elements (*t* element following Barnes et al. (1979)) together with symmetrical compressed elements (*u* elements) justifies the assignment of the species to a genus with a Type IA apparatus such as *Semiacontiodus*. A differently compressed symmetrical element (*s* element) may also belong in the apparatus but could not be determined from the material at hand.

Occurrence.- Beds 12 and 14.

Material.- 27 elements.

Repository.- Hypotype: GSC 90506.

Genus *Serratognathus* Lee, 1970

Type species.- *Serratognathus bilobatus* Lee, 1970.

SERRATOGNATHUS DOUGLI n. sp.

Pl. 5.7, figs. 14-16

Scolopodus? sp. C s.f. STOUGE, 1982, p.44, Pl.3 figs. 16-18.

Derivation of name.- In honour of Douglas W. Haywick.

Diagnosis.- A species of *Serratognathus* with armadillo-shaped elements.

Description.- Aberrant barrel-shaped coniform elements with a blunt or pointed tip. The basal cavity is shallow and lacks a tip. (In accordance with Sweet (1981) the concave margin of the basal cavity is taken as posterior side). A broad posterior groove dissects the element producing a kidney-shaped cross section. The anterior and lateral faces are ornamented with several serrated "girdles" which traverse the element, reaching from one side of the posterior groove to the other. This surface ornamentation resembles the armour of an armadillo. Between six and seven "girdles" or ridges may be developed. The apparatus appears to be mono-elemental.

Remarks.- Nowlan (1976) described the forms from the Canadian Arctic and suggested that they might be fish teeth. Undescribed material of Z. Ji, however, yielded a species of *Clavohamulus* which resembles *S. dougli* in its shape but bears only faint ornaments. This suggests relationship of the genus to *Clavohamulus*. The species *S. bilobatus* Lee shows similar surface ornamentation to *S. dougli* but expands laterally from the posterior groove to attain the characteristic bilobate shape.

Occurrence.- Older clasts in beds 12 and 14.

Material.- 20 elements.

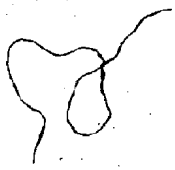
Repository.- Holotype: GSC 90508; paratypes: 90507,90509.

Genus *Strachanognathus* Rhodes, 1955

Type species. *S. parvus* Rhodes, 1955.

STRACHANOGNATHUS PARVUS Rhodes

Pl. 5.8, fig. 3



Strachanognathus parva RHODES, 1955, Pl.7, fig.16, Pl.8, figs.1-4; LOFGREN, 1978, p.112, Pl.1, fig.29, (includes synonymy through 1976).

Remarks.- The species possesses a monoelemental apparatus displaying a symmetry transition of symmetrical or nearly symmetrical to asymmetrical elements (Bergström, 1962). The symmetrical forms have both the cusp and anterior denticle in the same plane as the base while asymmetrical forms have inward deflected cusps and/or denticles and a slightly flaring basal cavity. The cusp may be more or less reclined in both element types. All elements contain white matter in the cusp while the base is dark and hyaline.

Occurrence.- Beds 10 and 12, older clasts in Bed 14.

Material.- 70 specimens.

Repository.- Hypotype: GSC 90526.

Genus *Texania* n. gen.
Fig. 5-21

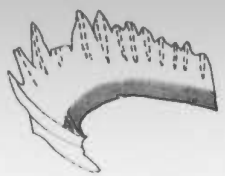
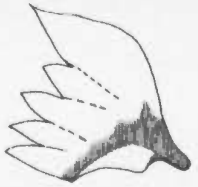
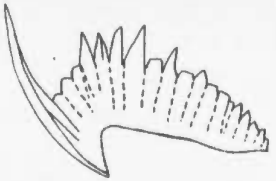
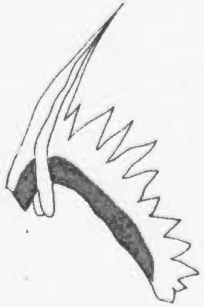
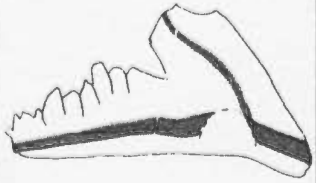
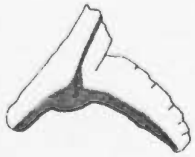
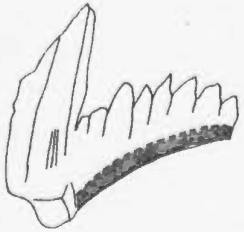
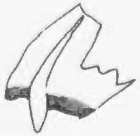
Type species. *Gothodus marathonensis* Bradshaw, 1969.

Gothodus marathonensis BRADSHAW, 1969, p.1151, Pl.137, figs. 13-15, Text-figs. S,T,U.

Derivation of name.- Named after U.S. State Texas where genus was first found.

Definition.- Genus includes multielement conodonts with ozarkodiniform, oistodontiform and ramiform albid elements in the apparatus. Ozarkodiniform and ramiform elements possess a single denticulated (posterior) process. Cusp is reclined and may be costate or have two short lateral processes which extend downward below the base. Oistodontiform elements display a reclined cusp which is longer than the posterior process and sharp edged. Base of most elements is dark brown; basal cavity is shallow. Collections of R.L. Ethington and C.R. Barnes from the Whiterock type section in the Antelope Valley, Nevada, yielded a blade-like element which apparently also belongs in the apparatus of some species of the genus (e.g. *T. marathonensis*). The element is similar in shape to that of *Protoprioniodus* McTavish but is denticulated. It was not found in any of the Cow Head material and the figured paratype from Nevada is courtesy of C.R. Barnes.

Figure 5-21: Comparison of elements of different species of *Texania*. The first two lateral items *T. marathonensis*, *T. adentata* are traced from illustrations in Ethington and Clark (1981) and McTavish (1973) respectively; the remaining figures are camera lucida drawings of specimens found in the CH material, with the exception the blade-like element of *T. marathonensis*. All X60.

SPECIES	oistodontiform elements	ozarkodiniform elements	ramiform elements
Texania marathonensis (Bradshaw) from Ethington & Clark, 1981			  
Texania adentata (McTavish) from McTavish, 1974			  
T. sp. aff. *T. adentata*			  
T. heligma n.sp.			  
T. marathonensis			  
T. sp.			  

Remarks.- The difficulty of assigning the species of *Texania* to an existing genus has been previously recognized (see discussion in McTavish, 1973, p. 49-50). and the consistently different apparatus structure justifies their collective assignment to a new genus. Typically developed features include:

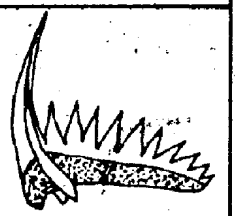
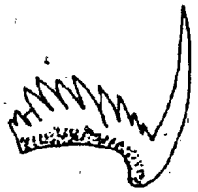
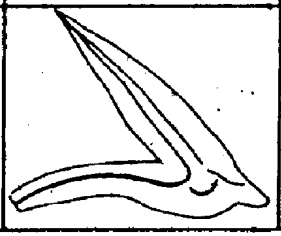
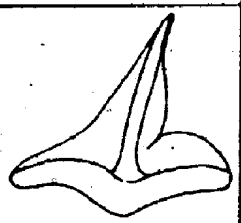
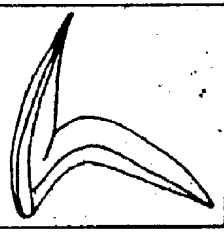
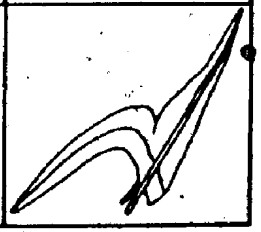
- ramiform elements with symmetry transition series of asymmetrical costate to symmetrical costate and acostate elements;
- ozarkodiniform elements with underdeveloped adentate anterior processes and relatively short stout cusps;
- fast evolving and/or highly variable oistodontiform elements.

The characteristics of *Texania* imply relationships to *Periodon* and *Protoprioniodus* and to *Microzarkodina* (Fig. 5-22). *Texania* shares the elemental composition of the apparatus with *Periodon*, i.e. oistodontiform, ozarkodiniform and ramiform elements are present. Particularly some of the ramiform elements of *T. heligma* are difficult to distinguish from small (juvenile or stunted?) ramiform elements of *Periodon*. The ozarkodiniform elements of *Texania*, however, always lack a denticulated anterior process.

Texania and *Protoprioniodus* appear to be as closely related as for example *Acodus* and *Prioniodus*. *Texania* represents the denticulated relative of *Protoprioniodus*. This relationship is particularly emphasized by the presence of the rare blade-like element of *T. marathonensis* which has its adentate counterpart in *P. aranda*. Both genera show highly variable morphologies of all elements in the apparatus.

The new genus has about as much in common with *Microzarkodina* as with *Periodon* with regard to elemental composition. *Texania*, as a rule, lacks the denticulate lateral processes which characterize ramiform elements of *Microzarkodina* but posesses a basically similar apparatus. The different elements of the four species of *Texania* found in the Cow Head material are illustrated in Text-fig. 5-21.

Figure 5-22: Comparison of apparatuses of different genera related to *Texania*

Genus	"oistodontiform"	"prioniodiniform"	"ozarkodiniform"	"cordylodiform"	"trichonodelliform"
Texania (as in Fig. 2-22)		 "blade" element			
Microzarkodina (after Lindström, 1971)		 aulodiform el.			
Periodon (CH material)					
Protoprioniodus (after Cooper, 1981)		 "blade" element			

TEXANIA HELIGMA n. sp.
Pl.5.8, figs. 11-15; Fig. 5-21

?Microzarkodina adentata sp. nov. MC TAVISH, 1973, p.49, PL.3, Fig.42 only.

Derivation of name.- From Greek 'ηελιξ'=coiled referring to the strong lateral flexion found in some elements.

Description.- A species of *Texania* in which the oistodontiform and ramiform elements are characterized by strong flexure of the posterior process. The upper part of all elements is filled with white matter, and the basal part is dark and translucent.

Cusp of the oistodontiform elements is reclined, the curved posterior process is usually flexed sideways. Outer side of cusp is weakly carinate to costate. The antero-basal and postero-basal corners are sub-rounded. Oral and aboral margins are curved. The basal cavity is shallow and faintly sigmoidal. It runs parallel to the aboral margin along the entire length of the unit. The posterior process is straight or flexed sideways opposed to the orientation of the cusp.

The "ozarkodiniform" element has a straight aboral margin which meets the anterior margin of the cusp at a right or slightly obtuse angle. Three to four laterally compressed denticles on the posterior process decrease in size from anterior to posterior. The denticles are reclined to suberect, and the anterior process is rudimentary and adentate. The whole unit or only the denticles may be flexed inwards with respect to the base.

The ramiform elements are most abundant in this collection. They possess a long slender recurved cusp which is laterally compressed and maybe weakly costate on one side. Costate ramiform elements have two or three edges of the cusp developed as keels. The latter possess five to seven flat denticles while the usually larger acostate elements have up to fifteen denticles of unequal length.

The largest denticle is separated from the cusp by three to four shorter ones. The posterior process may be more or less strongly arched and the antero- and postero-basal corners are rounded. The flexure of the ramiform elements maybe very complicated because the base of the denticles and the cusp can be deflected in three different directions. The acostate elements can be straight or flexed sideways or the posterior process deviates in S-shape from the vertical plane with the cusp deflected with respect to the rest of the unit. In the costate ramiform elements a slightly different curvature transition is developed. Cusp and denticles may be flexed sideways with respect to the base or the strongest flexure may occur along a line which runs from the antero-basal corner to the second or third denticle.

Remarks.- The unusual flexure of the elements sets this species quite apart from other forms. The oistodontiform element of *T. heligma* differs from *?M. adentata* in lacking the upward curvature of the anterior part of the aboral margin. It can be distinguished from the corresponding element of *T.* sp. aff. *adentata* whose cusp terminates with a smaller angle at the antero-basal corner. The "ozarkodiniform" element of *T. heligma* has less denticles compared to *T.* aff. *adentata* and cusp and denticles are more erect. The species is obviously related to *T.* aff.*adentata* and may be its successor. It is therefore assigned to the same genus although the species shows a denticulation similar to *Periodon*. McTavish's specimen (1973, Pl.3, fig.12) maybe part of the apparatus described herein. According to the sample number given by that author the element was found in the uppermost part of the sampling interval which correlates to the *Prioniodus evae* Zone. This stratigraphic position is in agreement with the age of the Cow Head species which was found in a clast from Bed 12.

Occurrence.- Bed 12.

Material.- 263 elements.

Repository.- Holotype: GSC 90535; paratypes GSC 90534, 90536-90538.

TEXANIA sp. aff. T. ADENTATA (McTavish)

Pl. 5-8, figs. 7-10; Fig. 5-21

aff. *?Microzarkodina adentata* **MCTAVISH, 1973, p.49, Pl.3, figs.28,33-35, 38-40, 42-44.**

Remarks.- This species contains all elements described by McTavish (1973). The ramiform elements can be distinguished from similarly delicate cordylodontiform elements of *Prioniodus elegans* by the different denticulation. Denticles of the former species are longer, thinner and of unequal length.

Compared to McTavish's specimens of *?Microzarkodina adentata*, the costate ramiform elements have a stronger, more downwardly curved posterior process.

The oistodontiform elements possess a more arched aboral margin than the corresponding elements in *?M. adentata* and the lower portion of the cusp is erect while the upper part is reclined. The point of declension is graphically the horizontal extension of the highest point on the oral margin of the posterior process. This element is the one most different when compared to the *?M. adentata* apparatus.

The "oulodontiform" element differs from corresponding elements of *?M. adentata* by possessing less denticles (only 4, as opposed to 5 or 6). The same applies for the ozarkodiniform element which in addition lacks the short adentate anterior process described by McTavish. The anterior margin of the cusp meets the aboral margin with an angle of approximately 90°. As in the oistodontiform elements only the upper two thirds of the cusp is reclined whereas the lower part is erect.

The differences described above between *?M. adentata* and *T.* sp. aff. *T. adentata* may be sufficient to justify the assignment of the latter to a new species but the overall similarity in elemental composition suggests that *T.* aff. *adentata* is a North American variant of the Australian species rather than a different taxon.

Occurrence.- Bed 10, clasts of Bed 9-age in Bed 14.

Material.- 60 elements.

Repository.- Hypotypes: GSC 90530-90533.

TEXANIA sp.

Pl. 5.8, figs. 21-25; Fig. 5-21

Remarks.- Only a few specimens of *Texania* sp. have been recovered from boulders. Two different morphologies of ramiform elements are present, each in separate samples.

Type I includes ramiform elements with slender discrete denticles and a long slender cusp. Cusp and denticles are filled with white matter; the aboral margin is translucent and of brown colour. The elements resemble closely the form species of *Gothodus marathonensis* Bradshaw and agree with the ramiform elements illustrated in Ethington & Clark (1981, Pl.5. figs. 23, 27) and Stouge & Boyce (1982, Pl.4, fig. 12). These delicate forms are assigned to *Texania marathonensis* (Bradshaw) and are in contrast with robust elements found in stratigraphically older samples assigned to *T.* sp. The latter are distinguished by possession of shorter, basally fused denticles and a broader, stout cusp on ramiform elements. They resemble the older elements from sampling sites lower in the sequence of the Pogonip Group, Utah, illustrated by Ethington & Clark (1981, Pl.5, figs. 14, 20?).

Occurrence.- Bed 10, older clasts in Bed 14.

Material.- 14 elements.

Repository.- Figured specimens: GSC 90544-90548.

Genus *Tripodus* Bradshaw, 1969

Type species. *T. laevis* Bradshaw, 1969.

TRIPODUS sp. aff. T. LAEVIS Bradshaw

Pl. 5.8, figs. 27-29, 31-32; Fig. 5-23

aff. *Scolopodus alatus* BRADSHAW, 1969, p.1162, Pl. 132, fig 4.

aff. *Tripodus laevis* BRADSHAW, 1969, p.1164, Pl. 135, figs. 9, 10.

aff. *Tripodus laevis* Bradshaw. ETHINGTON & CLARK, 1981, p. 110, figs. 24, 25, 27-29; fig.33.

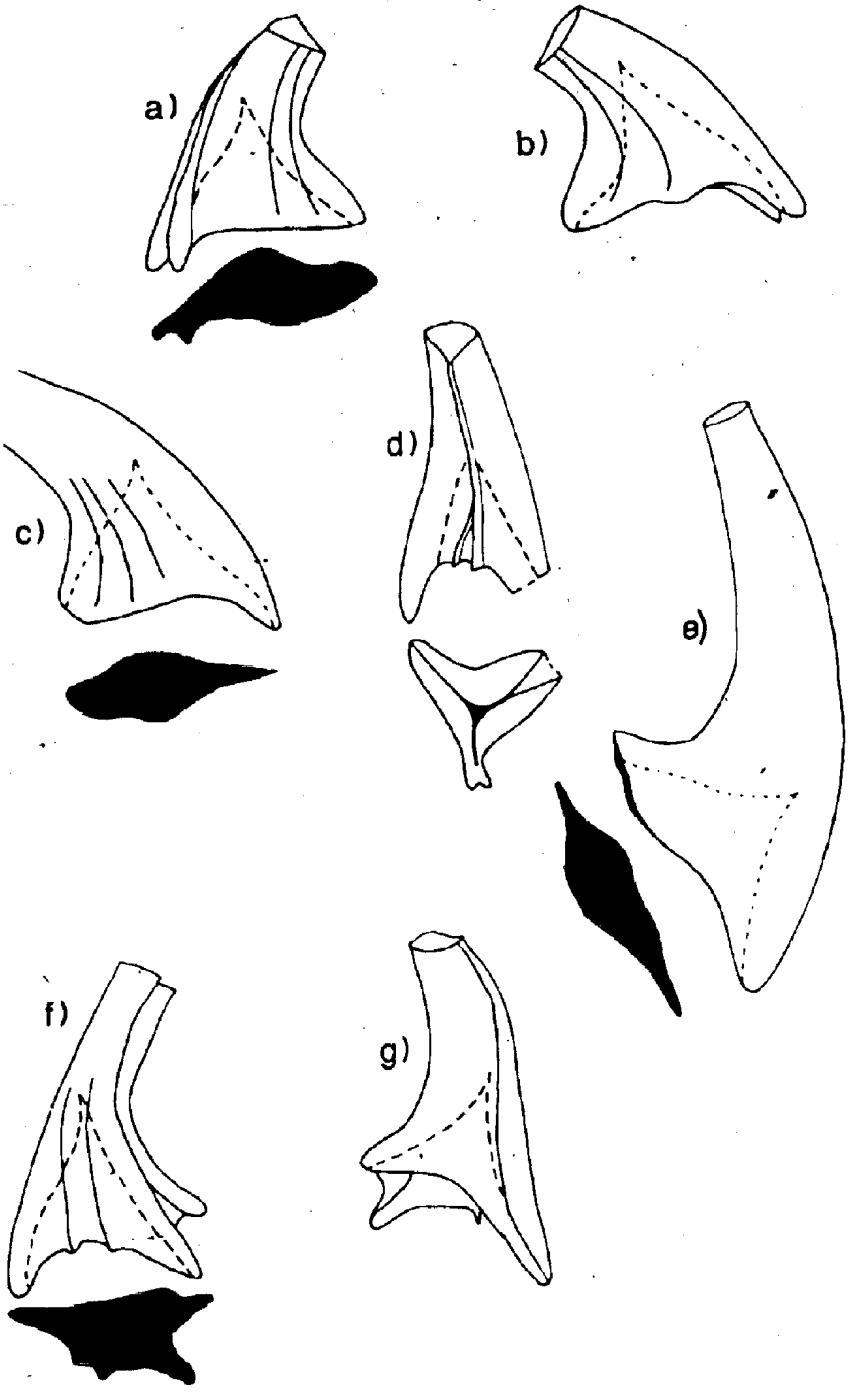
Remarks.- The composition of the apparatus of *Tripodus* sp. aff. *T. laevis* is similar to that reconstructed by Ethington & Clark (1981) for *T. laevis* Bradshaw except that no oistodontiform element can be assigned. The Cow Head specimens differ in possessing distacodontiform elements with two costae on both lateral faces well in front of the midline. In addition distacodontiform and paltodontiform elements commonly have one of the anterior, lateral or anterior edges with the keel bifurcated. This bifurcation is restricted to the basal area and along the cusp, only one keel remains fading into a sharp edge distally.

Occurrence.- Bed 10.

Material.- 35 elements.

Repository.- Hypotypes: GSC 90550-90554.

Figure 5-23: Elemental composition of the apparatus of *Tripodus* sp. aff. *T. laevis*. A) Antero-lateral and b) postero-lateral views of distacodontiform element. X100. C) lateral views of costate and e) acostate drepanodontiform elements. X100. D) posterior view of paltodiform element. X100. F) anterior and g) postero-lateral views of paltodontiform element. X100.


a)
b)
c)
d)
e)
f)
g)

TRIPODUS sp.
Pl. 5.8, figs. 33-34; Fig. 5-24

Description.- Drepanodontiform and trichonodelliform elements of *Tripodus* were found in one sample. Similarities in shape of basal cavity, colour and general morphology suggest that they belong in the same apparatus. Drepanodontiform element has sharp anterior and posterior edges and swollen lateral faces. Both lateral faces are convex and unornamented. Basal cavity is deep and apex is near anterior margin at point of greatest curvature of cusp.

Trichonodelliform element is recurved_with convex anterior side and concave lateral faces. Basal cavity is deep and apex reaches anterior margin at point of greatest curvature. Base is not strongly expanded. Both elements are small with dark-stained cavities.

Occurrence.- Bed 12, clasts of Bed 11-age in Bed 14.

Material.- 8 elements.

Repository.- Figured specimens: GSC 90557-90558.

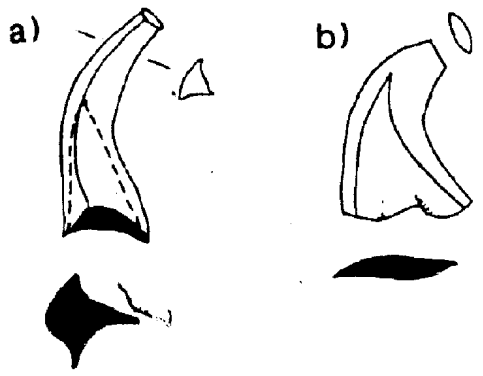


Figure 5-24: Lateral views of a) the trichonodelliform and b) the drepanodiform element of *Tripodus* sp. X100.

Genus *Walliserodus* Serpagli, 1967

Type species. *Paltodus debolti* Rexroad, 1967.

WALLISERODUS AUSTRALIS Serpagli

Pl. 5.7, figs. 21-22

Walliserodus australis SERPAGLI, 1974, p.89, Pl. 19, figs. 5a-10c; Pl. 29, figs. 8-15; Text-figs. 23, 24.

Tropodus comptus (Branson & Mehl), STOUGE, 1982, p.45, Pl.4, figs.3-4, 6-8.

Remarks.- Ramiform elements with two (?), three, four, five, six and ten costae were found in the Cow Head material. They follow most closely the description of *Walliserodus australis* by Serpagli (1974): the elements are strongly costate and show lateral compression or are round. They are collectively included in *Walliserodus australis* although the low abundance does not allow a separation from the related (conspecific?) form *Walliserodus comptus* (Branson & Mehl). Furthermore *W. comptus* is associated only with Midcontinent faunas (Kennedy, 1979) and the fauna described herein is mainly of North Atlantic aspect. Ramiform elements of *Walliserodus comptus* have been reported from the lower part of the Catoche Formation (St. George Group) by Stouge (1982). A boulder in Bed 14 contained this species of *Walliserodus* associated with a fauna similar to the one reported by Stouge (1982) from the Catoche Formation. These specimens do not differ from others in the Cow Head material and are therefore included in *W. australis*.

Acodontiform elements recovered from boulders in Bed 10 differ from those from Bed 12 in being generally larger and more robust. Two bicostate elements were found which strongly resemble the other ramiform elements of *W. australis* in their morphology and they probably also belong in the apparatus of that species.

Occurrence.- Beds 10 and 12, older clasts in Bed 14.

Material.- 34 elements.

Repository.- Hypotypes: GSC 90514-90515.

WALLISERODUS sp. aff. W. AUSTRALIS Serpagli

Pl. 5.7, figs. 23-24

aff. *Walliserodus australis* SERPAGLI, 1974,
p. 89, Pl. 19, figs. 10a-c; Pl. 29, figs. 8-15;
Text-figs. 23, 24.

Walliserodus australis Serpagli, LANDING, 1976,
p. 641, Pl.4, figs. 16,19,22,23.

Remarks.- Acodontiform elements recovered from boulders in Bed 10 differ from those from Bed 12 in several respects, and are generally larger and more robust. Only one of the four- to five- costate forms has been found to bear minute denticles on the lateral costae. In contrast, the younger forms from Bed 12 with three, four and five costae commonly possess one denticulated lateral costa. Symmetrical five costae elements usually have two denticulated postero-lateral costae. Landing (1976) described a similar five-costae element of *W. australis* from the *Prioniodus evae* Zone of the Taconic Allochthon. It is likely that these denticulated elements are more advanced forms. The development of denticulation appears to be gradual and a larger collection would be necessary to determine the stratigraphic position of the changeover. Possibly two different species are present in the Cow Head material.

Occurrence.- Bed 12, older clasts (Bed 11-age) in Bed 14.

Material.- 22 elements.

Repository.- Hypotypes: GSC 90516-90517.

New Genus A s.f.

Remarks.- Erect coniform elements, laterally compressed with bulging basal region and short suberect stout cusp. Basal cavity is shallow. Surfaces are finely striated. Cusp is albid, base may be hyaline.

New Genus A new species 1 s.f.
Pl. 5.7, fig. 29; Fig. 5-25

Description.- Simple cones, laterally compressed with sharp-edged anterior and posterior margins. In lateral view the basal region shows bulges on both sides which give the element the shape of a bulbous spire. Cusp and base are of equal length. Element surface is covered with fine striations. Antero-basal corner is deflected to inner side forming a groove which dissects inner face while outer face is smoothly curved.

Occurrence.- Bed 14.

Material.- 2 specimens.

Repository.- Figured specimen: GSC 90522.

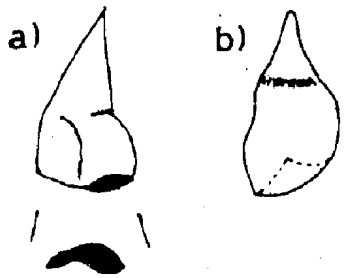


Figure 5-25: a) Posterior and b)anterior views of New Genus A new species 1. X60

New Genus A new species 2 s.f.
Pl. 5.7, figs. 27-28; Fig. 5-26

Description.- Proclined simple cone, laterally compressed with bluntly edged posterior and anterior margins. Depth and shape of basal cavity cannot be determined because the walls are opaque and basal filling is present. A few shallow protrusions are developed around base of element obscuring the overall bulbous outline. Base and cusp are of about equal length. Surface is covered with fine striae.

Occurrence.- Bed 14.

Material.- 1 specimen.

Repository.- Figured specimens: GSC 90520-90521.



Figure 5-26: a) Antero-lateral and b) posterior view of New gen. A n.sp. 2. X90.

New Genus B s.f.

Remarks.- This new genus includes albid laterally compressed, antero-posteriorly extended coniform elements with a shallow basal cavity. The anterior extension exceeds that of the posterior one in length.

New genus B new species 1 s.f.
Pl. 5.7, fig. 30; Fig. 5-27

Description.- Coniform albid elements with gently recurved inwardly flexed cusp and drawnout antero-basal and postero-basal corners. Both anterior and posterior margins have sharp edges. A weak costa is developed on outer face of cusp; inner face is smoothly curved. Cross section of cusp is lanceolate. Basal cavity opens to inner side. Basal excavation begins at antero-basal corner as a shallow narrow trough, continues posteriorly to beneath cusp, where it flares prominently to inner side of element, then narrows to posterior extremity. Apex of shallow basal cavity is centrally situated. Basal outline forms gentle curve from distal end of anterior to tip of posterior extension. Thin dark brown band is developed adjacent to basal margin. Oral margin of anterior extension continues straight into cusp or forms obtuse angle (up to 150°) with it. Straight oral margin of posterior extension forms 130°-150° angle with cusp. Elements are crudely triangular in lateral view.

Remarks.- No additional elements which might belong in the apparatus were detected and the species is therefore described as a form taxon until larger collections are available. The two fragmentary specimens recovered resemble the oulodiform element of *Oistodus bransoni* Ethington & Clark. They lack, however, the strong striations typical for that species and the constriction of the basal cavity, and no accompanying elements of such an apparatus have been found.

Occurrence.- Bed 14.

Material.- 2 specimens.

Repository.- Figured specimen: GSC 90523.

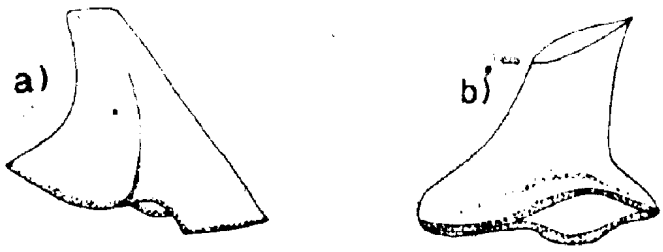


Figure 5-27: a) Anterior and b) posterior views of New Genus B new species 1. X65.

New Genus C s.f.

Remarks.- This new genus is proposed herein for robust denticulate elements with crown-shaped morphology.

New Genus C species 1 s.f.
Pl. 5.7, fig. 26; Fig. 5-28

Description.- Crown-shaped element with one denticle fused to either side of cusp. Cross section of cusp and denticles is lanceolate. Basal cavity is shallow with its apex situated under cusp. Dark band is developed adjacent to basal rim. The specimen shows crystalline overgrowth.

Occurrence.- Clast of Bed 9-age in Bed 14.

Material.- 1 specimen.

Repository.- Figured specimen: GSC 90519.

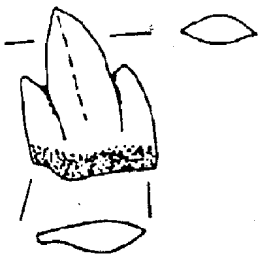


Figure 5-28: Lateral view of New Genus C new species 1. X90.

PLATE 5.1

Figures 6, 7, 14, 25, 28 and 29 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figures. 1-4. *Acodus deltatus* Lindström. Hypotypes. (Bed 10, 239). 1. Drepanodontiform element, lateral view, GSC 90303, x40. 2. Prioniodontiform element, lateral view, GSC 90304, x50. 3. Tetraprioniodontiform element, lateral view, GSC 90305, x70. 4. Oistodontiform element, lateral view, GSC 90306, x100.

Figure 5. *Acodus? gladiatus* Lindström s.f.. Hypotype. (Bed 12, 184). Lateral view, GSC 90307, x50.

Figure 6. *Acodus? mutatus* (Branson and Mehl). Hypotype. (Bed 12, 99). Acodontiform element, lateral view, GSC 90308, x70.

Figure 7. Acodontiform element 2. Figured specimen. (Bed 11, 51). Lateral view, GSC 90309, x90.

Figures 8-9. *Acodus? sweeti* (Serpagli). Hypotypes. (Bed 10, 184). 8. Oistodontiform element, inner lateral view, GSC 90310, x40. 9. Prioniodontiform element, lateral view, GSC 90311, x40.

Figure 10. Acodontiform element 1. Figured specimen. (Bed. 198). Lateral view, GSC 90312, x40.

Figures 11-12. *Acontiodus reclinatus* Lindstrom. Hypotypes. (Bed 12, 25). 11. element, outer lateral view. GSC 90313, x40. 12. element, lateral view, GSC 90314, x40.

Figure 13. *Acontiodus* sp. 2 Barnes and Tuke s.f.. Hypotype. (Bed 12, 167). Inner lateral view, GSC 90315, x35.

Figure 14. *Acontiodus* sp. aff. *A. latus* Pander s.f.. Hypotype. (Bed 14, 54). Posterior view, GSC 90316, x75.

Figures 15-17. *Ansella jemtlandica* (Löfgren). Hypotypes. (Bed 14, 181). 15. Triangular element, antero-lateral view, GSC 90317, x90. 16. Biconvex element, lateral view, GSC 90318, x80. 17. Oistodontiform element, lateral view, GSC 90319, x80.

Figure 18. *"Acontiodus" iowensis* Furnish. Hypotype. (Bed 14,). GSC 90320. x90.

Figures 19-22. *Bergstroemognathus extensus* Serpagli. Hypotypes. 19. (Bed 12, 167) Prioniodiniform element, posterior view, GSC 90321, x35. 20. (Bed 12, 94-A). Flat prioniodiniform element, posterior view, GSC 90322, x50. 21. (Bed 12, 94-A). Trichonodelliform element, posterior view, GSC 90323, x50. 22. Falodontiform element, lateral view, GSC 90324, (Bed 12, 94-A), x35.

Figures 23-24. *Cristodus loxoides* Repetski. Hypotypes. 23. Multidenticulate element, inner lateral view, GSC 90325, (Bed 10, 300), x30. 24. Monodenticulate element, outer lateral view, GSC 90326, (Bed 14, 54), x30.

Figure 25. *Coelocerodontus bicostatus* Van Wamel s.f.. Hypotype. Lateral view, GSC 90327, (Bed 10, 239), x75.

Figure 26. *Cordylodus proavus* Müller. Hypotype. Lateral view, GSC 90328, (Bed 14,), x60.

Figure 27. *Cordylodus caboti* Bagnoli et al. Hypotype. Lateral view, GSC 90329, (Bed 12, 275), x55.

Figures 28-29. *Cornuodus longibasis* (Lindström). Hypotypes. 28. Lateral view, GSC 90330, (Bed 14, 92), x45. 29. Lateral view, GSC 90331, (Bed 12, 94-A), x65.

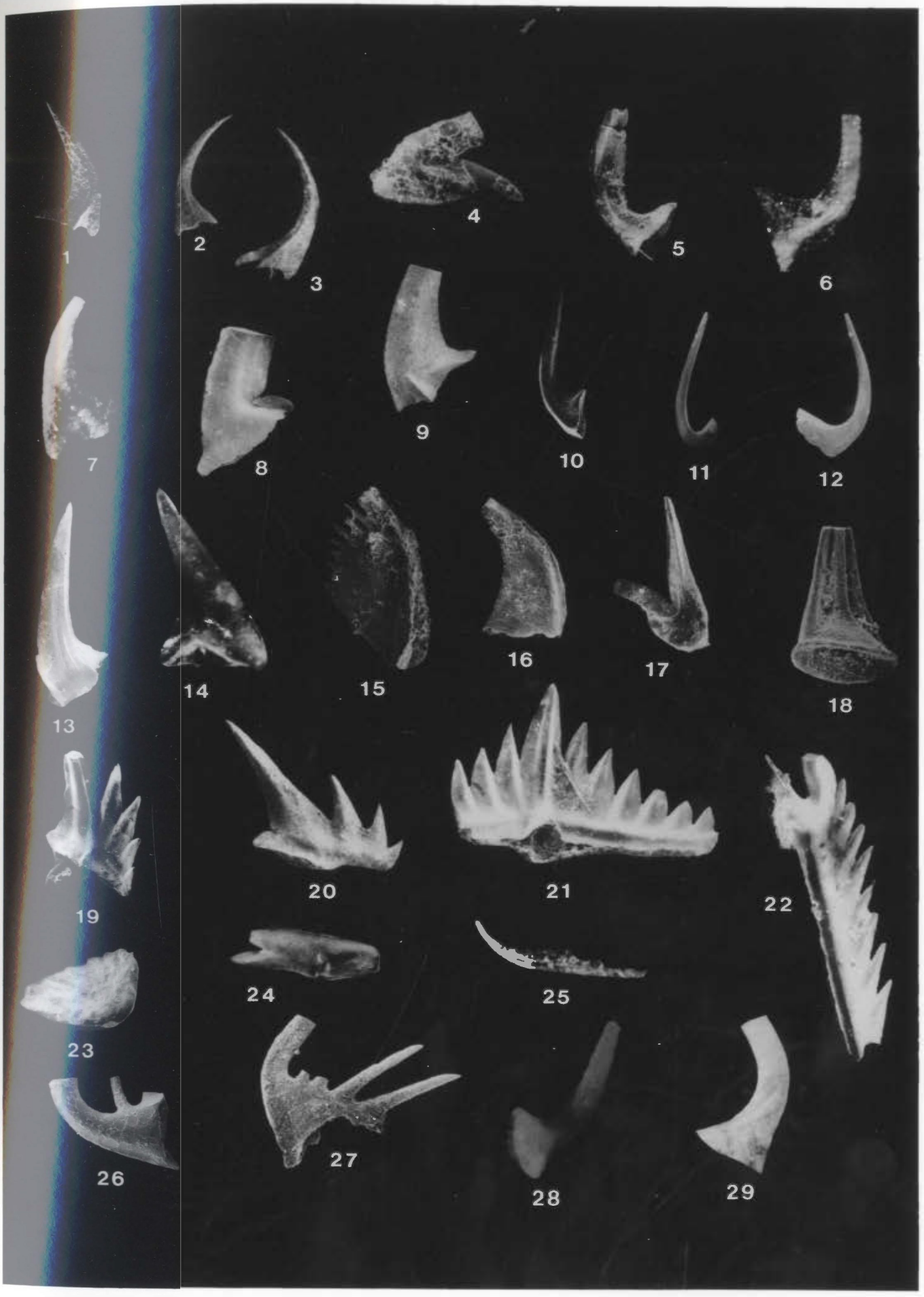

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29

PLATE 5.2

Figures 1, 4, 6, 8 and 16-31 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figures 1-7. *Drepanodus arcuatus* Pander. Hypotypes. 1. Arcuatiform element, lateral view, GSC 90332, (Bed 14, 18), x35. 2. Sculponeaform element, lateral view, GSC 90333 (Bed 14, 110), x35. 3. Costate pipaform element, postero-lateral view, GSC 90334, (Bed 14, 110), x40. 4. Pipaform element, lateral view, GSC 90335, (Bed 14, 167), x50. 5. Arcuatiform element, lateral view, GSC 90336, (Bed 14, 184) 40. 6. Graciliform element, lateral view, GSC 90337, (Bed 14, 11), x40. 7. Acontiodontiform element, postero-lateral view, GSC 90338, (Bed 14, 11), x35.

Figure 8. *"Drepanodus" toomeyi* Ethington and Clark s.f. Hypotype. Lateral view, GSC 90339, (Bed, 246), x65.

Figure 9. *Drepanodus* sp. 4 Repetski s.f.. Hypotype. Inner lateral view, GSC 90340, (Bed 14, 267), x70.

Figure 10. *Drepanodus* sp. 2 Ethington and Clark s.f.. Hypotype. Lateral view, GSC 90341, (Bed 14, 51), x65.

Figure 11. *Drepanodus* sp. 4 Serpagli s.f.. Hypotype. Postero-lateral view, GSC 90342, (Bed 10, 262), x50.

Figure 12. Drepanodontiform element 1. Figured specimen. Postero-lateral view, GSC 90343, (Bed 10, 230-2), x35.

Figure 13. Drepanodontiform element 2. Figured specimen. Lateral view, GSC 90344, (Bed 12, 184), x40.

Figures 14-15. *Drepanoistodus* sp. aff. *D. basiovalis* (Sergeeva) sensu Ethington and Clark. Hypotypes. (Bed 10, 225). 14. Homocurvatiform element, outer lateral

view, GSC 90345, x60. 15. Suberectiform element, outer lateral view, GSC 90346, x60.

Figures 16-17. *Drepanoistodus* sp. aff. *D. basiovalis* (Sergeeva). Hypotypes. (Bed 12, 91). 16. Homocurvatiform element, lateral view, GSC 90347, x100. 17. Oistodontiform element, lateral view, GSC 90348, x100.

Figure 18. *Drepanodus?* sp. 1 s.f.. Figured specimen. Outer lateral view, GSC 90349, (Bed 10, 138), x75.

Figure 19. *Drepanodus* sp. 2 s.f.. Figured specimen. Postero-lateral view, GSC 90350, (Bed 14, 11), x65.

Figures 20-23. *Drepanoistodus concavus* (Branson and Mehl). Hypotypes. (Bed 14, 163). 20. Homocurvatiform element, lateral view, GSC 90351, x60. 21. Oistodontiform element, lateral view, GSC 90352, x60. 22. Suberectiform element, lateral view, GSC 90353, x100. 23. Pipaform element, postero-lateral view, GSC 90354, x90.

Figures 24-26. *Drepanoistodus forceps* Lindström. Hypotypes. (Bed 12, 218). 24. Oistodontiform element, lateral view, GSC 90355, x90. 25. Homocurvatiform element, lateral view, GSC 90356, x70. 26. Suberectiform element, lateral view, GSC 90357, x70.

Figure 27. *Drepanoistodus inaequalis* (Lindström). Hypotype. GSC 90358, (Bed 10, 236), x75.

Figures 28-31. *Drepanoistodus inconstans* (Lindström). Hypotypes. (Bed 10, 236). 28. Homocurvatiform element, note costa, lateral view, GSC 90359, x75. 29. Homocurvatiform element, lateral view, GSC 90360, x75. 30. Suberectiform element, lateral view, GSC 90361, x75. 31. Oistodontiform element, lateral view, GSC 90362, x75.

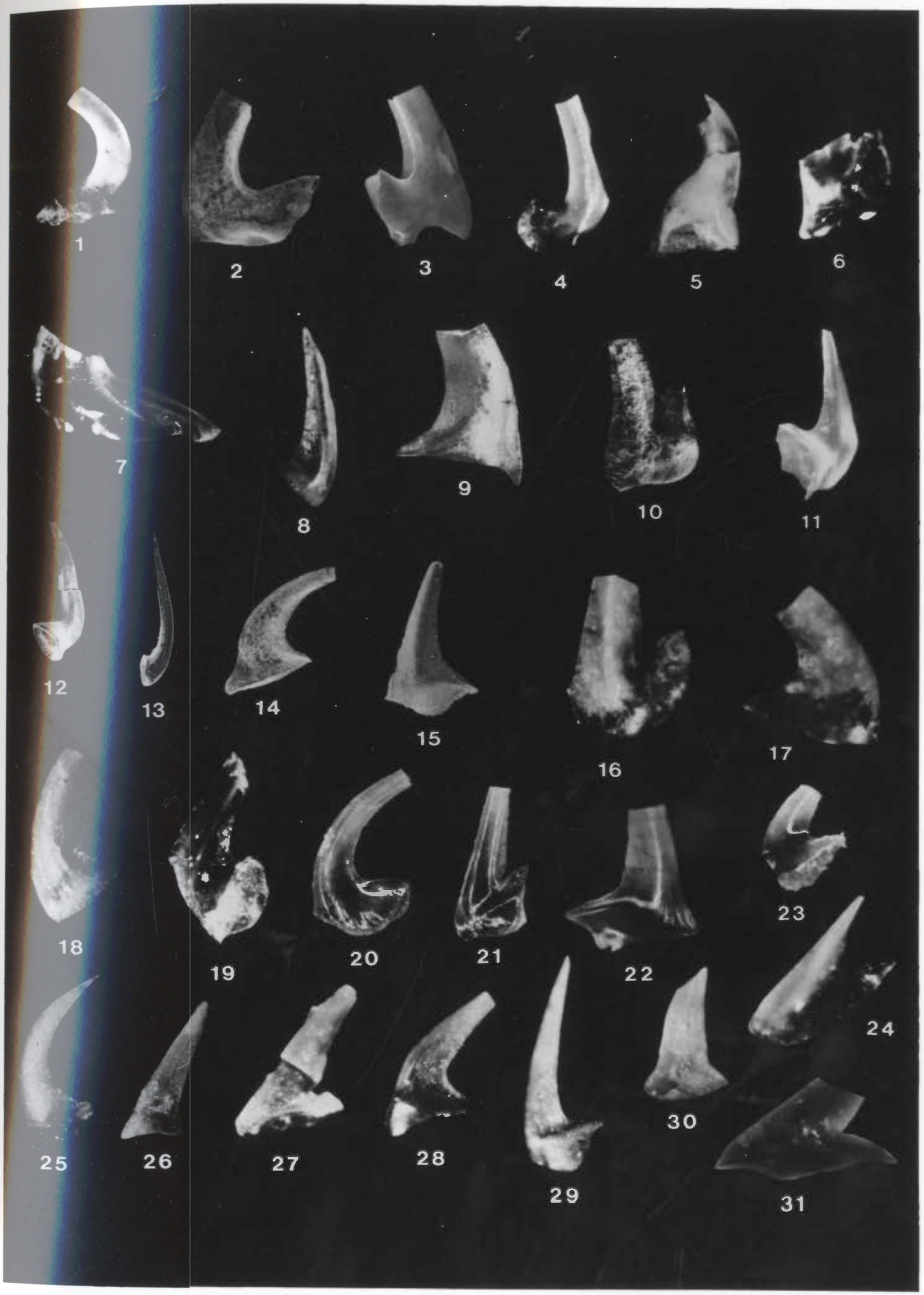

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

PLATE 5.3

Figures 11, 12, 18-21, and 30-33 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figure 1. *Drepanoistodus?* sp. cf. *D. venustus* (Stauffer). Hypotype. Costate homocurvatiform element, lateral view, GSC 90363, (Bed 14, 271), x55.

Figure 2. *Eoconodontus notchpeakensis* (Miller). Hypotype. Lateral view, GSC 90364, (Bed 14, 41), x65.

Figures 3-5. *Erraticodon* sp. aff. *E. balticus* Dzik. Hypotypes. (Bed 14, 112). 3. Fragment of ozarkodiniform element, lateral view, GSC 90365, x70. 4. Fragmented hindeodelliform element, lateral view, GSC 90366, x35. 5. Fragment of element, lateral view, GSC 90367, x30.

Figure 6. *Eucharodus parallelus* (Branson and Mehl). Hypotype. Postero-lateral view, GSC 90368, (Bed 14, 163), x35.

Figure 7. *Glyptoconus quadratus* (Branson and Mehl). Hypotype. Postero-lateral view, GSC 90369, (Bed 10, 135), x45.

Figure 8-10. *Fryxellodontus?* sp. aff. *F.? corbatoi* Serpagli. Hypotypes. (Bed 12, 275). 8. "Symmetricus" element, GSC 90370, x30. 9. "Intermedius" element, GSC 90371, x60. 10. "Intermedius" element, GSC 90372, x70.

Figure 11. *Fryxellodontus? ruedemanni* Landing. Hypotype. "Intermedius" element, GSC 90373, (Bed 14, 54), x80.

Figure 12. *Fryxellodontus?* sp. s.f. Figured specimen. Posterior view, GSC 90374, (Bed 12, 275), x80.

Figure 13. *Juanognathus jaanussoni* Serpagli. Hypotype. Posterior view, GSC 90375, (Bed 12, 199), x40.

Figure 14. *Juanognathus variabilis* Serpagli. Hypotype. Postero-lateral view, GSC 90376, (Bed 14, 65), x40.

Figures 15-16.. *Jumodontus gananda* Cooper. Hypotypes. 15. Lateral view, GSC 90377, (Bed 12, 254), x35. 16. Aboral-lateral view, GSC 90378, (Bed 12, 295), x60.

Figure 17. *Loxodus bransoni* Furnish. Hypotype. Lateral view, GSC 90379, (Bed 14, 16), x100.

Figures 18-22. *Oistodus elongatus* Lindström. Hypotypes. (Bed 10, 239). 18. lateral view, GSC 90380, x65. 19. lateral view, GSC 90381, x65. 20. lateral view, GSC 90382, x70. 21. lateral view, GSC 90383, x70. 22. lateral view, GSC 90384, x80.

Figures 23-26. *Oistodus lanceolatus* Pander. Hypotypes. (Bed 12, 18). 23. Cladognathodontiform element, outer lateral view, GSC 90385, x35. 24. Cordylodontiform element, outer lateral view, GSC 90386, x35. 25. Cordylodontiform element, lateral view, GSC 90387, x35. 26. Deltaform element, posterior view, GSC 90388, x70.

Figure 27. *"Oistodus" inaequalis* Pander sensu Ethington and Clark s.f.. Hypotype. Inner lateral view, GSC 90389, (Bed 12, 254), x70.

Figure 28. *Oistodus? tablepointensis* Stouge. Hypotype. Outer lateral view, GSC 90390, (Bed 14, 112), x40.

Figure 29. *"Oistodus" triangularis* Furnish. Hypotype. Outer lateral view, GSC 90391, (Bed 14, 16), x115.

Figure 30. *Oistodus*? sp. 1 s.f. Hypotype. Lateral view. GSC 90392, (Bed 12, 218), x95.

Figure 31. *Oistodus? venustus* Stauffer s.f.. Hypotype. Lateral view, GSC 90393, (Bed 12, 91), x100.

Figure 32. Oistodontiform element 1 s.f. Lateral view, figured specimen, GSC 90394, (Bed 14, 181), x70.

Figure 33. Oistodontiform element 2 s.f. Lateral view, figured speciment, GSC 90395, (Bed 12, 199), x80.

Figure 34. Oistodontiform element 3 s.f. Lateral view, figured specimen, GSC 90396, (Bed 14, 47), x45.

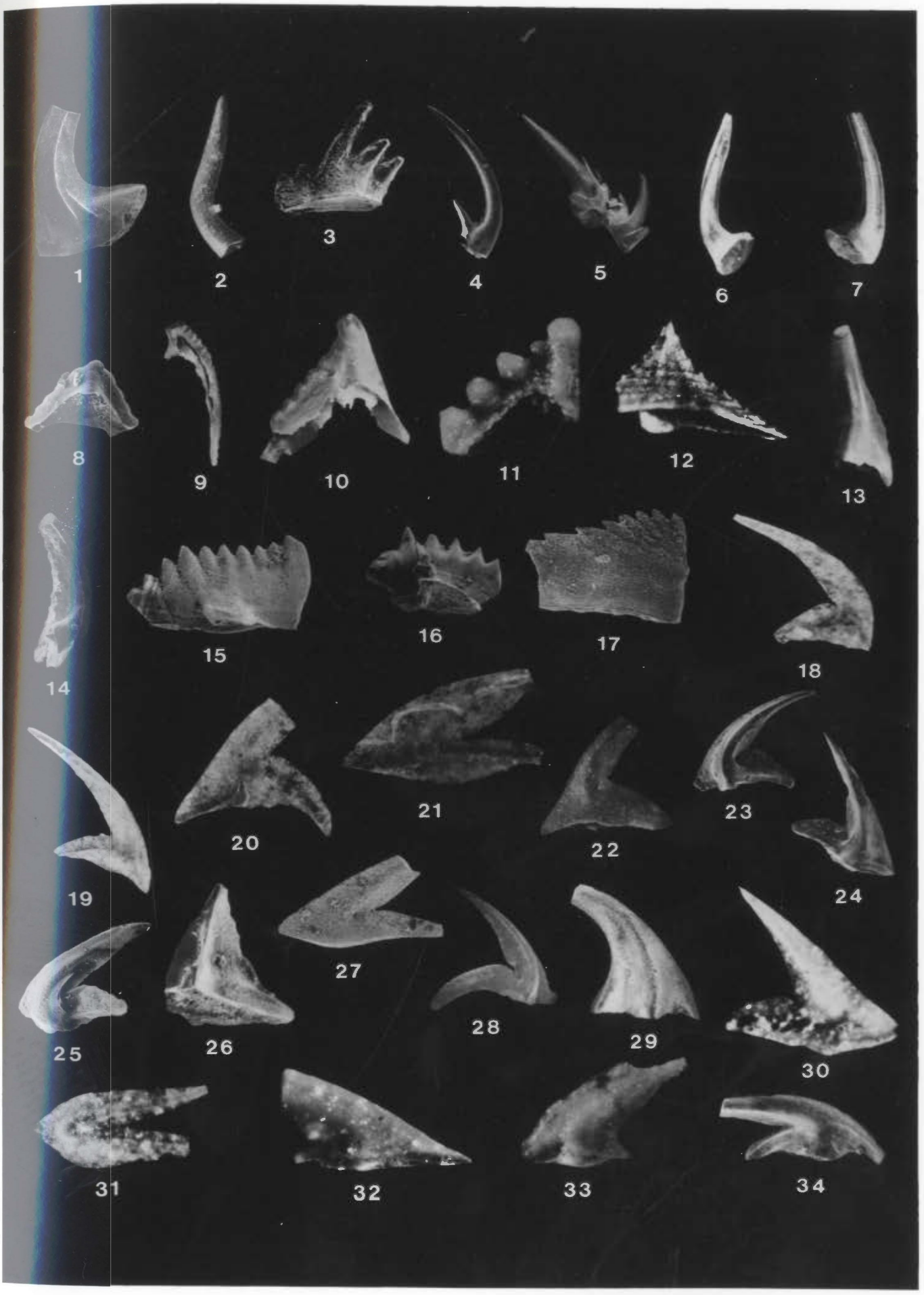

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

PLATE 5.4

Figures 2-3, 7-9, 11, 13-15, 16-17, 22-24 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figure 1. *Oneotodus costatus* Brand and Ethington. Hypotype. Lateral view, GSC 90397, (Bed 14, 54), x35.

Figure 2. *Paltodus* sp. aff. *P. jemtlandicus* Löfgren. Hypotype. Inner lateral view, GSC 90398, (Bed 14, 181), x100.

Figure 3. *Paltodus?* sp. s.f. Lateral view, figured specimen, GSC 90399, (Bed 10, 262), x100.

Figures 4-6. *Paracordylodus gracilis* Lindström. Hypotypes. (Bed 12, 275). 4. Oistodontiform element, lateral view, GSC 90400, x95. 5. Cordylodiform element, lateral view, GSC 90401, x60. 6. Paracordylodiform element, lateral view, GSC 90402, x60.

Figure 7. *Parapaltodus simplicissimus* Stouge. Hypotype. Lateral view, GSC 90403, (Bed 14, 213), x85.

Figure 8-9. *Parapaltodus* sp. s.f. Figured specimen. 8. Lateral view, GSC 90404, (Bed 10, 225), x50. 9. Lateral view, GSC 90405, (Bed 10, 225), x90.

Figure 10. *Parapanderodus arcuatus* Stouge. Hypotype. Lateral view, GSC 90406, (Bed 14, 181), x55.

Figure 11. *Parapanderodus gracilis* (Ethington and Clark). Hypotype. Lateral view, GSC 90407, (Bed 12, 184), x55.

Figure 12. *Parapanderodus* sp. 1 s.f. Lateral view, figured specimen, GSC 90408, (Bed 14, 45), x40.

Figures 13-15. *Paraprioniodus costatus* (Mound). Hypotypes. 13. Broken cordylodiform element, lateral view, GSC 90409, (Bed 14, 287), x75. 14-15. Tetraprioniodiform elements, lateral views, GSC 90410-90411, (Bed 14, 281), x75.

Figures 16-17. *Paroistodus numarcuatus* Lindström. Hypotypes. (Bed 10, 236). 16. Drepanodontiform element, lateral view, GSC 90412, x80. 17. Oistodontiform element, lateral view, GSC 90413, x80.

Figures 18-19. *Paroistodus originalis* Lindström. Hypotypes. (Bed 12, 218). 18. Oistodontiform element, lateral view, GSC 90414, x80. 19. Drepanodontiform element, lateral view, GSC 90415, x80.

Figures 20-21. *Paroistodus parallelus* Pander. Hypotypes. (Bed 10.). 20. Drepanodontiform element, lateral view, GSC 90416, x70. 21. Oistodontiform element, lateral view, GSC 90417, x70.

Figures 22-23. *Paroistodus proteus* (Lindström). Hypotypes. (Bed 12, 275). 22. Drepanodontiform element, lateral view, GSC 90418, x90. 23. Oistodontiform element, lateral view, GSC 90419, x90.

Figure 24. *Paroistodus?* sp. B Stouge s.f. Hypotype. Lateral view, GSC 90420, (Bed 12, 189), x75.

Figures 25-27. *Periodon aculeatus* Hadding. Hypotyes. Intermediate form, (Bed 14,). 25. Oistodontiform element, lateral view, GSC 81354, x70. 26. Multiramiform element, lateral view, GSC 81356, x70. 27. Ozarkodiniform element, lateral view, GSC 81355, x70.

Figures 28, 29, 33, 34. *Periodon flabellum* (Lindström). Hypotypes. (Bed 14, 25). 28. Ozarkodiniform element, early form, lateral view, GSC 90421, x75. 29 Multiramiform element, lateral view, GSC 90422, x90. 33. Ozarkodiniform element, lateral view, GSC 90423, x90. 34. Oistodontiform element, lateral view, GSC 90424, x50.

Figures 30-32. *Periodon aculeatus* Hadding. Hypotypes. Advanced form, (Bed 14, 45), x75. 30. Ozarkodiniform element, lateral view, GSC 81358. 31. Multiramiform element, lateral view, GSC 81359. 32. Oistodontiform element, lateral view, GSC 81357.

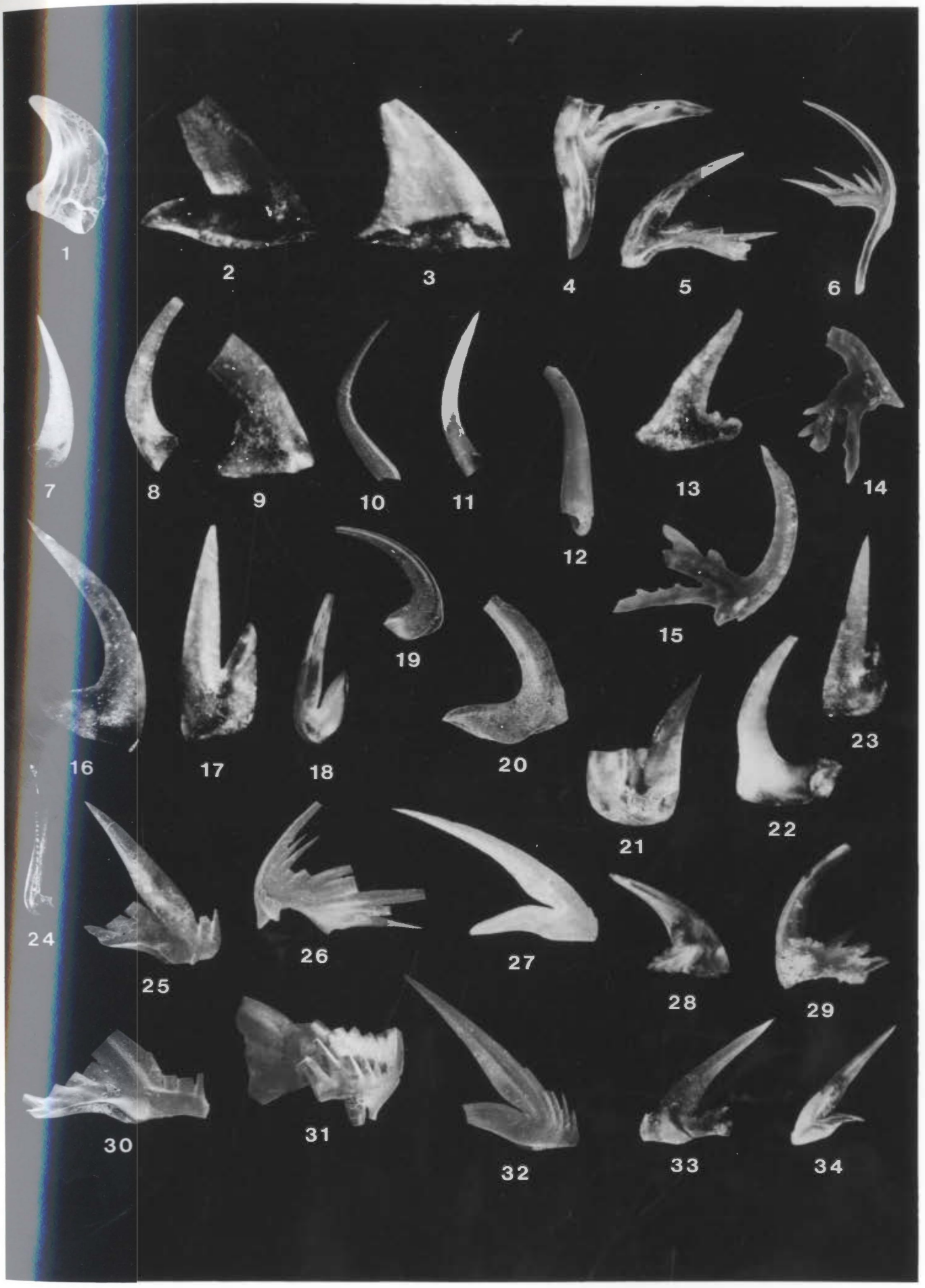

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

PLATE 5.5

Figures 24-25 and 26-30 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figures 1-3. *Periodon? selenopsis* (Serpagli). Hypotypes. (Bed 12, 275). 1. Oistodontiform element, lateral view, GSC 90425, x90. 2. Ozarkodiniform element, lateral view, GSC 90426, x100. 3. Cordylodiform element, lateral view, GSC 90427, x100.

Figures 4-6. *Prioniodus (Oepikodus) communis* (Ethington and Clark). Hypotypes. (Bed 12, 92). 4. Oepikodiform element, lateral view, GSC 90428, x100. 5. Oistodontiform element, lateral view, GSC 90429, x65. 6. Prioniodontiform element, lateral view, GSC 90430, x80.

Figures 7-9. *Prioniodus (Oepikodus) evae* Lindström. Hypotypes. (Bed 14, 18). 7. Oistodontiform element, lateral view, GSC 90431, x90. 8. Oepikodiform element, lateral view, GSC 90432, x75. 9. Prioniodontiform element, posterior view, GSC 90433, x100.

Figures 10-12. *Prioniodus (Oepikodus)* sp. aff. *P. (O.) communis* (Ethington and Clark). Figured specimens. (Bed 12, 83). 10. Oepikodiform element, lateral view, GSC 90434, x75. 11. Prioniodontiform element, lateral view, note second denticulate process, GSC 90435, x80. 12. Prioniodontiform element, lateral view, note second denticulate process, GSC 90436, x80.

Figures 13-16. *Prioniodus (Prioniodus) elegans* Pander. Hypotypes. (Bed 10, 233). 13. Oistodoniform element, lateral view, GSC 90437, x40. 14. Belodontiform element, lateral view, GSC 90438, x80. 15. Prioniodontiform element, lateral view, GSC 90439, x80. 16. Tetraprioniodontiform element, antero-lateral view, GSC 90440, x80.

Figures 17-20. *Prioniodus marginalis* n.sp. (Bed 10, 239). 17. Oistodontiform element, lateral view, Holotype, GSC 90441, x75. 18. Belodontiform element, lateral view, Paratype, GSC 90442, x75. 19. Prioniodontiform element, lateral view, Paratype, GSC 90443, x75. 20. Tetraprioniodontiform element, lateral view, Paratype, GSC 90444, x75.

Figures 21-25. *Prioniodus (Prioniodus) serratus* n.sp. (Bed 10, 202). All x90. 21. Oistodontiform element, lateral view, note incipient denticulation. Paratype, GSC 90445. 22. Belodontiform element, lateral view. Holotype, GSC 90446. 23. Prioniodontiform element, lateral view. Paratype, GSC 90447. 24-25. Tetraprioniodontiform elements, lateral views. Paratypes, GSC 90448-90449.

Figures 26-30. *Prioniodus?* sp.. Figured specimens. All x110. (Bed 12, 275). 26. Oistodontiform element, lateral view, GSC 90450. 27. Oepikodiform element, lateral view, GSC 90551. 28. Prioniodontiform element, lateral view, GSC 90452. 29. Oepikodontiform element, lateral view, GSC 90453. 30. Costate oepikodiform element, lateral view, GSC 90454.

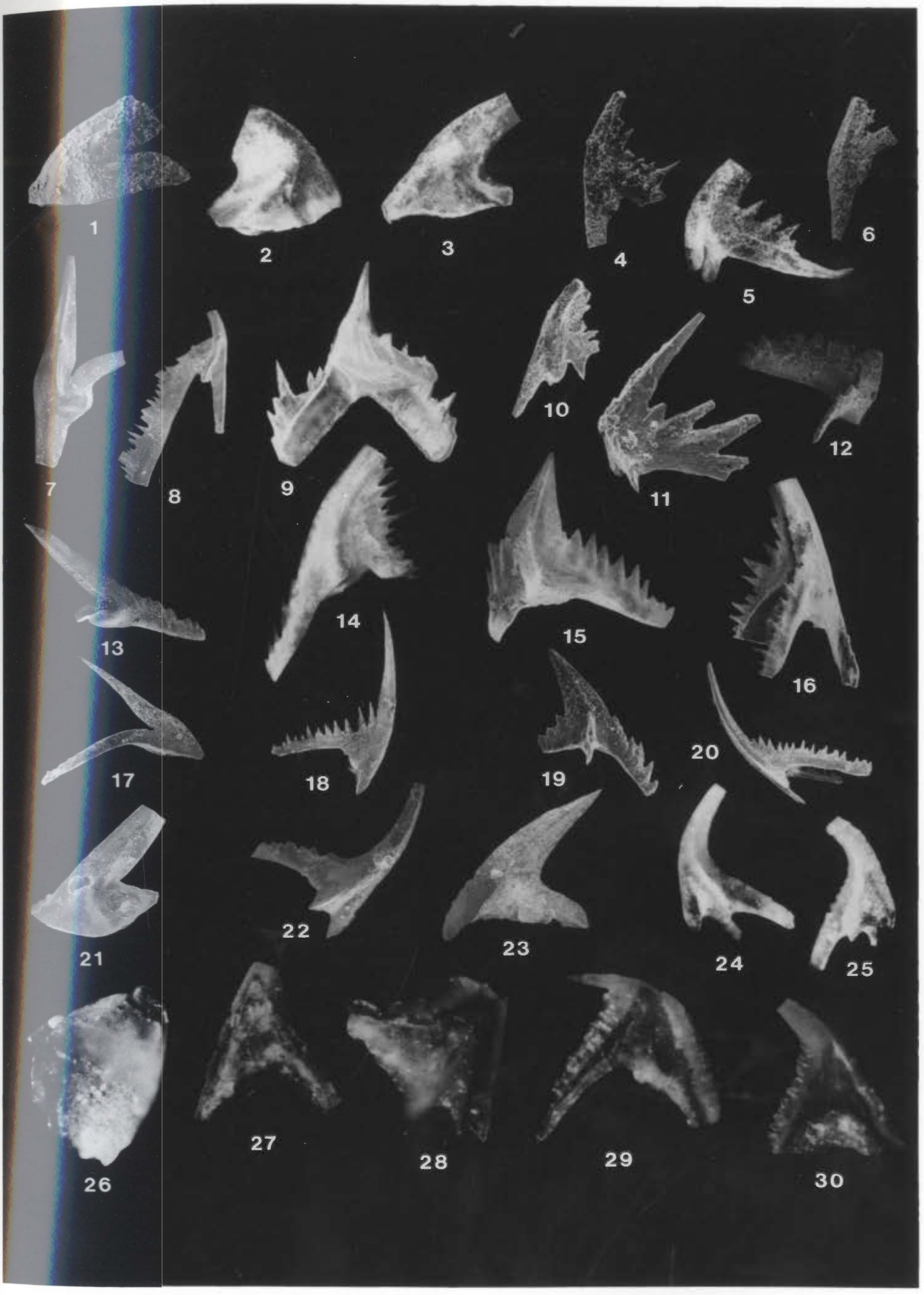

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

PLATE 5.6

Figures 5, 12,17, 30-37 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figure 1. Prioniodontiform element. Figured specimen. (Bed 14, 267). Posterior view, GSC 90455, x70.

Figure 2. *Proconodontues muelleri* Miller. Hypotype. Lateral view, GSC 90456, (Bed 12, 275), x50.

Figures 3-4. *Protopanderodus elongatus* Serpagli. Hypotypes. (Bed 14, 54). 3. Symmetrical acontiodontiform element, lateral view, GSC 90457, x85. 4. Scandodontiform element, lateral view, GSC 90458, x80.

Figure 5. *Protopanderodus gradatus* Serpagli. Hypotype. Symmetrical acontiodontiform element, lateral view, GSC 90459, (Bed 13, 261), x95.

Figures 6-8. *Protopanderodus rectus* (Lindström). Hypotypes. (Bed 12, 184). 6. Symmetrical acontiodontiform element, lateral view, GSC 90460, x35. 7. Asymmetrical acontiodontiform element, inner side. GSC 90461, x65. 8. Asymmetrical acontiodontiform element, postero-lateral view, GSC 90462, x70.

Figure 9. *Protopanderodus* sp. cf. *P. varicostatus* (Sweet and Bergström). Hypotype. Postero-lateral view, GSC 90463, (Bed 15, 144), x50.

Figures 10-12. *Protoprioniodus aranda* Cooper. Hypotypes. 10. Oistodontiform element, lateral view, GSC 90464, (Bed 12, 218), x80. 11. Ramiform element, lateral view, GSC 90465, (Bed 12, 218). 12. Costate oistodontiform element, lateral view, GSC 90466, (Bed 12, 295), x100.

Figures 13-14, 20. *Protoprioniodus papiliosus* (Van Wamel). Hypotypes. (Bed 12, 91). 13. Ramiform element, lateral view, GSC 90467, x135. 14. Deltaform

element, posterior view, GSC 90468, x150. 20. Oistodontiform element, lateral view, GSC 90469, x120.

Figures 15-16. *Protoprioniodus simplicissimus* McTavish. Hypotypes. (Bed 12, 275). 15. Oistodontiform element, lateral view, GSC 90470, x80. 16. Ramiform element, lateral view, GSC 90471, x75.

Figure 17. *Protoprioniodus* sp. 1 s.f. Figured specimen. (Bed 12, 218). Lateral view, GSC 90472, x90.

Figures 18-19, 21-23. *Pteracontiodus cryptodens* (Mound). Hypotypes. 18, 21. Distacodontiform elements, lateral views, GSC 90473-474, (Bed 12, 199; Bed 12, 246). 19. Trichonodelliform element, postero-lateral view, GSC 90475, (Bed 14, 57), x45. 22. Acodiform element, lateral view, GSC 90476, (Bed 14, 57), x45. 23. Trichonodelliform element, antero-lateral view, GSC 90477, (Bed 13, 261), x55.

Figure 24. *Ptiloncodus simplex* Harris. Hypotype. Lateral view, GSC 90478, (Bed 14, 21), x85.

Figure 25. *Rossodus manitouensis* Repetski and Ethington. Hypotype. Posterior view, GSC 90479, (Bed 14, 16), x55.

Figures 26-29. *Scalpellodus* sp. 1. Figured specimens. 26. Costate asymmetrical specimen, lateral view, GSC 90480, (Bed 14, 5), x55. 27. Asymmetrical specimen, GSC 90481, (Bed 14, 24), x60. 28. Specimen with two costae, lateral view, GSC 90482, (Bed 14, 45), x50. 29. Acostate asymmetrical specimen, lateral view, GSC 90483, (Bed 14, 111), x45.

Figures 30-31. *Scandodus furnishi* Lindström. Hypotypes. Lateral views of drepanodontiform elements. 30. GSC 90484, (Bed 14, 54), x85. 31. GSC 90485, (Bed 14, 54), x100.

Figures 32-34. *"Scandodus" mysticus* Barnes and Poplawski. Hypotypes. (Bed

14, 269)3. 32. Acostate acodiform element, lateral view, GSC 90486, x70. 33. Costate acodiform element, lateral view, GSC 90487, x70. 34. Costate acodiform element with "anticusp", lateral view, GSC 90488, x70.

Figures 35-37. *"Scandodus" pseudoramis* (Serpagli). Hypotypes. (Bed 10, 244-B). 35. Acodiform element with "anticusp", lateral view, GSC 90489, x80. 36. Ostodontiform element, lateral view, GSC 90490, x75. 37. Costate acodiform element, lateral view, GSC 90491, x75.

Figures 38-39. Scandodontiform element 1. Figured specimens. GSC, (Bed 14, 51). 38. Lateral view of acostate specimen, GSC 90492, x70. 39. Lateral view of costate specimen, GSC 90493, x80.

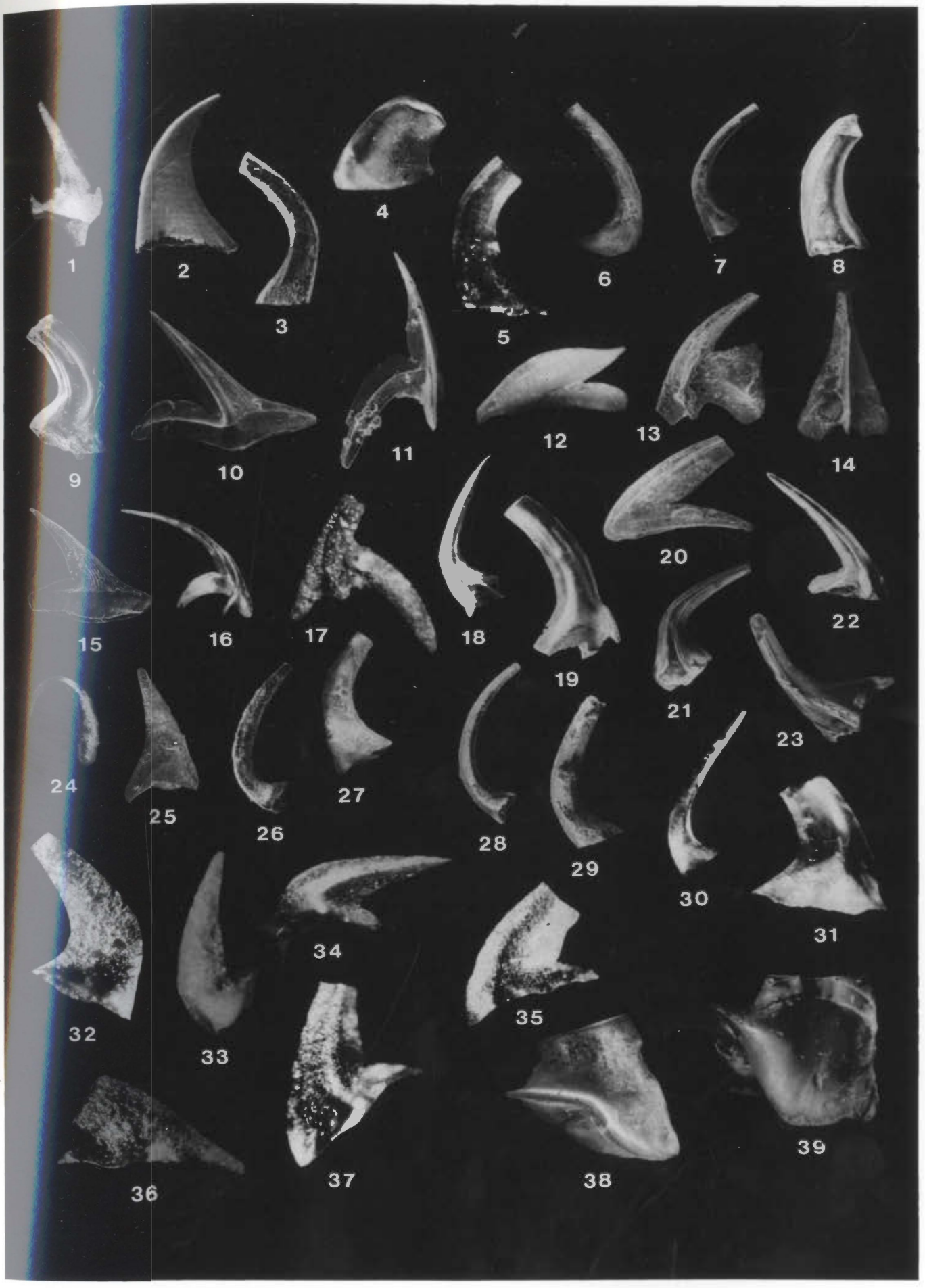

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39

PLATE 5.7

Figures 3-8, 12, 23-26, 29 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figure 1. Scandodontiform element 2 s.f. Figured specimen. Posterior view, GSC 90494, (Bed 14, 110), x15.

Figure 2. *Scolopodus emarginatus* Barnes and Tuke. Hypotype. Lateral view, GSC 90495, (Bed 14, 246), x35.

Figure 3. *Scolopodus giganteus* Sweet and Bergström s.f. Hypotype. Lateral view, GSC 90496, (Bed 14, 18), x50.

Figure 4. *Scolopodus multicostatus* Barnes and Tuke. Hypotype. Lateral view, GSC 90497, (Bed 14, 15), x50.

Figure 5. *Scolopodus oldstockensis* Stouge. Hypotype. Lateral view, GSC 90498, (Bed 14, 181), x50.

Figure 6. *Scolopodus paracornuformis* Ethington and Clark. Hypotype. Posterior view, GSC 90499, (Bed 12, 102-A).

Figure 7. *Scolopodus quadratus* Pander. Hypotype. Lateral view, GSC 90500, (Bed 12, 184), x45.

Figure 8. *Scolopodus? peselephantis* Lindström. Hypotypes. Element with bladelike cusp, lateral view, GSC 90501 (Bed 12, 91), x70.

Figure 9. *Scolopodus* sp. aff. *S. filosus* Ethington and Clark s.f. Hypotype. Lateral view, GSC 90502, (Bed 14, 54), x90.

Figure 10. *?Scolopodus* sp. Ethington and Clark. Hypotype. Postero-lateral view, GSC 90503, (Bed 10, 202), x50.

Figure 11. Scolopodontiform element, l s.f. Figured specimen. Lateral view, GSC 90504, (Bed 14, 24), x35.

Figure 12. *"Scolopodus"* sp. Figured specimen. Posterior view, GSC 90505, (Bed 12, 92), x90.

Figure 13. *Semiacontiodus asymmetricus* (Barnes and Poplawski). Hypotype. Posterior view, GSC 90506, (Bed 12, 102-A), x55.

Figures 14-16. *Serratognathus dougli* n.sp. (Bed 14, 54). All x80. 14. Paratype. Anterior view, GSC 90507. 15. Holotype. Antero-lateral view, GSC 90508. 16. Paratype. Aboral view. GSC 90509.

Figure 17. *?Trichodina wisconsinensis* Furnish. Hypotype. Posterior view. GSC 90510, (Bed 10, 135), x50.

Figures 18-19. *Variabiliconus* sp. aff. *V. bassleri* (Furnish). Hypotypes. (Bed 14, 16). 18. Symmetrical costate element, posterior view, GSC 90511, (Bed 14, 16), x45. 19. Asymmetrical costate element, lateral view, GSC 90512, (Bed 14, 16), x40.

Figure 20. *Walliserodus ethingtoni* Fahraeus. Hypotype. Lateral view, GSC 90513, (Bed 14, 21), x50.

Figure 21-22. *Walliserodus australis* Serpagli. Hypotypes. (Bed 14, 110). 21. Multicostate element, postero-lateral view, GSC 90514, x30. 22. Tricostate element, lateral view, GSC 90515, x30.

Figures 23-24. *Walliserodus* sp. aff. *W. australis* Serpagli. Hypotypes. (Bed 12, 184). 23. Multicostate element, lateral view, GSC 90516, x30. 24. Tricostate element, lateral view, GSC 90517, x30.

Figure 25. *Westergaardodina* sp. Figured specimen, GSC 90518, (Bed 14, 110), x70.

Figure 26. New Genus C new species 1 s.f. Figured specimen. Lateral view, GSC 90519, (Bed 14, 54), x90.

Figures 27-28. New Genus A new species 2 s.f. Figured specimen. (Bed 14, 181). 27. Aboral view, GSC 90520, x75. 28. Antero-lateral view, GSC 90521, x90.

Figure 29. New Genus A, new species 1 s.f. Figured specimen. Postero-lateral view, GSC 90522, (Bed 14, 112), x100.

Figure 30. New Genus B new species 1 s.f. Figured specimen. Posterior view, GSC 90523, (Bed 14, 24), x65.

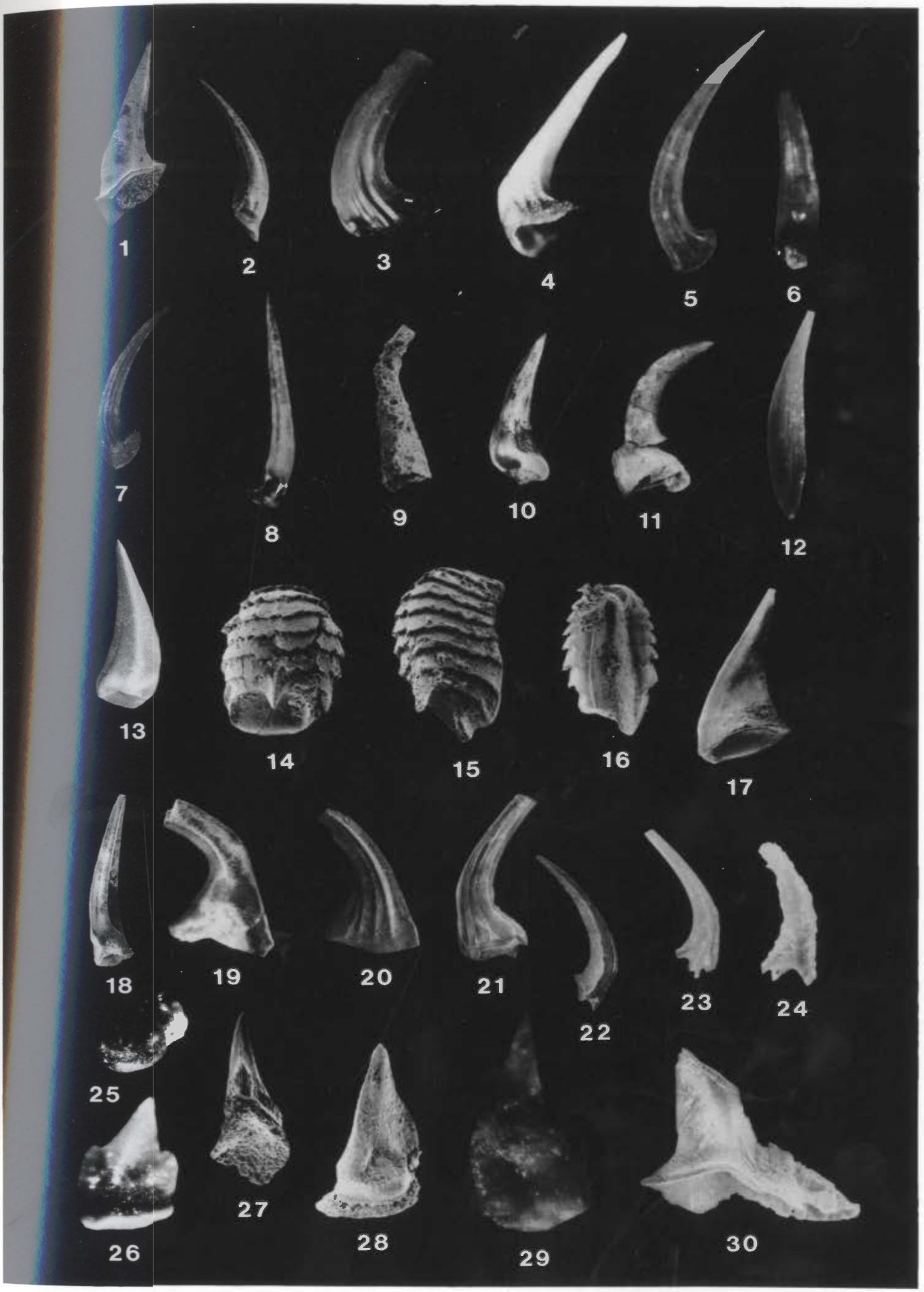

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

PLATE 5.8

Figures 4-5, 9-10, 14, 20, and 26-35 were photographed with a light microscope, the remainder with a Scanning Electron Microscope.

Figure 1. *Spinodus horridus* (Barnes and Poplawski). Hypotype. Lateral view, GSC 90524, (Bed 12, 186), x105.

Figure 2. *Spinodus spinatus* (Hadding). Hypotype. Broken specimen, lateral view, GSC 90525, (Bed 15, 144), x50.

Figure 3. *Strachanognathus parvus* Rhodes. Hypotype. Lateral view, GSC 90526, (Bed 12, 91), x80.

Figures 4-5. *Stolodus* sp. 1 Serpagli. Hypotypes. (Bed 12, 102). 4. Lateral view, GSC 90527, x70. 5. Posterior view, GSC 90528, x70.

Figure 6. *Teridontus nakamurai* (Nogami). Hypotype. Lateral view, GSC 90529, (Bed 14, 33), x60.

Figures 7-10. *Texania* sp. aff. *T. adentata* (McTavish). Hypotypes. (Bed 10, 239). 7. Ramiform element, lateral view, GSC 90530, x100. 8, 10. Ozarkodiniform elements, lateral views, GSC 90531, 90533, x110. 9. Oistodontiform element, lateral view, GSC 90532, x100.

Figures 11-15. *Texania heligma* n.sp. (Bed 12, 91). 11. Ramiform element, lateral view, paratype, GSC 90534, x100. 12. "Curled" ozarkodiniform element, inner lateral view, holotype, GSC 90535, x110. 13. Oistodontiform element, lateral view, Paratype, GSC 90536, x105. 14-15. Ozarkodiniform elements, lateral views, paratypes, GSC 90537-538, x110.

Figures 16-20. *Texania marathonensis* (Bradshaw). Hypotypes. 16. Costate ramiform element, lateral view, GSC 90539, (Bed 12, 83), x50. 17-18.

Ozarkodiniform elements, lateral views, GSC 90540-541, (Bed 10, 239), x90. 19. Oistodontiform element, lateral view, GSC 90542, (Bed 10, 239), x95. 20. Blade-like denticulate element, GSC 90543, Ninemile Formation, Zone K of Ross/Hintze, sample N.1 of C.R. Barnes, Whiterock Canyon, Nevada). x100.

Figures 21-25. *Texania* sp.. Figured specimens. (Bed 14, 175). 21. Costate ozarkodiniform element, lateral view, GSC 90544, x80. 22. Slightly costate ozarkodiniform element, lateral view, GSC 90545, x75. 23. Acostate ozarkodiniform element, lateral view, GSC 90546, x80. 24. Oistodontiform element, lateral view, GSC 90547, x65. 25. Oistodontiform element with "anticusp", lateral view, GSC 90548, x45.

Figure 26. *Tripodus laevis* Bradshaw. Hypotype. Lateral view, trichonodelliform element, GSC 90549, (Bed 14, 269), x85.

Figures 27-31. *Tripodus* sp. aff. *T. laevis* Bradshaw. Hypotypes. 27. Paltodiform element, lateral view, GSC 90550, (Bed 10, 230-1), x90. 28. Paltodiform element, anterior view, GSC 90551, (Bed 10, 230-1), x80. 29. Distacodontiform element, lateral view, note bifurcated costa, GSC 90552, (Bed 10, 230-1), x95. 30. Oistodontiform element, lateral view, GSC 90553, (Bed 10, 226), x90. 31. Drepanodontiform element, lateral view, GSC 90554, (Bed 10, 230-1), x85.

Figures 32-33. *Tripodus* sp.. Figured specimens. (Bed 12, 186). 32. Drepanodontiform element, lateral view, GSC 90555, x110. 33. Trichonodelliform element, lateral view, GSC 90556, x120.

Figures 34-35. *Tripodus subtilis* (Van Wamel). Hypotypes. 34. Trichonodelliform element, postero-lateral view, GSC 90557, (Bed 12, 275). 35. Paltodiform element, lateral view, GSC 90558, (Bed 12, 275), x90.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35

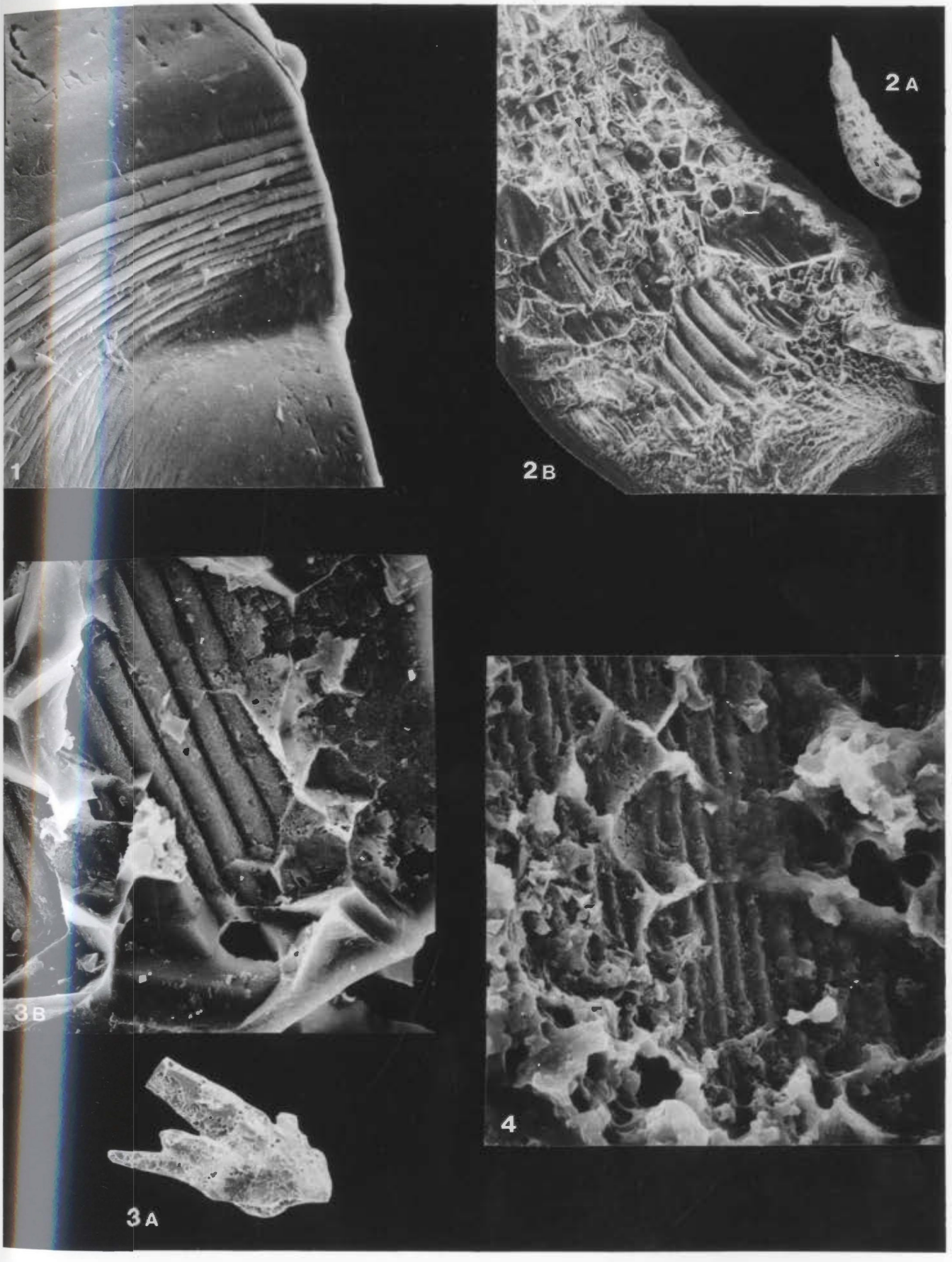
PLATE 5.9

Figure 1. Smooth surface of *Periodon aculeatus* Hadding from a local (lower slope-derived) clast. GSC 90559, (Bed 12, 208), x1000.

Figures 2A-2B. *Scolopodus carlae* Repetski s.f. Hypotype. Specimen derived from foreign (upper slope derived) clast. 2A. Posterior view with crystalline overgrowth. GSC 90560, (Bed 12, 99), x90. 2B. Close-up of basal region of same specimen illustrates original striations with crystalline overgrowth. X600.

Figures 3A-3B. *Periodon flabellum* (Lindström). Hypotype. GSC 81360, (Bed 12, 187), x80. 3A. Specimen from foreign (upper slope derived) clast with overgrowth obliterating original surface structures. 3B. Close-up of cusp of same specimen with striations partly concealed by overgrowth.

Figure 4. Overgrowth on specimen of *Rossodus manitouensis* Repetski and Ethington. Hypotype. GSC 90479, (Bed 14, 16), x3000. Conodont is from older shelf derived sample and shows somewhat different overgrowth than the others.


1
2A
2B
3B
3A
4

Chapter 6
CONGLOMERATE SEDIMENTOLOGY

6.1. Introduction

The Middle Cambrian to Middle Ordovician Cow Head Group is a 300-500m thick slope sequence that was deposited at the continental margin of the lower Paleozoic Iapetus (Harland and Gayer, 1972) or Proto-Atlantic Ocean. The slope deposits are characterized by sedimentary structures indicating deposition in an inheritently unstable environment expressed by gravity induced sediment failures (McIlreath and James, 1984; Coniglio, 1985). These include the different types of conglomerates which punctuate the bedded sequence of the CHG. (Fig. 6-1).

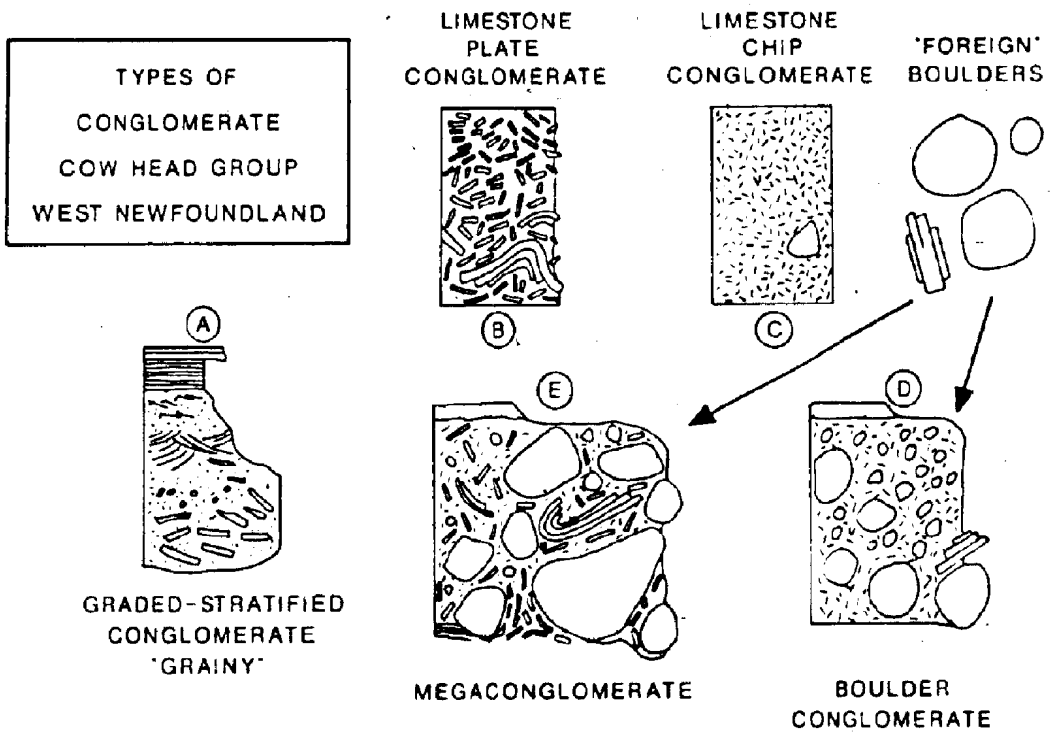


Figure 6-1: Conglomerate types in the Cow Head Group.

Several megaconglomerate horizons in the Arenig sequence are striking expressions of margin instability. They are interpreted as debris flows based on the presence of features typical for subaerial debris flows (Hiscott and James, 1985) which are thought to show characteristics similar to subaqueous flows of this type (Johnson, 1970). These characteristics include the presence of irregular tops with large boulders projecting, poor sorting and random clast fabric, matrix supported clasts and tapered flow margins (Middleton and Hampton, 1976). As mentioned earlier (Chapter 2) rocks of the CHG crop out in several facies belts. From northwest to southeast successively more distal facies belts are encountered which preserve a segment of the lower continental slope of the early Paleozoic Proto-Atlantic (James and Stevens, 1986). Proximal facies are characterized by a high proportion of coarse conglomerate horizons interbedded with limestones while distal facies have fewer and finer grained conglomerate beds and more shale. The proximal facies of the Arenig part of the slope sequence is called the Factory Cove Member (James and Stevens, 1986), while the St. Pauls Member (James and Stevens, 1986) comprises more distal equivalents (Figs. 2-6, 2-7). In this study proximal facies have been investigated at Lower Head, Cow Head and on Stearing Island and those of the distal facies at St. Pauls Inlet, Martin Point, Green Point and Western Brook Pond.

6.2. Clast character

Conglomerates and megaconglomerates of the CHG are characterized by presence of carbonate clasts of variable composition, age, morphology and origin.

(1) Composition: The majority of the clasts are limestone; minor chert, shale, siltstone, marl, dolomite, phosphatic conglomerate and sandstone are also present and these lithologies can be found in the underlying bedded sequence. No basement-derived crystalline nor volcanic clasts are present.

(2) Age: Clasts older than the bed immediately underlying a conglomerate horizon are present in all three megaconglomerates but in variable amounts. Like

penecontemporaneous clasts they come from shelf, shelf margin, upper and lower slope environments (Fig. 6-2.).

(3) Morphology: Conglomerates are poorly sorted with poorest sorting in the coarsest (proximal) facies. Clast sizes here range from boulders hundreds of meters across to pebbles less than a cm in diameter. Clasts are angular to rounded. In general foreign clasts are better rounded than local clasts Induration is also variable: thin bedded local clasts commonly show soft sediment deformation and some clasts have an exterior studded with small pebbles ("armored mudballs" of Breakey, 1974).

(4) Origin: Massive or thinly bedded, shallow water derived clasts are mixed with thin bedded or conglomeratic deepwater limestone clasts. Conodont paleontology (Chapter 4) indicates that most shallow water clasts came from a carbonate platform margin and very few from a platform interior (St. George Group). Deep water clasts are similar in composition to sediments of the underlying bedded sequence and derived from the deep upper and the lower slope. These deep water clasts are herein termed local clasts. All penecontemporaneous lithologies which cannot be assigned to this category are summarized as foreign clasts. Clast origins are summarized in Fig. 6-2.

6.3. Investigative techniques

In order to determine the lithofacies of different clasts and to reconstruct the sedimentary realm from which they came the following procedures were followed:

1. Determination of different clast lithologies in the field. This procedure included classification of the boulders and clasts and description of their lithologies with emphasis of foreign lithologies. In order to interpret lateral and vertical facies relationships mainly large boulders (30cm in diameter or length and larger) were studied in detail because it was thought they would best display the spectrum of variability within each lithofacies. Field work concentrated on

Figure 6-2: Origin of clasts found in the megaconglomerates of the Cow Head Group

FOREIGN PENECONTEMPORANEOUS LITHOLOGIES

shelf derived clasts

bedded - massive grainstone, packstone, wackestone - rounded to subangular



shelf margin derived clasts

bedded - massive grainstone, packstone, wackestone, boundstone



upper slope derived clasts

soft deformed rafts of lime mudstone

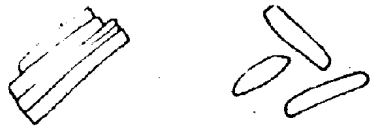


LOCAL PENECONTEMPORANEOUS LITHOLOGIES

lower slope derived clasts

a) limestone plates and rafts

calcarenite and lime mudstone



b) soft deformed rafts of parted limestone

lime mudstone



c) rounded clasts of chert dolomite and conglomerate



OLDER CLASTS

similar origin as above but older conodont and trilobite faunas.

proximal facies which yielded the highest proportion of foreign lithologies. Conglomerates on Stearing Island were somewhat neglected because of the poor preservation of rock surfaces due to weathering.

2. Determination of clast abundance. To recognize all lithologies present, $5m^2$ were chosen and demarcated in selected outcrops of each bed. All clasts larger than 10cm maximum diameter were then classified according to their lithologies and point-counted using a 10cm spaced grid, (Pl. 6.1, fig. 1). The results of the count were converted to percentages (volume percentages). Knowledge of the clast abundances solves the following problems: (1) The most abundant clasts should theoretically be the penecontemporaneous clasts which are expected to be the main contributors to the flows. It has to be taken into consideration, however, that unlithified sediments may not be preserved in form of clasts but may supply the bulk of the matrix. Thus early lithified clasts from marginal buildups and the upper slope will be over represented. (2) Determination of the percentage of the different lithologies will enable reconstruction of shelfbreak and upper slope lithofacies.

6.4. Previous work

Kindle and Whittington in 1958 first suggested that the Cow Head Group is a slope sequence with limestone conglomerates containing clasts sourced from a shallow carbonate platform. Rodgers and Neale (1963) subsequently recognized the allochthonous nature of the Cow Head Group and considered that the surrounding and structurally underlying shallow water carbonates were part of an originally adjacent carbonate platform. Later Rodgers (1968) concluded that the eastern edge of the early Paleozoic North American continent was located to the east in the White Bay area (cf. Lock, 1972) assuming a westward transport of the allochthon. Early workers interpreted the abundance and clast size of the conglomerates as tectonically controlled (Schuchert and Dunbar, 1934; Oxley, 1953) but later students suggested that presence of megaconglomerates was a depositional phenomeon linked to a carbonate platform (Kindle and Whittington,

1958; Rodgers, 1968; Stevens, 1970). Previous work dealing with the conglomerates and their clast composition is summarized in Appendix 6. Some of the statements found in early publications have been revised in later studies.

6.5. Description of conglomerate horizons

Much of the description and age of the conglomerates is based on studies of other authors. Most contributions are from the following sources: Johnston (1987); Fahraeus and Nowlan (1978); Hiscott and James (1985); James and Stevens (1986); Ross and James (1987); Williams and Stevens (in press).

The Factory Cove Member comprises the original beds 9 through 14 of the proximal slope sequence as defined by Kindle and Whittington (1958). Megaconglomerate beds 10, 12 and 14 were investigated at Lower Head, on Cow Head Peninsula and to a lesser extend on Stearing Island (Figs. 2-2, 2-3). The St. Pauls Member represents the contemporaneous distal facies. Distal conglomerates have been studied at St. Pauls Inlet, Martin Point, Green Point and Western Brook Pond (Fig. 2-4). The descriptions of conglomerate beds 10-14 are summarized in Tables 6-1 to 6-3. Abbreviations are used as follows: arg.=argillaceous, sst.=siltstone, ms.=mudstone, cc.=calcareous, gs.=grainstone, sil.=silicified, cc=calcitic, dol.=dolomitic. Unit numbers are those introduced by James and Stevens (1986).

6.6. Bed 10, proximal sections

Bed 10, the oldest of the three megaconglomerates occurs in all sections but not as the same conglomerate (James and Stevens, 1986, e.g. Fig. 55). It contains the smallest clasts and conodont data indicate that it has the lowest abundance of clasts older than the underlying bed (Bed 9). Bed 10 was defined on Cow Head Peninsula (Kindle and Whittington, 1958) where it is exposed in a single bed at the Ledge (Point of Head) but it is a series of conglomerates around Shoal Cove

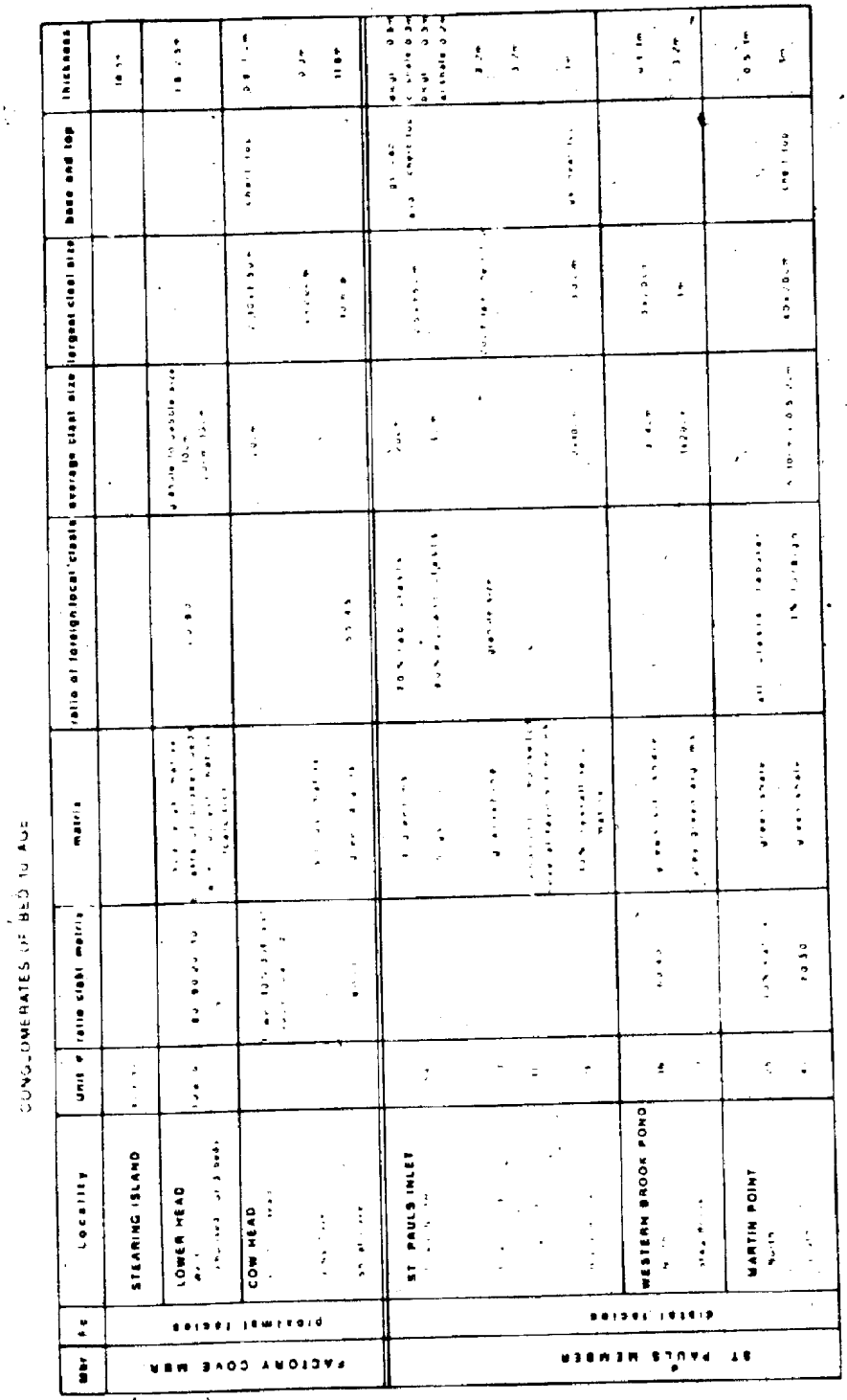


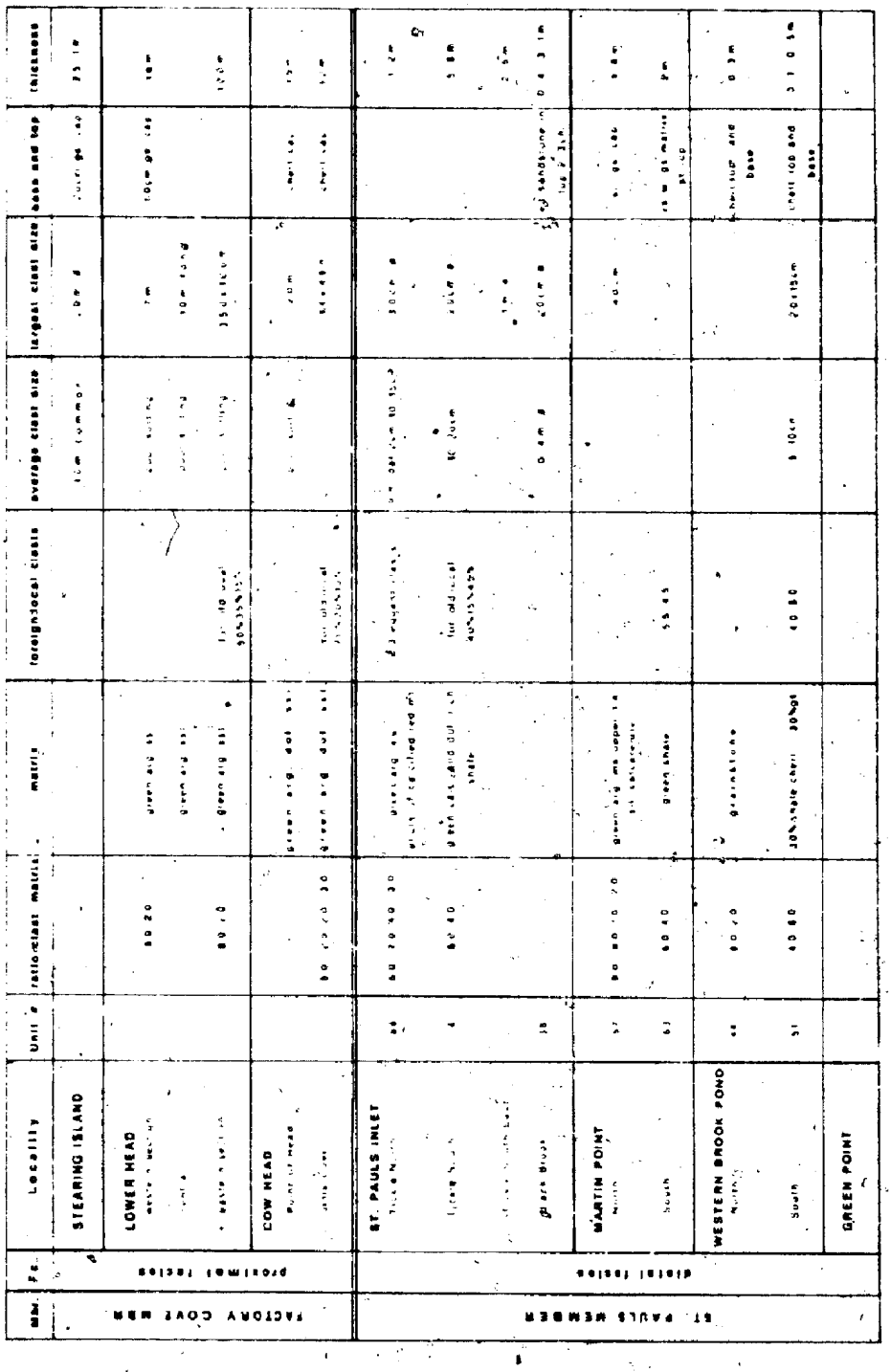
Table 6-1: Summary of conglomerate descriptions of Bed 10 and equivalents.

CONGLOMERATES OF BED 12 AGE

Map #	Locality	Unit #	ratio clast:matrix	Matrix	ratio of foreign:local clasts	average clast size	largest clast size	base and top	thickness
FACTORY COVE MEMBER									
Proximal facies	STEARING ISLAND		80 : 20						
	COW HEAD								
ST. PAULS MEMBER									
distal facies	ST. PAULS INLET								
	WESTERN BROOK POND								
	MARTIN POINT								
	GREEN POINT								

Table 6-2: Summary of conglomerate descriptions of Bed 12 and equivalents.

CONGLOMERATES OF BED 14 AGE



Mbr.	Fc.	Locality	Unit #	ratio clast matrix	matrix	foreign local clasts	average clast size	largest clast size	base and top	thickness
FACTORY COVE MBR	proximal facies	STEARING ISLAND					10cm common	[illegible]	[illegible]	25 1m
		LOWER HEAD								
		western section		80 20	green arg ss		[illegible]	7m	10cm gs cap	10m
		[illegible]			green arg ss		[illegible]	10m long		
		eastern section		80 20	green arg ss	for old local 50%35%15%	[illegible]	350x100m		100m
		COW HEAD								
		Point of Head			green arg. dol ss		[illegible]	20m	chert cap	15m
		[illegible]		80 20 20 30	green arg dol ss	for old local [illegible]		50x40m	chert cap	[illegible]
ST. PAULS MEMBER	distal facies	ST. PAULS INLET								
		Tickle North	66	80 20 40 30	green arg ss [illegible]	23 equant clasts	[illegible]	30cm		1 2m
		Tickle South	4	80 40	green cals and dol rich shale	for old local 40%15%45%	30 20cm	20cm		5 8m
		[illegible]						1m		2 5m
		Black Brook	38				0 4m	20cm	[illegible] sandstone in top 2 3cm	0 4 3 1m
		MARTIN POINT								
		North	57	80 80 10 20	green arg ms upper 1 a [illegible] calcareous			40cm	[illegible] gs cap	9 8m
		South	63	60 40	green shale	55 45			[illegible] gs matrix at top	9m
		WESTERN BROOK POND								
		North	44	80 20	grainstone				chert sup and base	0 3m
		South	51	40 80	30% shale chert 30% gs	40 80	5 10cm	20x15cm	chert top and base	3 1 0 5m
		GREEN POINT								

Table 6-3: Summary of conglomerate descriptions of Bed 14 and equivalents.

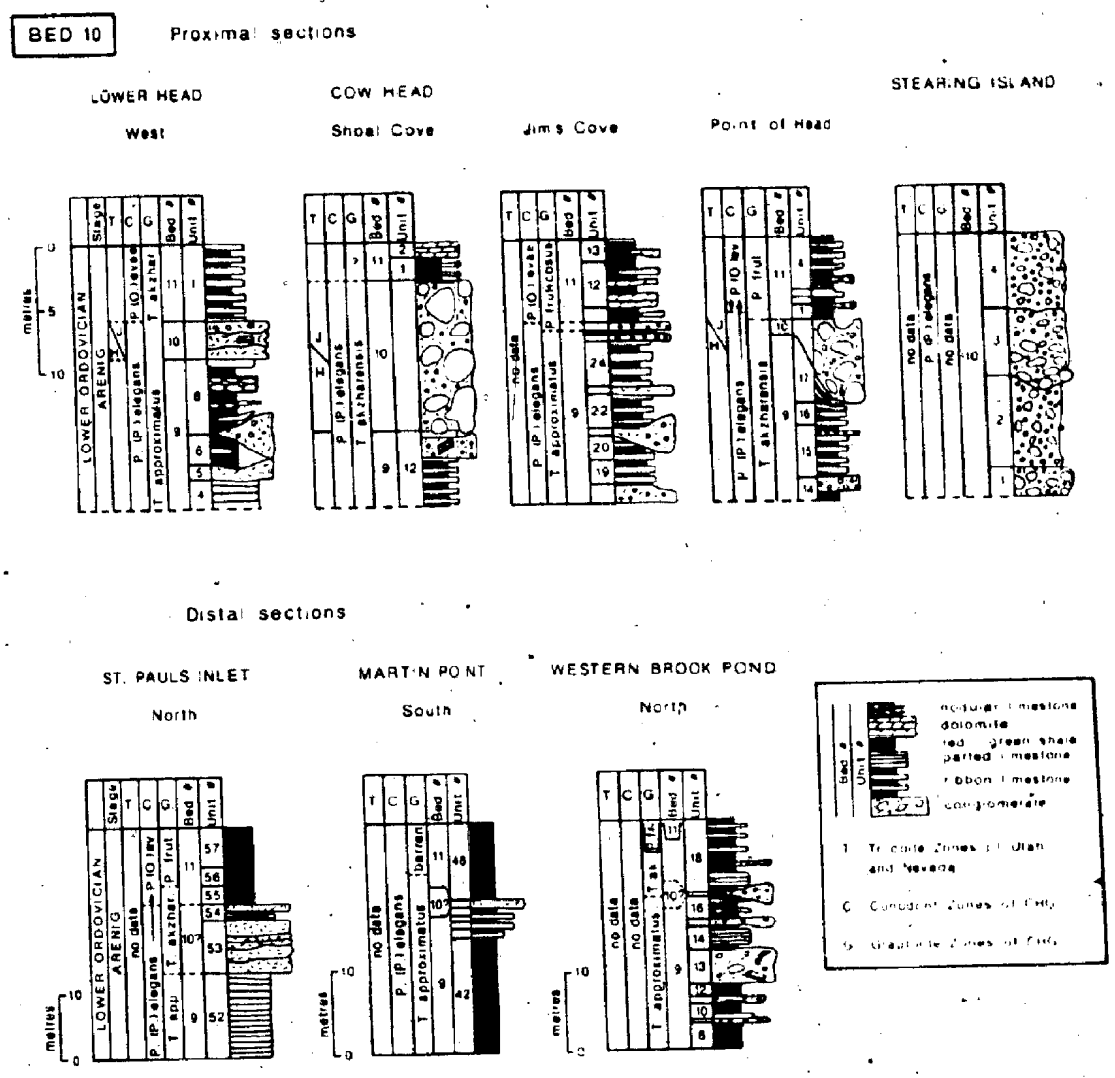


Figure 6-3: Bio- and lithostratigraphy of Bed 10 and equivalents.

(Fig. 6.3). The presence of several conglomerate horizons at this level which show lateral variation in thickness makes correlation and recognition of Bed 10 from the Ledge and the top of the Shoal Cove conglomerate difficult. On Stearing Island Bed 10 is represented by a series of welded conglomerates. At Lower Head only a thin conglomerate is present at this level suggesting that only part of the "Bed 10 complex" is present (James and Stevens, 1986). Figure 6.3. shows biostratigraphy and lithologies of bedded rocks above and below Bed 10.

6.6.1. Lower Head West

Bed 10 at Lower Head West is a, locally overturned, thin series of mostly platy conglomerates. Only the uppermost conglomerate near or at the top of Bed 9 was investigated and sampled because it shows the highest diversity (although not aoundance) of foreign lithologies.

Lithology: The uppermost conglomerate is between 1.80m and 2.50m thick with irregular slightly silicified top and relatively flat base. The horizon comprises three beds (Fig. 6-4). Layer 10a near the base is up to 50cm thick and composed of 80% plates of lime mudstone and 20% foreign lithologies. Foreign lithologies are commonly well rounded and comprise the largest clasts, which may be up to 50cm long and 20cm thick, but average 30cm in diameter. These foreign clasts are coarse calcirudite, massive burrowed wackestone and minor algal boundstone. Limestone plates are usually smaller, and average 20x10cm and are commonly bent. Other local clasts are of calcarenite and rarely dolomite. The matrix is microcrystalline calcite, possibly neomorphosed lime mud and the matrix:clast ratio varies from 10:90 to 15:85. Layer 10b is composed of tabular clasts which are commonly oriented parallel or subparallel to bedding and are uniform in composition suggesting disintegration of a bedded sequence of parted limestone. Clasts have rounded edges.

Age: An underlying shale horizon (unit 9.6 of James and Stevens, 1986) yielded *Tetragraptus approximatus* indicative of the *Tetragraptus approximatus* Zone

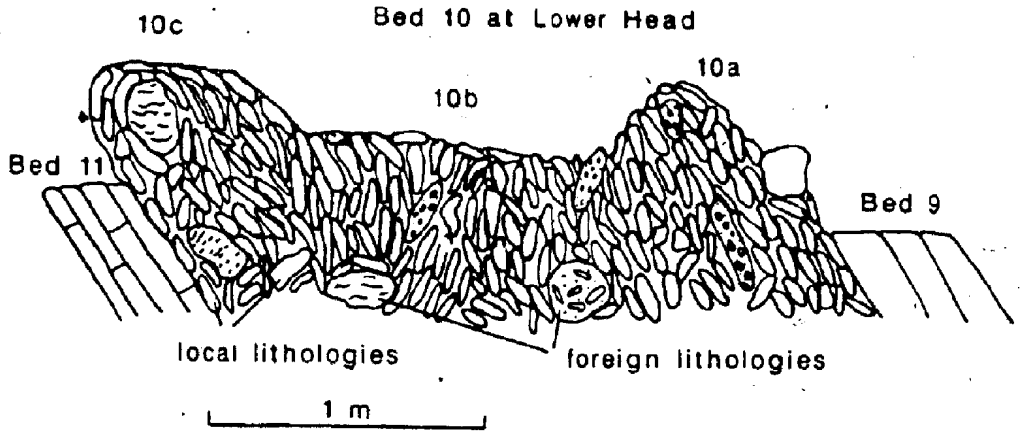


Figure 6-4: Sketch of Bed 10 at Lower Head.

Species characteristic of the *Tetragraptus akzharensis* Zone, which occurs beneath Bed 10 in most other localities have not been found (S.H. Williams, pers. comm., 1984). The ribbon limestone (unit 11.1) which overlies Bed 10 yielded species of the *Pendeograptus fruticosus* Zone typical for the lower part of Bed 11 (Fig. 6-3). No other fossil data are available from this tectonically somewhat complicated section, but the information present suggests that the conglomerate at Lower Head West is either coeval with the Bed 10 complex on Cow Head Peninsula or slightly older.

6.6.2. Cow Head Peninsula

Bed 10 is exposed at three localities on Cow Head Peninsula: at Point of Head (The Ledge), at Jims Cove and along the southern shore around Shoal Cove. The conglomerate is of variable thickness changing both along strike and from section to section.

Lithology: The unit is thickest at Shoal Cove (up to 12m) where it also contains

the largest clasts. Foreign lithologies comprise up to 60% of the clasts and reach 10m in diameter, but clasts between 2m and 4m across are most common. Rafts of local bedded lithologies of that size range are present, but rare and may be up to 7x2m in size. Large boulders are commonest in the thickest part of the conglomerate which is cut off abruptly to the west by a fault. Eastward along strike it thins to a 1m thick limestone plate conglomerate. The matrix is a greenish yellow to brown weathering argillaceous siltstone. At Jim's Cove Bed 10 thins to a 30cm thick conglomerate with silicified grainstone matrix and dominantly tabular clasts. The largest clasts here are about 30cm across.

At the Point of Head Bed 10 comprises a single unit up to 7m thick, thickest near the shore line and thinning seaward to less than 1m. Large boulders are typically located near the base of the conglomerate (Pl. 6.1, fig. 2; Fig. 6-5).

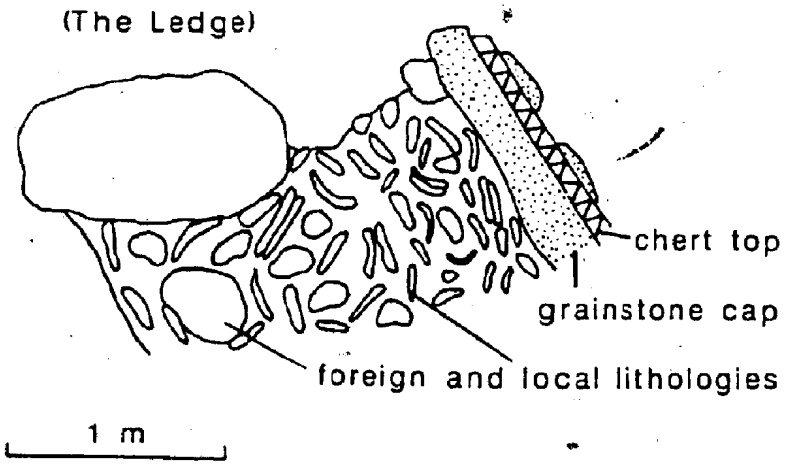


Figure 6-5: Field sketch of Bed 10 as seen at the seaward outcrop at The Ledge.

Most large clasts are of foreign lithologies, with clast sizes around 1m. The largest clast is a fossiliferous wackestone clast 2.1x1.5m, in size with abundant

calcite filled fractures. Average clast size is about 20cm. The matrix is greenish dolomite rich argillaceous siltstone with subangular to subrounded pebbles of disintegrated lime mudstone. Composition of the matrix suggests that local lithologies such as parted limestone added significant amounts of sediment to the flow. The conglomerate is capped by a grainstone up to 30cm thick. The top of this calcarenite is silicified with silicification gradually decreasing downwards (Pl. 6.1., fig. 6). The silicified top of the conglomerate is flat and protruding boulders have been leveled (Pl. 6.1., fig. 4).

Age: At Shoal Cove several small sections are present which differ in the position of the conglomerate horizon with respect to the underlying Bed 9. Bed 10 at the section described by James and Stevens (1986) is underlain by Unit 9.12 with graptolites of the *Pendeograptus fruticosus* Zone which continues into the overlying Bed 11. The *T. akzharensis* Zone is missing. Another section nearby described by Williams and Stevens (in press) shows the usual sequence with the *T. akzharensis* Zone underneath Bed 10.

At Jims Cove Bed 10 thins to a 50cm thick conglomerate underlain by ribbon limestone yielding graptolites of the *T. approximatus* Zone and overlain by parted and ribbon limestone with faunas of the *P. fruticosus* Zone.

At the Point of Head Bed 10 is underlain by the *T. akzharensis* Zone and overlain by the *P. fruticosus* Zone.

Conodonts are of the *Prioniodus elegans* Zone in beds 9 and 10 and of the *Oepikodus evae* Zone above Bed 10 (Fahraeus and Nowlan, 1978) in all sections investigated by these authors.

The trilobites found in Bed 10 are similar to those of Zone H and possibly Zone I of Nevada (James and Stevens, 1986).

6.6.3. Stearing Island

Bed 10 here is a series of welded conglomerates which cut out Bed 9 and rest unconformably on Bed 8.

Lithology: The conglomerate series ranges in thickness from 20m to 40m. In its composition it is very similar to the previously described units.

Age: Trilobites are known to the genus level from the conglomerate and a precise age cannot be assigned with confidence. Graptolites from the overlying ribbon limestone belong to the *P. fruticosus* Zone indicative of Bed 11.

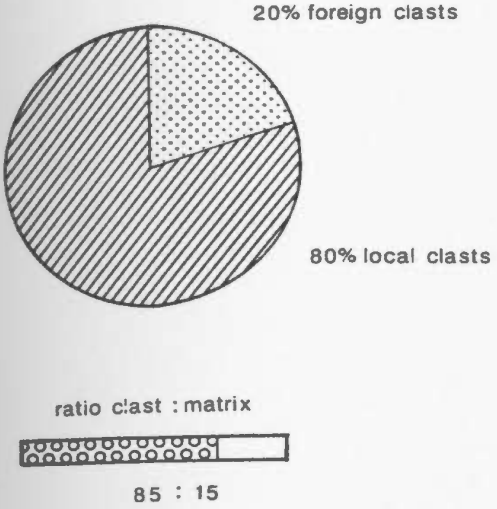
Results of conglomerate counts are summarized in Figure 6.6.

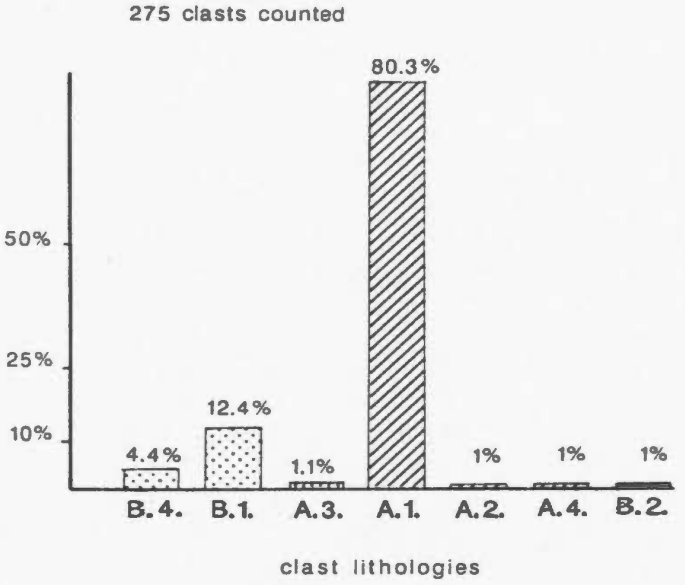
Figure 6-6: Clast counts and clast/matrix ratios in Bed 10 and equivalent conglomerates of the proximal facies.

BED 10 AGE CONGLOMERATES PROXIMAL FACIES

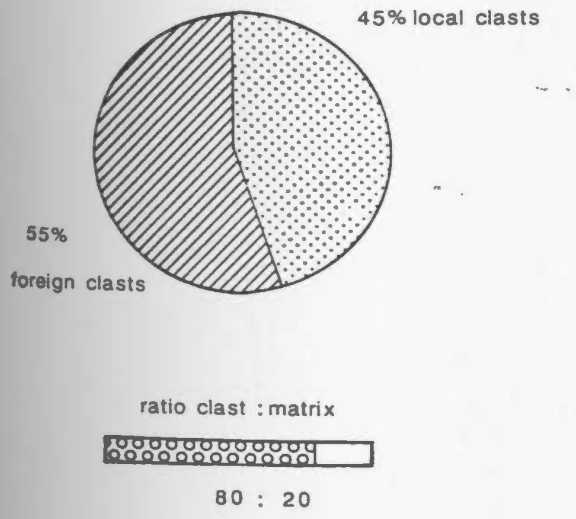
Factory Cove Member

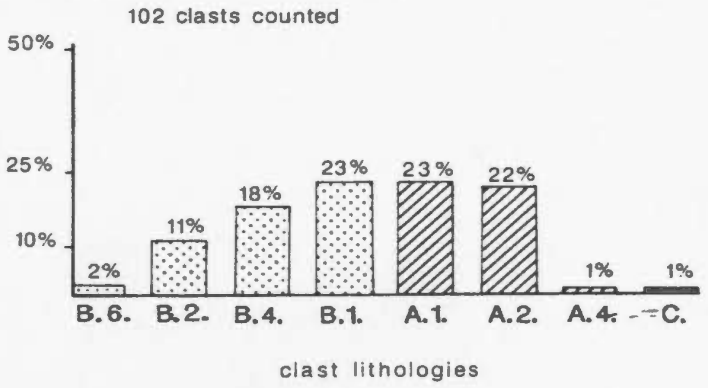
LOWER HEAD — West





COW HEAD — Shoal Cove





LEGEND

A.1. Parted and ribbon limestones
A.2. Calcarenites
A.3. Conglomerates
A.4. Dolostones
A.5. Chert
C.1. + C.2. Old foreign lithologies
C.3. Old local lithology

B.1. Massive wackestones
B.2. Algal–sponge boundstones
B.3. Bedded grainstones
B.4. Calcirudites
B.5. Lumpy wackestone
B.6. Lumpy mudstone

6.7. Bed 10, distal sections

6.7.1. St Pauls Inlet

At St. Pauls North Tickle a series of several conglomerates (units 53 and 54) (unit numbers of James and Stevens, 1986). is exposed of which only the uppermost one (unit 54) is the real Bed 10 from Cow Head Peninsula (Fig. 6-7).

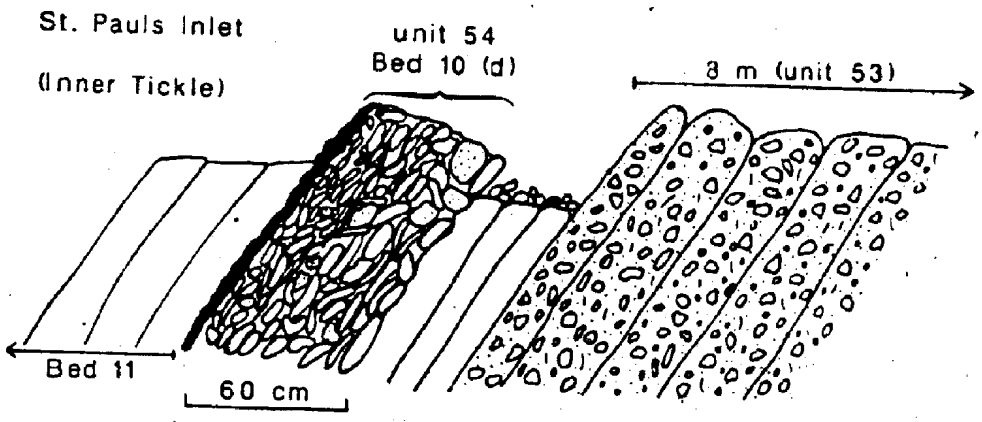


Figure 6-7: Field sketch of Bed 10 exposed in St. Pauls Inlet

Lithology: This topmost unit is 30-60cm thick with a silicified top and irregular base. Conglomerate is underlain by a 1m thick dark brown graptolite-rich wackestone followed by an older, up to 8m thick, series of chip conglomerate with granule to pebble sized clasts and a basal limestone plate conglomerate. A silicified grainstone cap is present locally. The underlying conglomerate is pervasively silicified near the top, but further down only the matrix is silicified. The matrix is green argillaceous dolomite-rich siltstone. Matrix to clast ratio

ranges from 15-20 to 85-80. The largest clasts are foreign lithologies up to 25x15cm in size, and rounded to subrounded. In the other sections around St. Pauls Inlet (Long Point, St. Pauls Inlet South) this uppermost conglomerate is missing and only the plate and chip conglomerates are present.

Age: Units 53 and 54 fall within the range of the *T. akzharensis* Zone. The conglomerate is underlain by parted limestone yielding graptolites of the *T. approximatus* Zone.

Conodonts from the conglomerate and the underlying Bed 9 are indicative of the *P. elegans* Zone. The zonal fossil persists into the strata overlying the conglomerate (Johnston, 1987). No other fossils have been collected from the interval.

6.7.2. Martin Point-South

This horizon outcrops on the shoreward cliff section north of the old garbage dump and reoccurs in the sea where it is only accessible at low tide (Fig. 6-8).

Lithology: The conglomerate is 0.5-1m thick and under- and overlain by red and green shale. North of the garbage dump an 1.80 x 0.5m large outcrop shows the matrix to be green shale with the ratio of matrix:clasts about 60:40. Average clast size is 5-10cm in length and 0.5-2cm in thickness. The largest clast is 40 x 20cm. All components appear to be derived from local sources, no foreign lithologies have been observed, suggesting that conglomerate horizon is not equivalent to Bed 10 at Cow Head but instead either a local event or one of the limestone plate conglomerates of the Bed 10 complex present for example at St Pauls Inlet.

Age: Bed 10 here falls within the range of the *T. approximatus* Zone. The overlying red shale is barren of graptolites and the exact stratigraphic position of the conglomerate horizon is thus difficult to evaluate. Conodonts from the conglomerate and the under- and overlying shales belong to the *P. elegans* Zone. These faunal data suggest that the clastic unit (unit 47 of James and Stevens,

1986) is not Bed 10 sensu strictu but one of the units below which are part of the Bed 10-complex.

6.7.3. Western Brook Pond

At Western Brook Pond North a 10-15cm thick conglomerate (Unit number 17, figs. 6-3, 6-8) contains predominantly lithologies derived from local sources and is probably not equivalent to Bed 10 sensu strictu at Cow Head like the Martin Point unit and others at St. Pauls Inlet.

Lithology: The conglomerate contains clasts of flat mudstone pebbles, averaging 3-4cm with the largest reaching 7cm. The matrix is grainstone at the bottom grading into siliceous grainstone and finally siliceous shale at top. The ratio clast:matrix ranges between 60-65:40-35. Most clasts are light brown pebbles of mudstone. A few foreign lithologies are represented by light brown packstone to wackestone and grainstone clasts with silicified cements. Fig. 6.8 shows the results of the clast counts in the various conglomerates and clast:matrix ratios.

Age: Shales underlying the conglomerate yield graptolites of the *T. approximatus* Zone; the overlying beds fall in the range of the *T. akzharensis* Zone. Trilobites from the conglomerate are suggestive of Zone H of Utah and Nevada. Conodonts from this section have not yet been studied.

6.8. Bed 12, proximal facies

6.8.1. Cow Head Peninsula

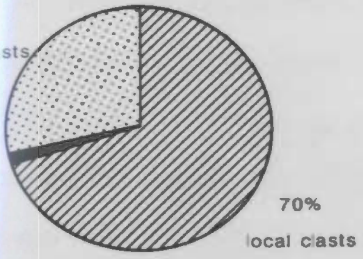
Bed 12 is exposed at Jims Cove on the south side of the peninsula and at the Point of Head.

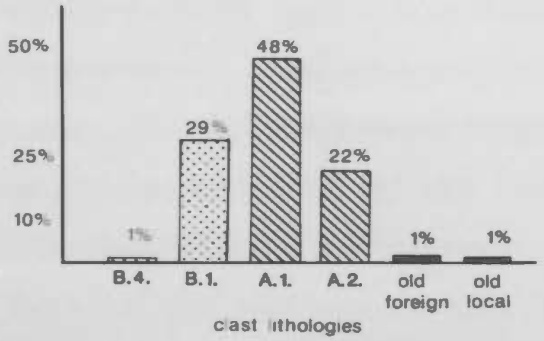
Lithology: Like Bed 10, this younger conglomerate varies in thickness from section to section; in the southern section it is between 3-5m thick; at the Point of Head it is up to 10m thick and downcuts as much as 20m into underlying beds

Figure 6-8: Clast counts and clast/matrix ratios of Bed 10 and equivalents.

BED 10-AGE CONGLOMERATES — DISTAL FACIES St. Pauls Member

ST. PAULS INLET — Tickle North





ratio clast : matrix



80 : 20



WESTERN BROOK POND — North

ratio clast : matrix

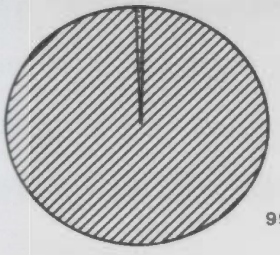


green silicified shale or chert

60 : 40

MARTIN POINT — South

1% foreign clasts



99% local clasts

ratio clast : matrix



60 : 40



(Hiscott and James, 1985). Underlying parted limestones have been injected into conglomerate contributing green dolomite rich shale and limestone plates to the matrix. As in Bed 10 much of the matrix is obviously derived from underlying beds which contribute flat tabular mudstone pebbles to the conglomerate.

Clasts are mixed local and foreign penecontemporaneous lithologies and older clasts. Most clasts are penecontemporaneous local and foreign lithologies from upper slope and shelf margin facies. Among the foreign lithologies are a few boulders derived from the shelf interior as indicated by the conodont faunas. A few older clasts are also present. The clast:matrix ratio ranges around 80:20. The largest clast is over 70x8m and is found at the northern section. The average clast size is around 2m.

At Jim's Cove about 60% of the lithologies are foreign with less than 1% being derived from the inner shelf and less than 1% older than Bed 11. Overall clast sizes in this conglomerate are smaller than at the Point of Head and it has a silicified top; clast composition is very similar to that Bed 12 further west. Clast counts are summarized in Fig. 6.9.

Age: At the Point of Head section Bed 12 is underlain by limestone and shale yielding graptolites of the *Didymograptus bifidus* Zone. At Jim's Cove underlying strata belong to the *I. v. lunatus* Zone. In both sections graptolites of the *I. v. victoriae* Zone occur above the conglomerate. Most of the trilobites from clasts in Bed 12 are correlative with zones H and I, a few are typical of Zone J. This observation is supported by the brachiopods obtained from the clasts (Ross and James, 1987). One boulder with the brachiopod *Orthidiella* sp. is suggestive of a Middle Ordovician age (James and Stevens, 1986).

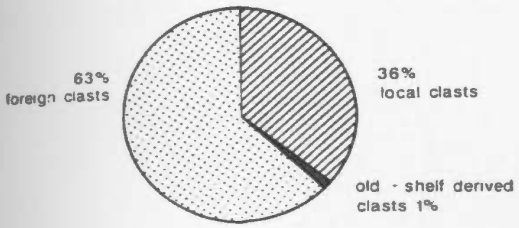
Conodonts from the upper part of Bed 11 on CHP are too scarce to evaluate their precise stratigraphic position but are probably slightly younger than the *O. evae* Zone (Fahraeus and Nowlan, 1978). The overlying Bed 13 yields a *Periodon* assemblage which cannot easily be integrated in standard conodont zonations

Figure 6-9: Clast counts and clast/matrix ratio of Bed 12-conglomerates.

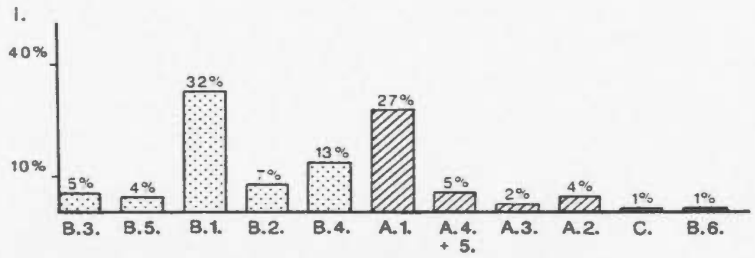
BED 12 AGE CONGLOMERATES PROXIMAL FACIES

Factory Cove Member

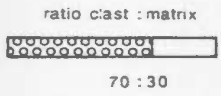
COW HEAD —— Jims Cove



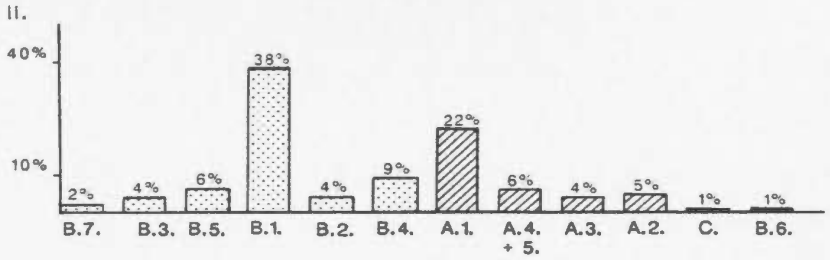
257 clasts > 10cm counted ($5m^2$ area)



Point of Head



247 clasts > 10cm counted ($5m^2$ area)



LEGEND

A.1. - 5. As before
B.1. Massive wackestones/packstones
B.2. Algal–sponge boundstones
B.3. Calcirudites
B.4. Lumpy wackestone
B.5. Bedded mudstone to wackestone
B.6. Shelf derived grainstone
B.7. Lumpy mudstone
C. Older clasts

from Scandinavia and North America. Conodonts obtained from the megaconglomerates belong to an older *Prioniodus-Periodon* Assemblage age-equivalent to the *O. evae* Zone and a younger *Periodon-Texania* Assemblage. The latter may be of Middle Ordovician (basal Whiterock) or latest early Ordovician (top Canadian) age (Fig. 6-10).

6.8.2. Lower Head

At Lower Head Bed 12 is missing; it was probably incorporated into the Bed 14 megaconglomerate as a result of deep erosion. The large number of Bed 12 aged clasts in Bed 14 supports this observation.

6.8.3. Stearing Island

Bed 12 on Stearing Island is 15-30m thick and eroded deeply into beds 11 and 10.

Lithology: It contains less than 20% matrix and most of the clasts are of foreign lithologies.

Age: Much of the underlying Bed 11 has been eroded and the few graptolites reported are from the *D. bifidus* Zone. The overlying Bed 13 belongs in the *I. v. victoriae* Zone. Trilobites and conodonts from Bed 12 clasts provide similar age assignments to those from Cow Head Peninsula (Fig. 6-10).

6.8.4. Martin Point North

The Martin Point North section is intermediate in composition between proximal and distal sections and shows characteristics of both facies.

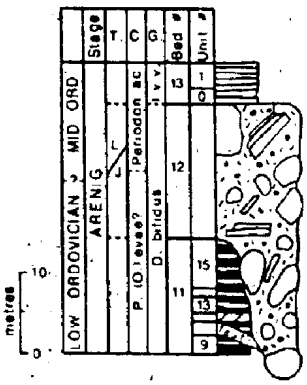
Lithology: The conglomerate horizon (Unit number 40) is up to 3m thick, and the top is covered or under water. Underlying beds are green shale. Conglomerate matrix is 30% green calcareous shale. The unit has a silicified calcarenite top which grades downward into up to 50cm thick lenses of chip conglomerate with

Figure 6-10: Bio- and lithostratigraphy of Bed 12 and equivalents.

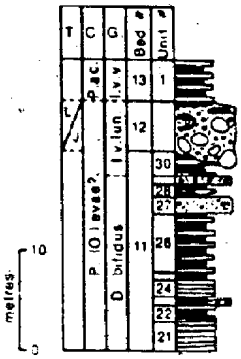
BED 12 Proximal sections

COW HEAD

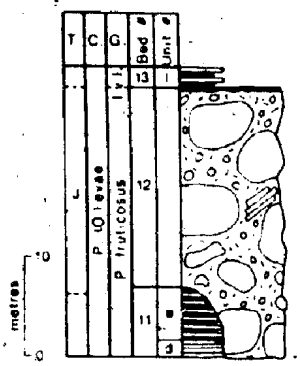
Jim's Cove



Shoal Cove



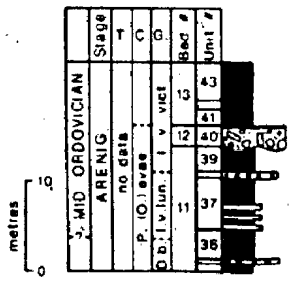
STEARING ISLAND



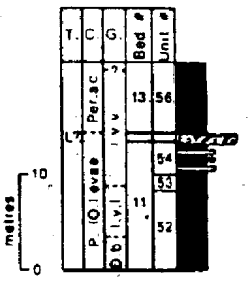
Distal sections

MARTIN POINT

North

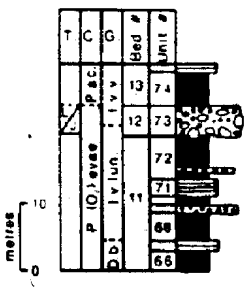


South



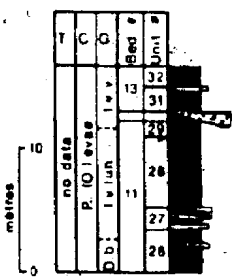
ST. PAULS INLET

North Tickle



WESTERN BROOK POND

South



calcarenite matrix. The ratio of foreign:local clasts is about 40:60 (measured near the base). The average clast size varies from bottom to top of unit. Boulders in the lower part are 20-50cm, the middle part contains mainly limestone plates up to 50cm long, averaging 20-30cm; in the upper third clasts measure 5-15cm in length; this part of the unit forms a resistant ledge over the coarser but more matrix rich lower conglomerate. Limestone plates are oriented parallel or subparallel to bedding. The largest clast is a light grey wackestone to packstone 1.50x1.0m in size. In most of the foreign lithologies pore spaces originally filled with calcite spar are now filled with silica. This replacement is typical in clasts of the distal sections and less common in those of proximal sections indicating that this type of silicification only occurred after transport of the boulders into deep water.

Age: Bed 12 at Martin Point North falls within the range of the *I. v. victoriae* Zone. Clasts in Bed 12 yielded conodonts of the *O. evae* Zone and the younger *Periodon-Texania* Assemblage (equivalent to assemblage A.4 of Johnston (1987)). Trilobites have not been obtained from the section (Fig. 6-10).

6.9. Bed 12, distal sections

6.9.1. Martin Point South

At Martin Point South a poorly exposed 1m thick conglomerate extends over 50m out into the sea. Only about 2m of the shoreward section are useful for study, the remainder is either heavily overgrown with algae or submerged (Fig. 6-11).

Lithology: The conglomerate is overlain by thick bedded parted limestone and underlain by parted to ribbon limestone with green shale partings. The conglomerate has a matrix of green shale and is capped by an up to 30cm thick grainstone which is partly silicified. The matrix:clast ratio is 30-25:70-75. Large foreign lithologies are more abundant near the bottom of the flow with the largest clast measuring 0.5m. Local clasts comprise between 50% and 55% of lithologies.

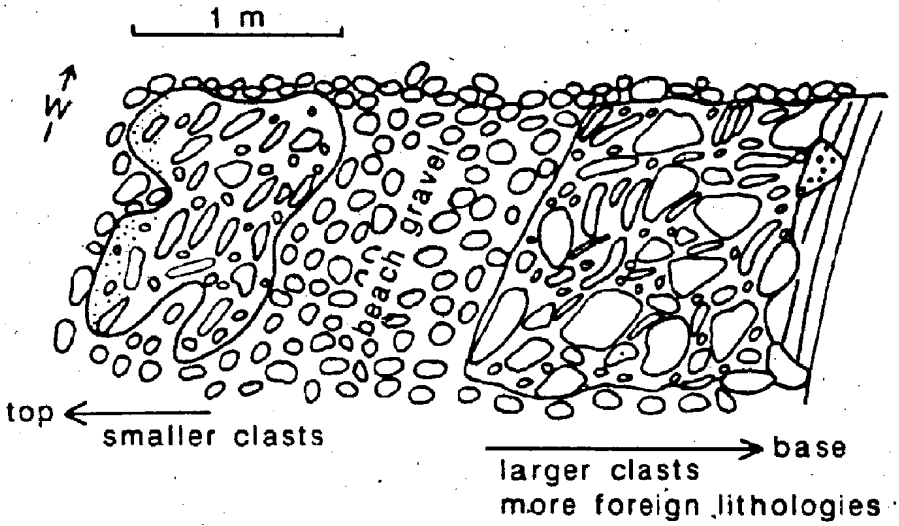


Figure 6-11: Field sketch of Bed 12 at Martin Point South

Age: As in the North section Bed 12 falls within the range of the *I. v. victoriae* Zone. Conodonts from this interval fall within the range of the *O. evae* Zone and assemblage A.4 of Johnston (1987).

6.9.2. St. Pauls Inlet

Bed 12 crops out at several localities around the Inlet (i.e. North Tickle, South Tickle, Southeast Tickle, Long Point, Black Brook).

Lithology: This conglomerate is 3-4m thick in the North Tickle section where the outcrop extends 44m. A chert cap is sporadically developed. Over- and underlying beds are green shale. The conglomerate matrix is green, dolomite-rich shale and the clast:matrix ratio is 65:35. The average clast size is 15-30cm in the lower part and about 20cm in the upper part which is dominated by limestone plates. The largest clast is a 1.50x2m raft of lumpy wackestone near the bottom of

the outcrop. A 50x5cm raft of laminated mudstone is the largest local penecontemporaneous lithology present. About 40% of clasts are foreign, while the remainder are local lithologies which are most abundant near the top of the conglomerate. A few older clasts are also present as indicated by the occurrence of a conglomeratic boulder with flat mudstone pebbles in a calcarenite matrix rich in well rounded quartz grains typical for Upper Cambrian and older Lower Ordovician rocks. Many of the foreign lithologies show silica-filled pore spaces, a few are red stained. According to Coniglio (1985) some of the green shale types were originally red and only subsequently reduced to their present green colour. This observation is confirmed by presence of red stained clasts in green shale matrix which obviously retained an earlier aquired red colour.

At the southern section (South Tickle, unit 5 of James and Stevens, 1986) the unit thins to a 10cm thick conglomerate with grainstone matrix and chert cap. The average clast size is 2x10cm. The remaining sections at Tickle Southeast, Long Point and Black Brook are very similar in composition. They all possess a green argillaceous matrix, chert cap and measure around 2m in thickness.

Age: At St. Pauls Inlet North Tickle Bed 12 is underlain by green shale with graptolites of the *I. v. lunatus* Zone and overlain by those of the *I. v. victoriae* Zone. Conodonts from beds 11 and 12 are indicative of the *O evae* Zone and Assemblage A.4 of Johnston (1987). At the base of Bed 13 species of Assemblage A.4 are also present. At St Pauls Inlet South Tickle graptolites are absent above and below the Bed 12 conglomerate.

6.9.3. Western Brook Pond

The probable correlative to Bed 12 at Cow Head is a 90cm thick conglomerate horizon which crops out at Western Brook Pond South. The unit is exposed over a distance of 5m and is over- and underlain by alternating red and green shale (Fig. 6-12). Lithology: The matrix in lower part of the bed is siliceous shale, and partly silicified calcarenite in the upper part. The clast:matrix ratio is

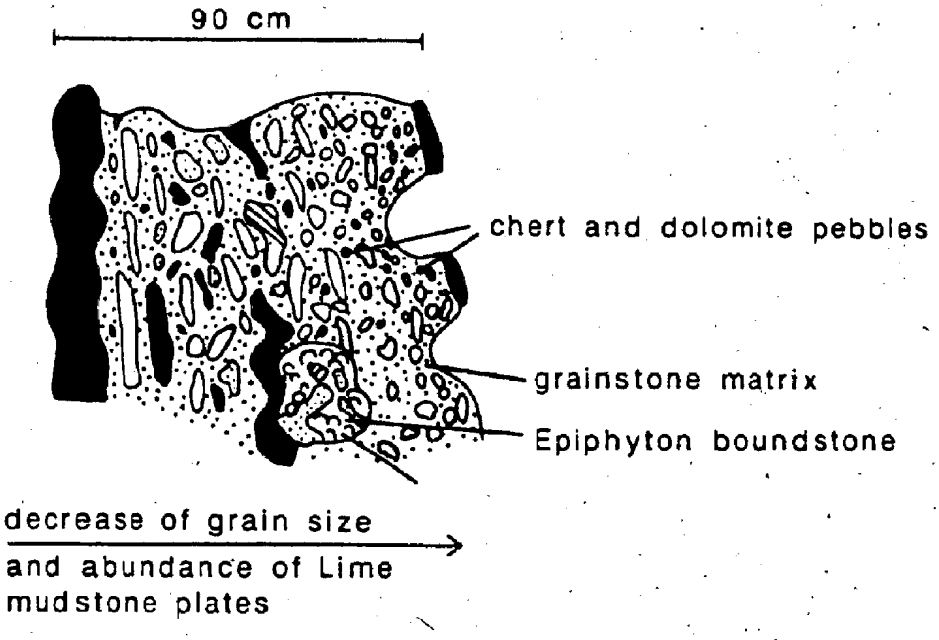


Figure 6-12: Field sketch of Bed 12 at Western Brook Pond-South

50-60:50-40. Many stylolites are developed at clast/matrix contacts suggesting that original ratio is obscured by carbonate dissolution. The average clast size is 7-8cm in the lower and 3-5cm in the upper part of the conglomerate. The largest clasts are limestone plates up to 40x6cm. Typical Bed 12 lithologies occur among foreign lithologies (e.g. grainstone, burrowed massive wackestone). No older clasts were observed. The bedded lithologies are similar in composition to those of other conglomerates of Bed 12 age with the exception of green chert fragments and clasts of red and brown shale which were obviously incorporated into the flow on lower slope.

At Western Brook Pond North Bed 12 is 2.50m thick with 10% green argillaceous matrix and has a cap of graded grainstone with a 2cm thick chert top.. About 30% of the clasts are foreign lithologies with the largest reaching

50cm in size. At Stag Brook Bed 12 conglomerate is only 2.10m thick with 20% green argillaceous matrix and a chert cap.

Age: At Western Brook Pond North and South Bed 12 falls within the range of the I. v. victoriae Zone. Conodonts of Bed 12 belong in the *P. (O.) evae* Zone and to Assemblage A.4 of Johnston (1987).

6.9.4. Green Point

Bed 12 at Green Point is about 2m thick.

Lithology: The matrix is green shale, and the clast:matrix ratio is 60-50:40-50 in the lower part of the conglomerate and 20-30:80-70 in the upper part. Clasts are dominantly limestone plates in the lower part, averaging 3-10cm in length and 1-3cm in thickness, in the upper part smaller equant clasts (1-3cm) are also present including some foreign lithologies such as red-stained silicified grainstone and light grey burrowed wackestone. Local penecontemporaneous lithologies are dominantly grey limestone plates which comprise about 70% of components. The largest clasts are fragments of green shale up to 60cm x 20cm in size. Conglomerate data are summarized in Fig. 6-13.

Age: Conodonts from the conglomerate are of similar age to Bed 12 elsewhere.

6.10. Bed 14, proximal sections

6.10.1. Lower Head

Bed 14 at Lower Head is exposed in three sections, called western, central and eastern (James and Stevens, 1986), which probably result from folding, faulting and slumping. The western and the central sections are similar in style and probably represent limbs of a faulted syncline.

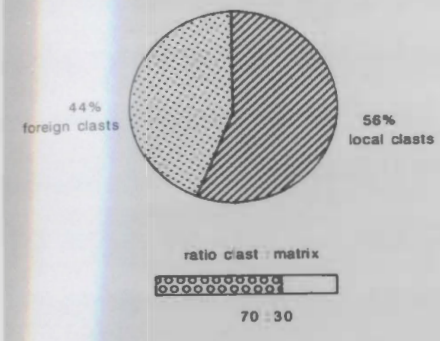
Figure 6-13: Clast counts and clast/matrix ratios of Bed 12 equivalents in the distal facies.

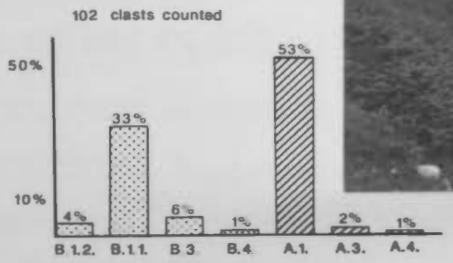
BED 12 AGE CONGLOMERATES — DISTAL FACIES

St. Pauls Member



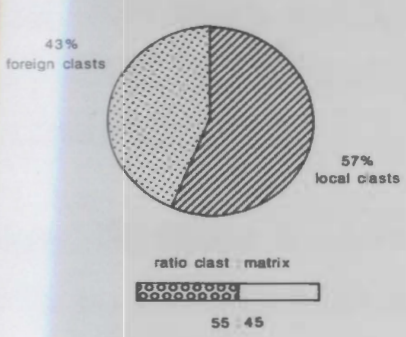
MARTIN POINT — North

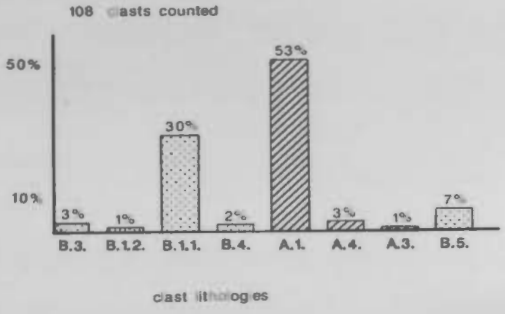




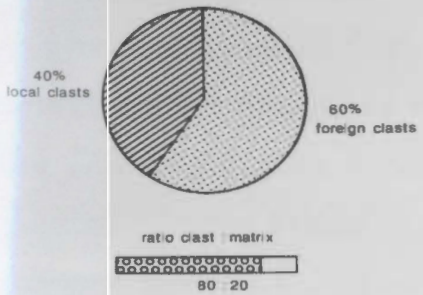


ST. PAULS INLET — Tickle North

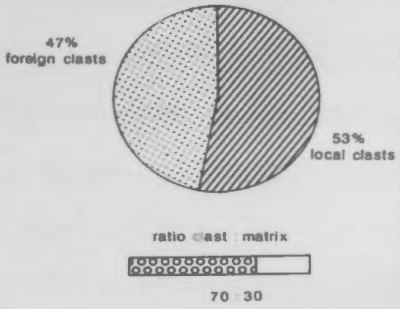




WESTERN BROOK POND — South



MARTIN POINT — South





Lithology: The western section is a 15m thick coarse conglomerate with green argillaceous matrix. The most common clast size is 1-2m^2 and clast:matrix ratio is about 80:20. The largest clast is a rounded foreign lithology of over 4m diameter. The central section is tectonically deformed and sheared but generally similar in composition. The largest clast is an algal boundstone over 10m long. Both conglomerates contain older clasts, some of which have a rind of older matrix suggesting that they were reworked from an older debris flow (Pl. 6.1, fig. 7). Boundstones with large gastropods, typical of Bed 14 shelf edge facies and shelf derived boulders equivalent to the Catoche Formation, are also present. The eastern megaconglomerate probably represents a more proximal facies than that of the western originally deposited higher on the slope. During deposition it eroded down into Bed 11 after incorporating both beds 13 and 12. Subsequently the mass of Bed 14 with its base of Bed 11 became detached and slid further downslope to rest on an even older sequence, possibly as old as Cambrian (James and Stevens, 1986). Bed 14 at Lower Head contains boulders of algal limestone more than 100m across. The enormous variety and size of the boulders goes beyond that of a normal debris flow and suggests a massive failure of a segment of the margin.

Age: At Lower Head East Bed 14 rests with erosional contact on Bed 11 which yields graptolites of the *I. v. lunatus* Zone. No younger strata are present above the conglomerate. At Lower Head West an interval barren of graptolites is present beneath the conglomerate but lithological evidence suggests correlation with Bed 11. The overlying Bed 15 belongs in the *Undulograptus austrodentatus* Zone. Limestones underlying the conglomerate at the central section contain graptolites of the *Didymograptus bifidus* Zone, indicating lower Bed 11 age. Clasts of Bed 14 yielded diverse brachiopod and trilobite faunas most of which indicate a basal Whiterock age but boulders as old as Upper Cambrian are also present (Fig. 6-14).

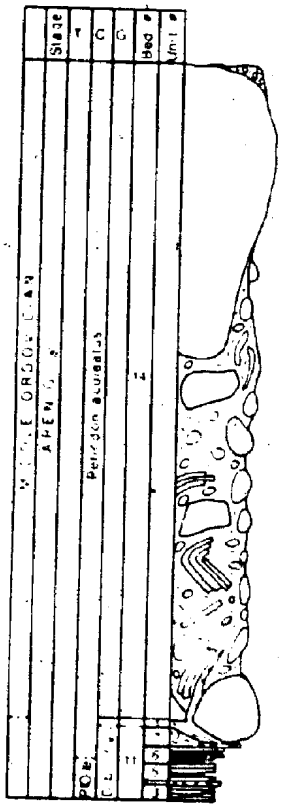
Figure 6-14: Bio- and lithostratigraphy of proximal sections of Bed 14.

BED 14

Proximal sections

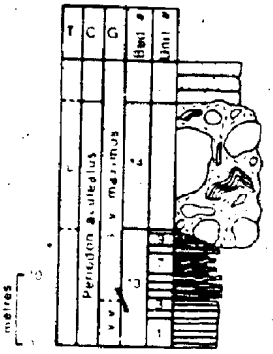
LOWER HEAD

East

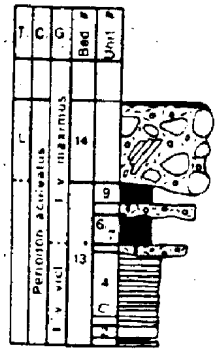


COW HEAD

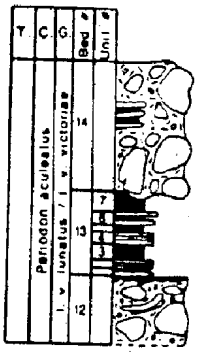
Point of Head



Jim's Cove



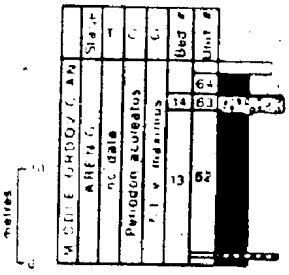
STEARING ISLAND



Distal sections

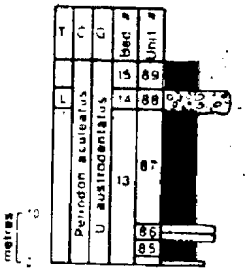
MARTIN POINT

South



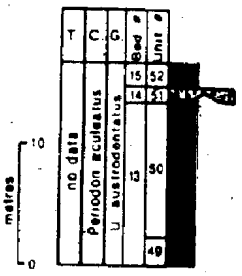
ST PAULS INLET

North



WESTERN BROOK POND

South



6.10.2. Cow Head Peninsula

Bed 14 is exposed on Cow Head Peninsula in 2 sections, east (Jim's Cove) and west (Point of Head) of Factory Cove (or Deep Cove).

Lithology: The chaotic conglomerate is 12-15m thick and has an erosive base, with over 4m of downcutting along strike. A wide variety of different clasts is present: 10% clasts and rafts of local lithologies such as parted and ribbon limestone, commonly soft-deformed; 20% older clasts; 70% foreign lithologies from the upper slope. Similar to Lower Head, clasts derived from the shelf itself are rare and dominantly older than Bed 14. The matrix is green argillaceous limestone. The clast to matrix ratio is typically 80-70:20-30 although at some locations many stylolites are developed making evaluation difficult. The results of point counts and clast composition are summarized in Figure 6-15.

Age: In both eastern and western sections, Bed 14 is underlain by Bed 13 bearing graptolites of the *Isograptus v. maximus* Zone. Clasts in Bed 14 yield trilobites and brachiopods of basal Whiterock age corresponding to zones L and lower M of Nevada. As at Lower Head some old clasts of Upper Cambrian age are also present. Conodonts from Bed 13 and 14 suggest earliest Whiterock age.

6.11. Bed 14, distal sections

6.11.1. St. Pauls Inlet

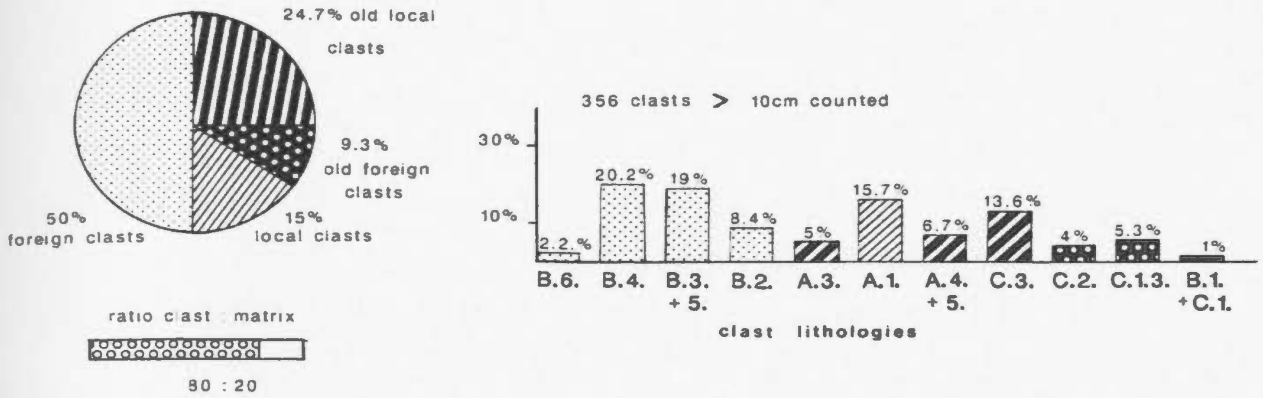
Bed 14 at St. Pauls Inlet has been studied at the North Tickle (Fig. 6-17) and South sections.

Lithology: The conglomerate in North Tickle section is about 1.20.m thick, exposed over 5m. Underlying beds are green shale, overlying sequence is covered by beach gravel. Conglomerate has green calcareous dolomite-rich mud with partly silicified top. The clast:matrix ratio is between 60-70:40-30. Largest clasts are rounded foreign lithologies up to 30x30cm. Average clast size is bimodal: 2cm

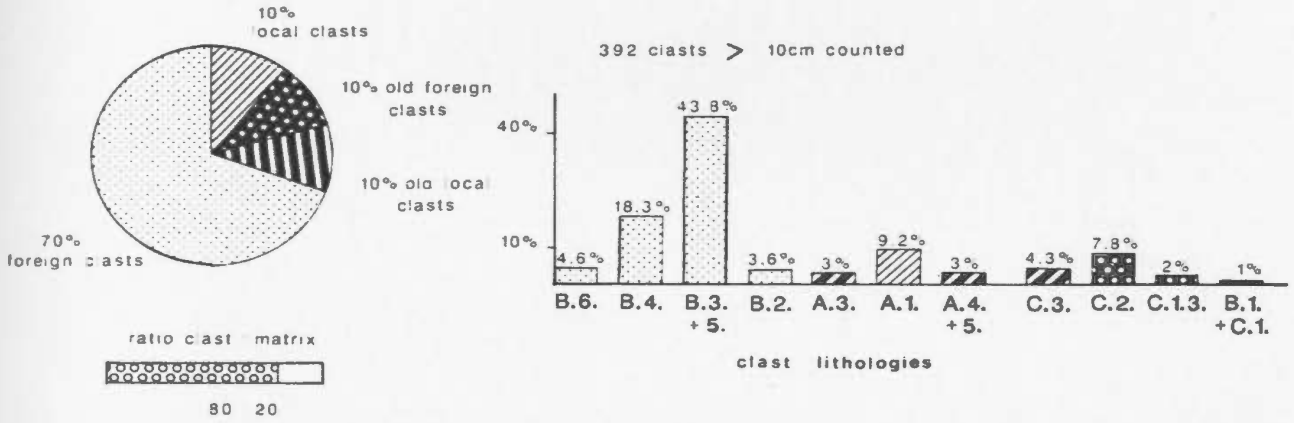
Figure 6-15: Clast counts and clast/matrix ratios of proximal sections of Bed 14.

BED 14-AGE CONGLOMERATES — PROXIMAL FACIES Factory Cove Member

LOWER HEAD — East



COW HEAD — Factory Cove



LEGEND

A.1. – A.5. As before
C.1. Shelf derived old lithologies
C.1.3. Shelf derived old lithologies with well rounded quartz grains
C.2. Old foreign lithologies
C.3. Old local lithology
B.1. Shelf derived penecontemporaneous clasts
B.2. Calcirudite
B.3. Massive wackestone to packstone
B.4. Grainstone
B.5. Boundstone
B.6. Lumpy mudstone

and 10-15cm. At St Pauls Inlet South a 5m thick conglomerate equivalent to Bed 14 is exposed over 20m and the conglomerate is overlain by Bed 15. The matrix is green, dolomite-rich calcareous shale. The average clast size is 10-20cm. Largest clasts are fragments of bedded chert intercalated with thin limestone layers up to 70x30cm and rounded clasts of foreign lithologies measure up to 50x25cm. The conglomerate reoccurs further east due to structural complication in the section and although clast composition is similar, clast sizes are smaller. All conglomerates of Bed 14 at St Pauls Inlet contain older clasts.

Age: In the North Tickle section Bed 14 falls within the range of the *U. austrodentatus* Zone. Conodonts are similar to those from the proximal sections of Bed 14. Clasts as old as earliest Ordovician have been found at the southern section.

6.11.2. Martin Point

Bed 14 at Martin Point is about 3m thick, but the base is covered along the 10m outcrop. Over- and underlying beds are red shale (Fig. 6.16).

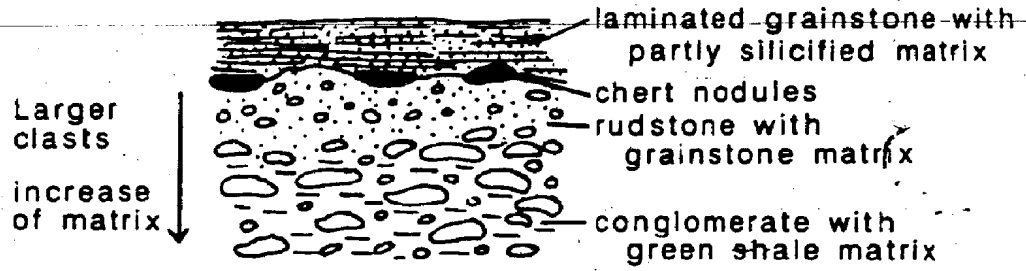


Figure 6-16: Field sketch of Bed 14 at Martin Point South

Lithology: Conglomerate matrix is green shale, grading upwards to calcarenite.

The conglomerate is overlain by laminated partly silicified grainstone. The clast:matrix ratio is about 30-40:70-60 with an average clast size of 5-15cm near the base, becoming smaller upwards. The base of the conglomerate is more matrix-supported than the upper parts. The long axis of limestone plates is oriented parallel or subparallel to bedding. Platy clasts comprise about 60% of lithologies. The largest clast is a local penecontemporaneous lithology (a green shale fragment, 50x20cm). Older clasts are foreign lithologies of Bed 12 age.

Age: Bed 14 here lies within an interval barren of graptolites underlain by red and green shale and graptolites indicative of the *I. v. maximus* Zone 20m below. Conodonts are similarly sparse in the bedded sequence but are indicative of Bed 13-age.

Western Brook Pond

A conglomerate occurs at the top of the St. Pauls Member, (Green Point Formation) at Western Brook Pond South (Unit number 51) and at Western Brook Pond North (Unit number 44) (Figs. 6-14, 6-17).

Lithology: The conglomerate is up to 50cm thick and exposed over a length of 10m in the South section. The conglomerate has a wavy base and appears to be graded with coarser clasts concentrated near base. A 1-10cm thick calcarenite cap is present at top. The conglomerate is overlain by dark brown laminated mudstone to wackestone. The matrix is grainstone which is partly silicified near bottom. Most abundant clasts are light grey, dense, lime mudstone and light brown packstone to wackestone up to 20x15cm. The most common clasts are in the range of 5-10cm.

In the northern section a 2-2.50m thick conglomerate, exposed over a length of 8m, possibly correlates to Bed 14. No typical Bed 14 lithologies have been observed but the presence of foreign lithologies suggests a source area at or near the shelf margin. The result of clast counts and clast:matrix ratios are summarized in Figure 6-17.

Age: In both, north and south section, Bed 14 falls within the range of the *U. austrodentatus* Zone. Conodonts from the conglomerate contain an advanced species of *Periodon* and the fauna may be slightly younger than that from most clasts of the proximal sections.



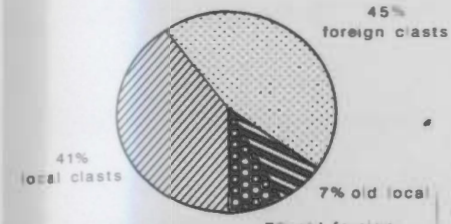
Figure 6-17: Clast counts and clast/matrix ratio in distal sections of Bed 14.

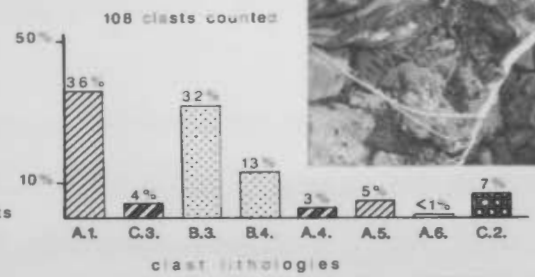
BED 14-AGE CONGLOMERATES — DISTAL FACIES

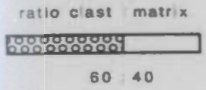
St. Pauls Member

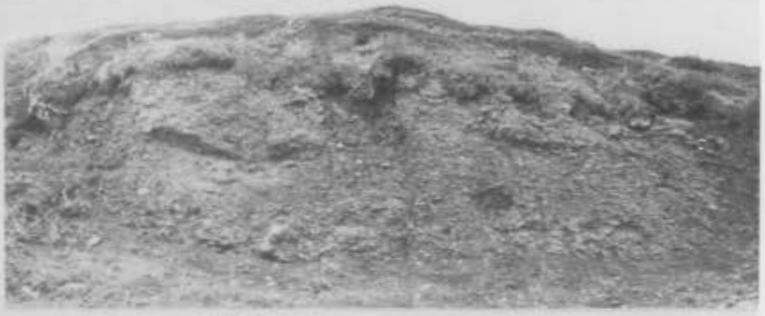


ST. PAULS INLET — Tickle South unit # 5

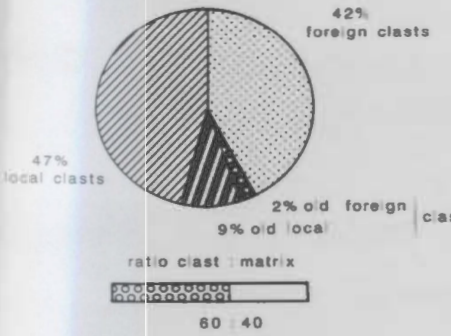


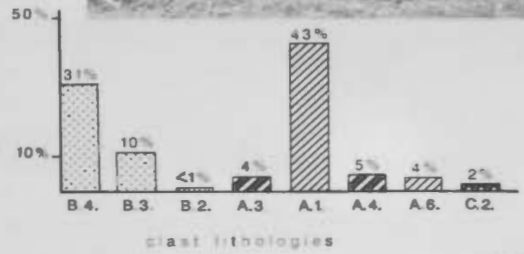




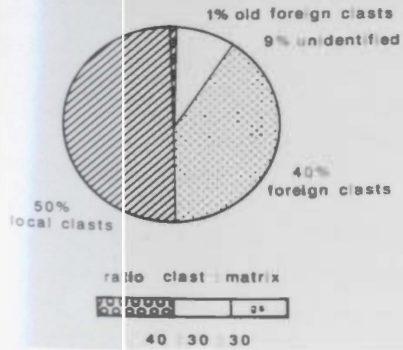


MARTIN POINT — South unit # 63





WESTERN BROOK POND — South unit # 51



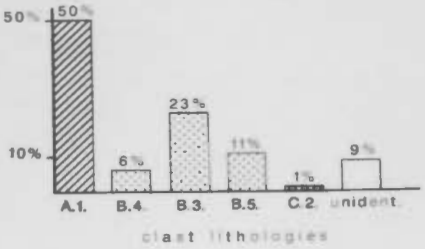




PLATE 6.1

Figure 1. Demarkated 5m square at Lower Head East for clast counts. Large boulder in right hand corner is of Cambrian age.

Figure 2. Bed 10 at the Ledge (Cow Head Peninsula) shows erosive base and variable thickness of conglomerate. Person for scale in left hand corner.

Figure 3. Soft deformed lumpy wackestone boulder at Lower Head East is shelf derived and equivalent in age to the Boat Harbour Formation below the "pebble bed". Deformation, age and atached matrix suggest reworking from an older conglomerate. Hammer for scale is 30cm long.

Figure 4. Planar silicified top of Bed 10 (left) on Cow Head Peninsula (Point of Head) with planed off boulders. Ruler is 20cm long.

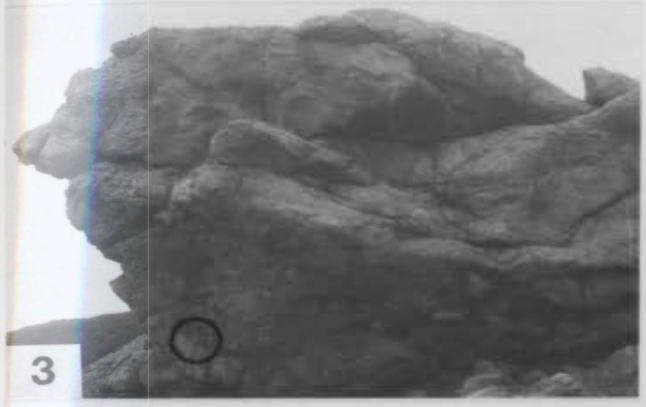
Figure 5. Brittle deformed local lithology at Lower Head East, Bed 14. Hammer for scale is 30cm long.

Figure 6. Top of Bed 10 at the Point of Head (Cow Head Peninsula) with dark chert top, grainstone cap and underlying conglomerate.

Figure 7. Rind of older matrix around Tremadoc-aged clast of *Epiphyton* boundstone, suggests reworking from older conglomerates.


1


2


3


4


5


6


7

6.12. Summary of conglomerate biostratigraphy

James and Stevens (1986) considered that conglomerate horizons of the CHG can be correlated from proximal to distal sections and that they indeed represent marker horizons. This has been questioned by S.H. Williams (pers. comm., 1986) who found, based on graptolite data, that some of the conglomerate horizons occur in slightly different stratigraphic positions within the bedded sequence in different sections (Figs. 6-3, 6-10, 6-14). The graptolite evidence is, however, not conclusive and may reflect erosion, reworking or ecological factors. To date the graptolite evidence cannot be substantiated with help of conodont data. For example the *Prioniodus evae* Zone begins in all sections at the bottom of Bed 11 but in some sections the zone fossil of the older *Prioniodus elegans* Zone is still present, in others it is missing (Johnston, 1987). The observed overlap may indicate that erosion occurred in those sections where the older *P. elegans* is missing at the bottom of Bed 11. It does, however, not represent evidence that the conglomerate beds are of different age. An exception is the Bed 10 conglomerate at Martin Point South and Western Brook Pond North which is older than the the other Bed 10 horizons (Fig. 6-3). Distal conglomerates of Bed 14 at St Pauls Inlet North and Western Brook Pond South (Fig. 6-14) are within the range of younger graptolite zones than those of the proximal sections and their age equivalence is therefore ambiguous. Equivalence of the conglomerates cannot be demonstrated based on lithological or faunal evidence because no continuous outcrop exists but the occurrence of similar clast lithologies in distal and proximal facies, particularly in Bed 14, suggests that at least some conglomerate horizons are equivalents.

6.13. Lower Ordovician conglomerate localities in the Appalachians and the Ouachita-Marathon region

Carbonate dominated conglomerates of Lower and early Middle Ordovician age

are known from localities along the length of the Appalachian Orogen and also from Paleozoic outcrops adjacent to the presumed southern continental margin of North America. Many of these are also interpreted as deposits of gravity flows derived from the continental margin of Lower/Middle Ordovician North America. Examples with references are summarized in Appendix 7. Most of the better preserved margin and slope facies are found in allochthonous sequences which were thrust onto platform rocks. Notable are from north to south: Hare Bay Allochthon (Newfoundland), nappes along the St. Lawrence River (Quebec and NW Vermont), Taconic Allochthons (New York and Vermont) and the Hamburg Klippe (Pennsylvania) (for references see Appendix 7). Autochthonous Cambrian and early Ordovician slope sequences are also preserved in the Frederick and Conestoga valleys (Maryland and Pennsylvania).

The southern margin of North America seems characterized by a longer period of stability because deep ocean floor deposits with turbidites and siliceous sediments are present through all but the youngest part of the Paleozoic sequence (Helwig, 1975). Lower to Middle Ordovician rocks interpreted as marine slope sediments crop out in the Ouachita Mountains and the Marathon region. No large carbonate clastic deposits have been reported from the Ouachitas where boulders in conglomerates are dominantly non-carbonates. Carbonate sequences in the Marathon region contain horizons with exotic bouldery debris such as the Lower Ordovician Marathon Limestone (Young, 1970) and the Middle Ordovician Wood Hollows Shale (Wilson, 1954). The latter contain blocks with trilobites dominantly of late Cambrian and early Ordovician age encased in a younger matrix. A similar phenomenon occurs in conglomerates of the Windsor Township Formation of the Hamburg Klippe which yield blocks of early Ordovician age in a Middle Ordovician shale matrix (Epstein et al., 1972; Bergström et al., 1972; Lash and Drake, 1984). Young (1970), who found a mixture of older and younger clasts in the Marathon Limestone suggested an earlier onset of orogeny as explanation, Hawley (1957), Wilson (1954) and Palmer et al. (1984) all suggested that fault scarps in the source area of the conglomerates account for the age discrepancy

between clasts and matrix. Structural complexity and poor exposure in all cases make interpretation difficult. Appendix 7 shows that conglomerates of Levis and Mystic formations in Quebec are most comparable in clast composition and size to the Cow Head deposit. The main differences are the presence of clasts of Grenvillean gneisses in the Quebec conglomerates and the generally larger clast size in CH conglomerates. Slope sequences in the Taconic Allochthon are interpreted as a more distal facies than the Cow Head deposits which explains the former's lack of coarse conglomerate horizons (E. Landing, pers. comm., 1986). Most of the other localities display conglomerates with larger amounts of non-carbonates. A proximal-distal polarity of slope deposits has also been suggested at several locations such as the Levis Formation (Landing and Benus, 1985), the Taconic Allochthon (Keith and Friedman, 1977), Conestoga Valley (Gohn, 1976) and Hamburg Klippe (Lash and Drake, 1984). Polarity is expressed in overall lithologic changes of the bedded slope sediments as well as in diminished bed thickness of conglomerate horizons and in the larger amount of matrix in more distal sections.

6.14. Comparable megaconglomerates

Mountjoy et al. (1972) pointed out the significance of megaconglomerates such as the Cow Head-megaconglomerates as indicators of shelf margins from which they originate usually as huge carbonate debris flows. Similar megaconglomerates are known from many other localities in geologic history and are related to depositional setting on slopes adjacent carbonate platform margins (Appendix 8). Most of the megaconglomerates discussed herein are derived from shelf margins dominated by organic buildups and they travelled as debris flows at least 0.5-25km downslope before they came to rest. Transport width of the CH conglomerates is not known but was probably in the range of several to tens of kilometres judging from the amount of coeval exotic facies collected on the way downslope. This variety of different clasts suggests that the flow crossed several marginal facies belts containing lithologies foreign to the depositional environment where it came to rest. Thin-bedded limestones, shales and cherts indicate a lower

slope setting as the final resting place. With the shelf break not preserved and water depth and exact slope angle indeterminable, the distance from the source area can neither be observed nor calculated.

It is not clear whether the conglomerates and megaconglomerates of the CHG were deposited as sheets or confined to channels. Most of the megaconglomerates described in the literature form sheets and/or channelized deposits, both types occuring together in the same sequence (Enos, 1977, Mountjoy and Playford, 1972, Crevello and Schlager, 1980). Irregular thickness of debris flow deposits on CH Peninsula (e.g. Bed 12 at Point of Head is between 0.7-7.2m thick) suggests that channeling occurred while in other outcrops the base of the flow is flat and conglomerate beds are parallel sided. It is thus likely that both types of structures are present possibly even grading into one another, a feature which has been observed by Surlyk (1978) and Crevello and Schlager (1980). Hill et al. (1982) who studied recent subaqueous debris flows suggest that old slump scars may develop later into channels. Stanley and Unrug (1972) who studied channel deposits point out that typically their lenticular nature can only be observed in large scale exposures (meaning tens of kilometres), which are not present in the CHG. Keith and Friedman (1977), faced with a similar problem in the Taconic sequence suggest that some conglomerates associated with turbidites (represented by grainstone caps commonly found in distal CHG conglomerates) may have been confined to channels because turbidites are typically associated with channels or canyons. Other authors use a similar circumstancial evidence (e.g. sea-level changes) to suggest deposition of the CH megaconglomerates off canyon mouths (Whittaker, 1970).

6.15. Recent equivalents

Deposits which may be recent equivalents to ancient megaconglomerates are difficult to detect because of their limited accessability. Examples with references are summarized in Appendix 9. Studies of seismic reflection profiles and drill cores from carbonate platform margins off the Bahama and Blake plateaus

indicate that large debris piles including huge carbonate slabs derived from cliff walls via rock falls (Stanley and Unrug, 1972) are present at the foot of the steep walled escarpments. Large sheet like flows have also been observed (Crevello and Schlager, 1980). Several factors are suggested to be responsible for megaconglomerate formation: Overloading (progradation, sea level changes, fracturing under sediment load), undercutting by currents, catastrophic events (earthquakes, tsunamis) and tectonic control (faulting), (Appendix 9).

6.16. Variations of CH megaconglomerate facies

6.16.1. Bed thickness

Conglomerates vary in thickness both along strike and from section to section in proximal as well as distal areas. Several reasons may account for these variations:

1. Different flows are present which are welded on Stearing Island but recognizable as several units separated by shaly interbeds at St. Pauls Inlet (Tickle North). Presence of different flows is also indicated by different stratigraphic position with respect to the graptolite zonation documented by Williams and Stevens (1987) (Figs. 6-3, 6-10, 6-14).

2. Downcutting and thickness variaton along strike, observed for example in Bed 10 on CH Peninsula (Point of Head) where the megaconglomerate is between 0.8 and 7.2m thick, indicates channeling of the flow into underlying strata. This interpretation is supported by missing graptolite zones beneath the conglomerate bed which indicates an erosional gap of 2-11m (Williams and Stevens, in press).

3. Decrease in mean bed thickness from proximal to distal sections has been observed in other localities (e.g. Marathon region, Young, 1970) and interpreted as an expression of distance from source area.

6.16.2. Ratio clast:matrix

The matrix increases by 10-20% from proximal to distal sections. A similar observation has been reported by Lash and Drake (1984) in proximal and distal slope conglomerates of the Hamburg Klippe. Matrix content, however, is obscured by stylolitization which probably explains the low matrix contents in some distal sections.

6.16.3. Matrix composition

Matrix composition is variable from outcrop to outcrop but a coarser grained silty matrix is generally present in proximal sections whereas green shale dominates in distal exposures. A grainstone or crystalline calcite matrix which may have formed through crystal aggradation of lime mud can be found locally. Composition of matrix obviously depends in most cases on character of underlying bedded sediments.

6.16.4. Ratio of foreign:local clasts

The percentage of foreign lithologies decreases relative to the percentage of local clasts which increase from proximal to distal settings (Fig. 6-18). This is consistent with the observed change of matrix composition and shows again the strong influence of the nearby facies on the debris flow composition. The foreign clasts which are generally massive limestones cannot have supplied the bulk of matrix which must have been aquired further downslope. The increase in abundance of local clasts together with the occurrence of matrix derived from distal shaly units may be due to several factors:

1. The flow originated near or at the shelf edge and involved progressively deeper water facies on its path downslope leaving coarser upslope material behind.

2. The flow originated as a slump, possibly caused by a catastrophic event such as an earthquake which led to failure of a large composite mass (over tens to hundreds of km^2) of material reaching from shelfbreak to lower slope.

3. Proximal and distal conglomerates may not be related but may represent deposits of several different debris flows which originated at different locations on the slope.

6.16.5. Average clast size and largest clast size

The average clast size as well as size of the largest clasts decreases from proximal to distal facies. Largest clasts are found in Bed 14 at Lower Head East. If the beds are related this indicates a decrease in transport ability of the flow with distance from the source area. If they represent different flows this means that closer to the shelfbreak larger clasts were mobilized as a function of slope morphology and/or sedimentology.

6.16.6. Top of conglomerate horizons

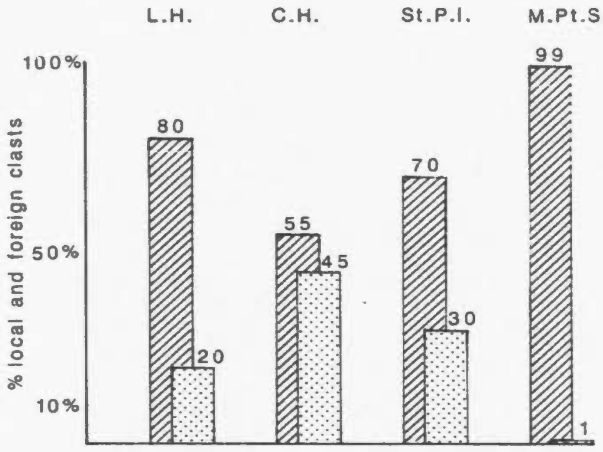
. Two features are commonly associated with conglomerate horizons: 1. a grainstone cap; 2. a chert top (Pl 6.1., fig.6).

1. Grainstone caps are interpreted as turbidites (Krause and Oldershaw, 1979) which were either generated by the debris flow or were deposited on top of it in a shortly following event. Stanley (1982) pointed out that turbidites are commonly found associated with debris flows and Hampton (1972) suggested that debris flows generate turbidity currents. Keith and Friedman (1977) suggest that the occurrence of a grainstone cap indicates a distal setting. In the Cow Head Group proximal as well as distal conglomerates locally have grainstone caps indicating that the cap is not indicative of a proximal or distal setting or that both conglomerates are sufficiently distal to be associated with turbidites. Mutti et al. (1984) recognized massive bouldery debris associated with thick turbidite sequences as seismoturbidites, the results of earthquake shocks and suggest a similar origin for the CH megaconglomerate which show an up to 1m thick grainstone top (Cow Head Peninsula, Bed 12 at Jim's Cove). The local nature of the grainstone cap may be the result of erosion.

Figure 6-18: Comparison of percentages of local, foreign and old clasts in different conglomerates.

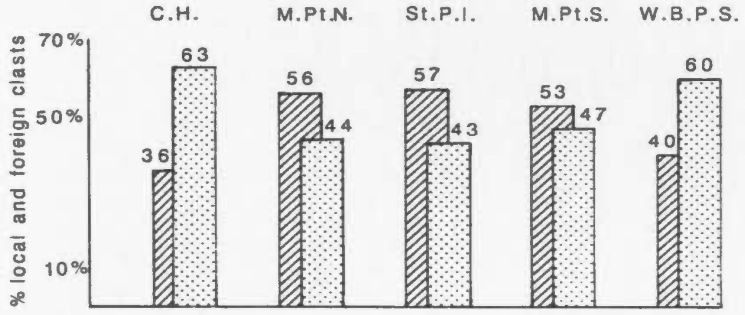
BED 10 AGE CONGLOMERATES

Clast composition of proximal and distal conglomerates



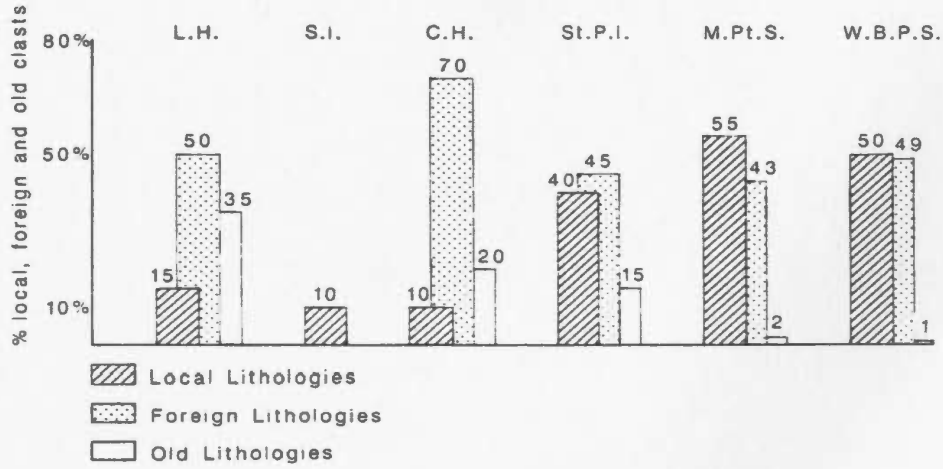
BED 12 AGE CONGLOMERATES

Clast composition of proximal and distal conglomerates



BED 14 AGE CONGLOMERATES

Clast composition of proximal and distal conglomerates



2. A chert cap is present on top of many conglomerate horizons. Chert commonly replaces grainy or laminated sediments, presumably previous limestones (Coniglio, 1985). Silicification probably occurred during times of slowed sedimentation and possibly deepening of the water. That silicification is associated with transport into deeper water is suggested by the presence of shallow water derived clasts of Bed 10 age which are silicified at the surface in Bed 10 but not in Bed 14 which is less affected by silicification. At the top of Bed 10 on CH Peninsula (Point of Head) limestone boulders which protruded from the grainstone cap were bevelled, presumably dissolved. The thin or absent chert top on these clasts suggests that dissolution occurred during or after after silicification, not before (Pl. 6.1, fig. 4).

6.16.7. Temporal variations

The character of the debris flows changes with respect to several parameters from Bed 10 through Bed 14:

1. Clast size and overall thickness of conglomerates increases from older to younger flows indicating that internal energy of debris flows increased. This may be due to changes in slope morphology (e.g. oversteepening, progradation, faulting) which may in part be a function of changes in slope sedimentation and sea level fluctuations. These will be discussed in a later chapter.

2. Clast composition changes with respect to percentages of local, foreign and particularly older lithoclasts. Bed 10 is characterized by the highest percentage of local slope derived clasts. This may have two explanations: a) the flows originated lower on the slope than the younger flows or b) lesser foreign lithologies were present at the site of the slide scar, i.e. slope sedimentation was dominated by bedded (local) lithologies.

It is also noteworthy that only few clasts in Bed 10 as well as in Bed 12 are

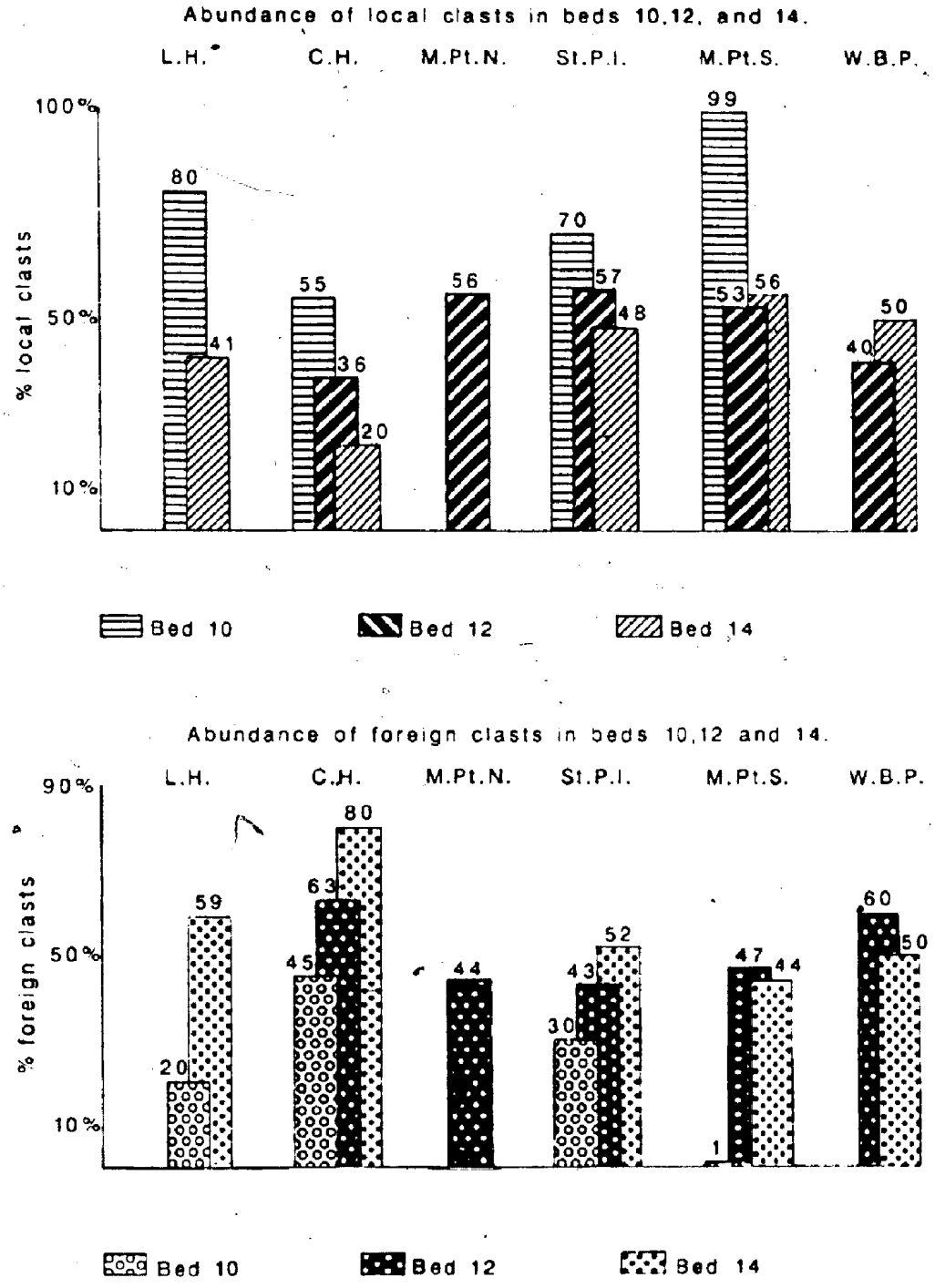


Figure 6-19: Abundances of local and foreign clasts in beds 10, 12 and 14.

derived from the inner shelf yielding conodont faunas typical of the St. George Group. The source area of clasts obviously did not tap the shallow carbonate platform or else these clasts were more abundant in most proximal conglomerate facies which may not be preserved in the CH area. The presence of mixed foreign and local clasts indicates that the debris flow was transported over a considerable distance sufficient to incorporate lower slope lithologies. The relatively low number of local clasts on Stearing Island suggests that this is indeed the most proximal facies as suggested by James and Stevens (1986) (Fig. 6-19).

Bed 14 has the highest percentage of old clasts in both proximal and distal facies. This could mean a change in the source area such as the development of a fault scarp. Faulting of the carbonate platform is recorded in the upper Aguathuna Formation (T. Lane, pers. comm.; Knight and James, in press) which is considered to be penecontemporaneous with upper Bed 13 and Bed 14. The tectonic activity may have triggered the formation of megaconglomerates. Such an interpretation has been used to explain the mixed age of clasts and matrix of conglomerates in Vermont (Hawley, 1957) and the Marathon region (Young, 1970, Wilson, 1954, Palmer et al., 1984).

Lithologies and conodonts of older clasts in the CHG show that there are three categories: 1. old local clasts, (Upper Cambrian); 2. old foreign clasts (Upper Cambrian); 3. old shelf derived clasts (Fauna C, equivalent to Boat Harbour Formation); all of which may show soft deformation or coatings of older matrix. Soft deformed clasts with a Midcontinent Fauna C (Pl. 6.1., fig. 3) cannot have been incorporated directly from the shelf or from a fault scarp. Most likely they have been reworked from older conglomerates which originally incorporated these clasts while they were still soft. This is also suggested by presence of old matrix rinds visible around some boulders (Pl. 6.1., fig. 7), the incorporation of beds 12 and 13 into Bed 14 at Lower Head and the presence of welded conglomerates on Stearing Island. The mixture of old clasts derived from very different sedimentary environments (shelf, shelf margin, upper and lower slope) cannot be accounted for by a single fault scarp but would require a staircase of several faults.

In summary, the analysis of clasts within the megaconglomerates suggests that large scale faulting of the margin may have been present but is not necessary to explain the presence of older clasts. Failure of a margin which accumulated bouldery debris already on its upper slope either in form of a peri-platform talus (Schlager and James, 1978; McIlreath and James, 1984) or in channels and canyon heads could explain the observed mixture of clasts. Stanley (1977) for example reported Jurassic limestone clasts in modern canyons in the Mediterranean. Fractured shelf margin derived clasts in Bed 14 at Lower Head may be indicative of faulting along the margin. Faulting would provide the trigger mechanism for the flows. Fracturing of the blocks, however, may also be the result of transport of semi-indurated sediments. The presence of older margin-derived clasts in distal sections as well as in proximal outcrops of Bed 14 age suggests either that distal beds are equivalents of Bed 14 or that they originated in an area which contained the debris deposited in Bed 14 and are thus slightly younger than Bed 14.

Different composition of Bed 14 at Lower Head compared to Cow Head is expressed in the relatively large amount of older (especially Cambrian) clasts at Lower Head. Together with a similar amount of local clasts this suggests that Cow Head is not a distal equivalent of Lower Head but rather a lateral equivalent which originated further along the margin. Penecontemporaneity of the flows is possible but difficult to demonstrate because debris flows are sudden events which cannot be traced merely on the time scale of fossil data without continuous outcrop.

Chapter 7
CLAST LITHOLOGIES OF BED 10

7.1. Introduction

The description and interpretation of clasts discussed in this and the following two chapters concentrates on those derived from the missing shelfbreak and the upper slope. Fig. 7-1 summarizes the terminology employed and as a reference framework to describe the morphology of the slope.

Bed 10 is a widespread complex unit which represents the first megaconglomerate of Arenig age. Compared to megaconglomerate beds 12 and 14 it contains: a) smaller average clast size; b) a smaller variety of clast lithologies; c) lower proportion of clasts from horizons older than immediately underlying beds (i.e. Bed 9).

Based on field observation, thin section examination and conodont faunas three types of clasts are distinguished (see also Chapter 6):

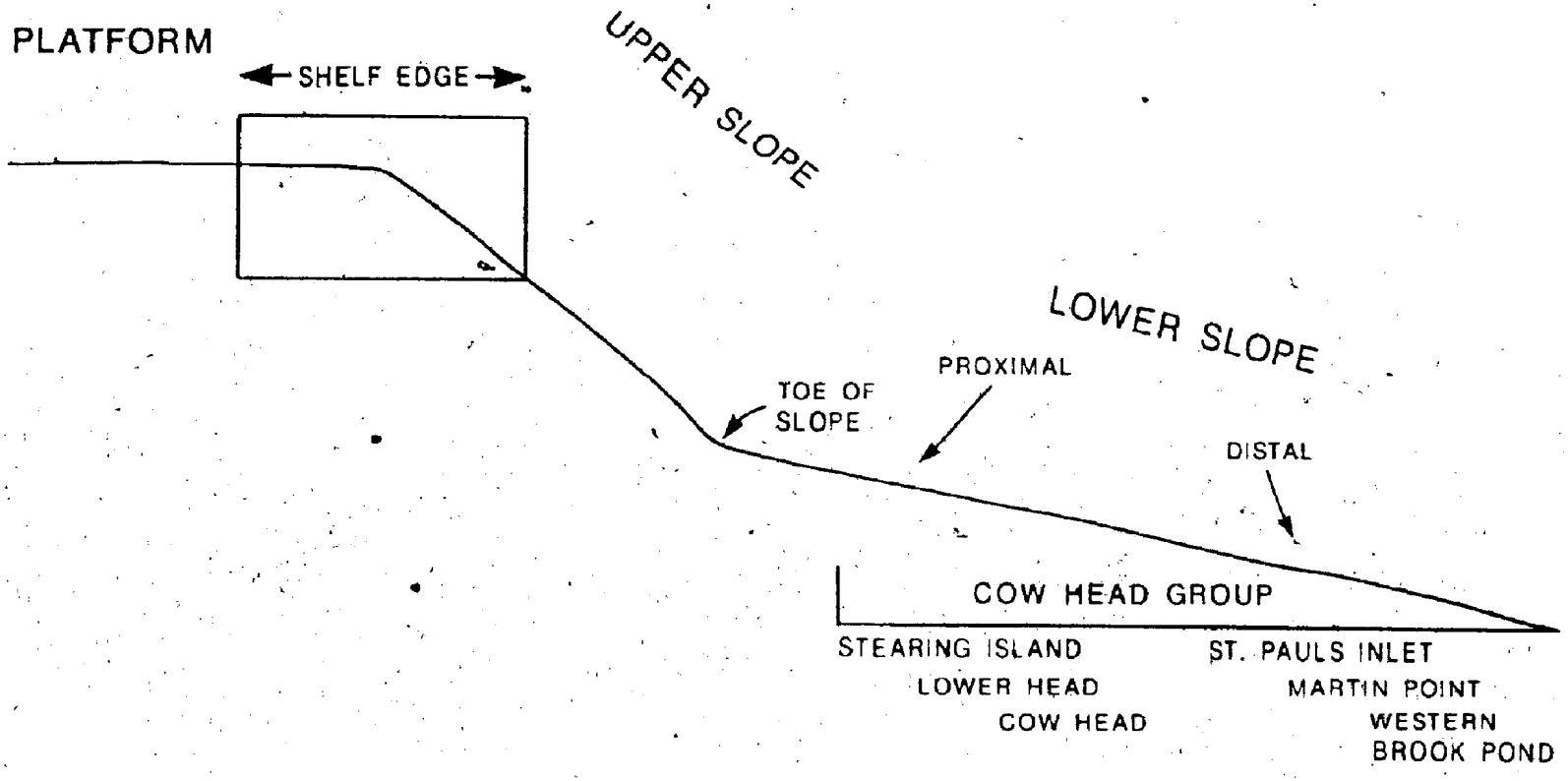
A. local penecontemporaneous lithologies,

B. foreign penecontemporaneous lithologies,

C. older lithologies (See Fig. 6-2.).

A. Local clasts are those obviously derived from a similar depositional setting as the bedded rocks immediately underlying the megaconglomerate. Sediments are fine grained mudstone, wackestone and packstone interbedded with argillaceous

Figure 7-1: Geomorphology of the slope and its environs.


PLATFORM
SHELF EDGE
UPPER SLOPE
LOWER SLOPE
TOE OF SLOPE
PROXIMAL
DISTAL
COW HEAD GROUP
STEARING ISLAND
LOWER HEAD
COW HEAD
ST. PAULS INLET
MARTIN POINT
WESTERN BROOK POND

dolomitic siltstone or shale and resedimented grainstone. Clasts were incorporated in the conglomerate as large soft- or brittle deformed limestone rafts and plates. They comprise more than 70% of all clasts in distal but less than 50% in proximal facies.

B. Foreign penecontemporaneous lithologies contain conodonts similar in age to those from Bed 9 in the slope sequence or the Catoche Formation in the shelf sequence. Three different facies types can be distinguished:

- 1. grainy facies composed of rudstone and grainstone; 2. massive facies composed of wackestone and boundstone; 3. bedded facies composed of lumpy wackestone and mudstone.

These clasts may comprise more than 40% of the clast total in proximal conglomerates to less than 10% in distal conglomerates. (Fig. 6-17).

C. Clasts older than limestones of Bed 9 are of variable lithologies and comprise less than 5% of the clasts in Bed 10.

Clast lithologies are summarized in tables 7.1-7.3.

7.2. A. Local penecontemporaneous clasts

A.1 Rhythmic limestone

Description: Clasts of the lower slope are dominantly parted and ribbon limestones characterized by rhythmic interlayered fine grained lime mudstone, wackestone or grainstone to packstone and argillaceous, commonly dolomitic, partings. They have been described in detail by James and Stevens (1986) and Coniglio (1985) from the bedded sequence of the CHG. In ribbon limestones the parting sediment exceeds or equals the limestone layers in thickness, in parted limestones it is thinner.

Although parted limestones are similar in their overall composition several types are recognized on the basis of differences in sedimentary structures (e.g. thickness

TABLE 7-1. CLAST LITHOLOGIES - LOCAL CLASTS

LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
A.1. Parted and ribbon limestones	Interbedded layers of homogenous or bioturbated lime mudstone and dolomitic argillaceous siltstone or shale. Variable thickness of carbonate rich and carbonate poor layers.	Hemipelagites Mud- or silt turbidites.
A.2. Calcarenites	Graded sands, parallel or ripple lamination.	Turbidites.
A.3. Conglomerates	Oligomict conglomerate composed of limestone plates and grainstone clasts of pebble to cobble size, chaotic fabric.	Debris flows.
A.4. Dolostones	Buff weathering laminated dolostone with silt sized detrital dolomite.	Detrital dolomite, dolomitized on sea floor
A.5. Chert	Brown weathering chert clasts with relict structures.	Limestone-replaced by silica prior to erosion.

TABLE 7-2. CLAST LITHOLOGIES - FOREIGN PENECONTEMPORANEOUS CLASTS.

LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
B.1. Massive wackestone	Massive microbioclastic peloidal wackestones and spiculitic wackestone; composed of algal derived muds and peloids. Abundant silica lined, fibrous calcite lined voids and irregular fractures filled with bedded sediment. Sediment intensely burrowed. Contain sponges, nautiloids, trilobites.	Upper slope mud deposits, partly algal bound.
B.2. Algal-sponge boundstone	Archaeoscyphid sponges in situ and Girvanella stromatolites in mud matrix or packstone. Grainstone lenses or pockets.	Organic buildup facies.
B.3. Bedded grainstone	Fine to very coarse sand sized grains to 90% of origin, neomorph calcite spar, abundant oriented skeletal debris, bedded sediment.	Intermound and mound flank sediment
B.4. Calcirudites	Pebble sized soft deformed lithoclasts and peloidal skeletal sands; geopetal matrix altered to neomorph calscite spar. Bedded, graded or massive fabric. Three types of calcirudites with: 1. dominantly shelf derived lithoclasts; 2. dominantly upper slope derived lithoclasts; 3. dominantly lower slope derived lithoclasts.	1. and 2. mound talus and fore slope breccias, 3. turbidite.
B.5. Lumpy wackestone	Bedded echinoderm rich sediment with cm sized limestone nodules and dolomite rich argillaceous internodular sediment.	Differentially lithified mud
B.6. Lumpy mudstone	Bedded lumpy lime mudstone layers with thin dolomitic partings; unfossiliferous, always soft deformed.	Peri-platform ooze.

TABLE 7-3. CLAST LITHOLOGIES - OLD CLASTS.

LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
C.1. *Epiphyton* boundstone	In situ *Epiphyton* colonies and *Girvanella* sheets, partial silicification.	Algal buildups along shallow shelf margin.
C.2. Oolites	90% superficial ooids.	Shallow shelf, Cambrian age.
C.3. Calcarenites	Bedded flat mud pebbles and rounded coarse quartz sands in dolomitic matrix.	Turbidites, Cambrian or Tremadoc age.

of parting material and limestone layers), texture (e.g. homogeneity of mudstone layers) and colour. Fig. 7-2 summarizes the different types.

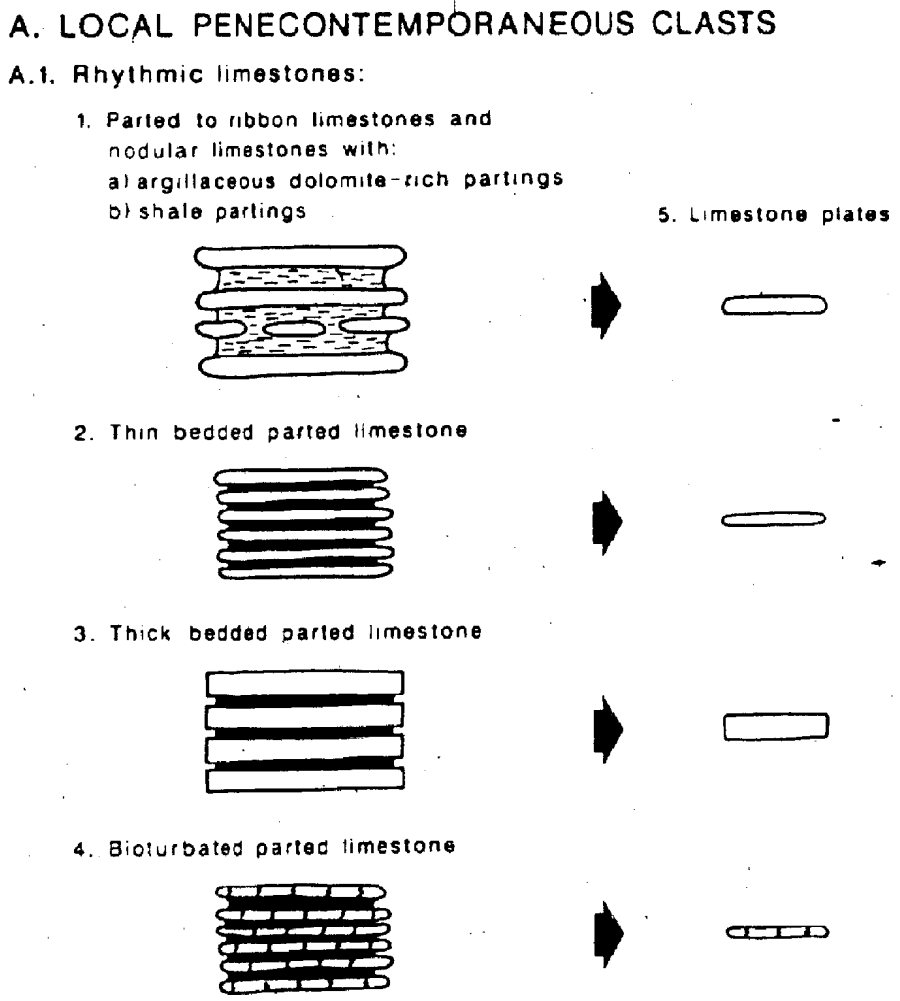


Figure 7-2: Different types of rhythmic limestones among local penecontemporaneous clasts. Scale is 1:10

Overall composition of mudstone and siltstone layers is similar in all types and is therefore only addressed in the first description. Four separate types are distinguished:

1. Parted to ribbon limestones and nodular limestones; 2. Thin bedded parted limestones; 3. Thick bedded parted limestones; 4. Bioturbated parted limestones.

A.1.1 Parted to ribbon limestone and nodular limestone.

This lithology is characterized by the relatively large amount of parting material which separates or surrounds light gray lime mudstone layers, lenses and concretions. Partings are composed of dark brown shale or greenish, dolomite rich argillaceous siltstone which is locally silicified. Partings are equal to, or exceed the 1 cm-4 cm thick limestone layers in thickness with thickest partings in limestones separated by shales. Contacts between limestone layers and parting shale and siltstone are sharp and planar but gradational in limestones separated by siliceous dolomite. Mudstone layers are typically coarse micrite to microspar, either homogeneous or faintly laminated in the case of silicified dolomite parted mudstones. Pelmicrite with up to 30% of silt to sand sized peloids and bioclasts is also common. The variable size of microspar crystals and the diffuse grain boundaries suggest an original micritic matrix which has been altered to larger crystals through aggrading neomorphism.

Bioclasts are single *Girvanella* tubules and small *Girvanella* rafts. The small peloids are presumably also of algal origin (Coniglio and James, 1985). Small miscellaneous shell debris is present, but rare (< 5% of all grains). Recrystallized calcified radiolaria and sponge spicules are oriented parallel or subparallel to bedding planes. One boulder yielded a cm-sized silicified brachiopod. Fine grained pyrite crystals are scattered throughout the lime mud matrix and concentrated along calcite filled fractures.

Rafts of the lithology are up to $1m^2$ in size and usually deformed. Partings are commonly plastically deformed but mudstone beds show brittle deformation or are bent to a certain extent and then fractured depending on the degree of lithification reached before transport.

A.1.2 Thin bedded parted limestones

Clasts of thin bedded lime mudstone separated by 1mm to 5mm thick partings

of dolomitic argillaceous siltstone are distinguished from the previously described parted to ribbon limestones by the small amount of parting material present. The light gray mudstone layers are 0.5-3cm thick with either wavy or planar contacts between the mudstone beds ("fitted fabric" of Coniglio, 1985, in press).

A.1.3 Thick bedded parted limestone

This lithology contains 3-5cm thick, light gray mudstone layers with numerous laminations. Partings are only a few mm thick and consist of grey to green calcite rich dolomitic siltstone. The laminations are caused by one to several 0.1-1mm thick peloid sand layers in spar cement. Single laminae vary in thickness along strike. Very thin, planar clay bands (less than 0.1mm thick) are also present. The largest clast measures 7x2m and is partly soft and partly brittle deformed (Pl. 7.1., fig.1).

A.1.4 Bioturbated parted limestones

This is thin bedded, slightly nodular mudstone with mottled surfaces. The sediment is strongly bioturbated with mm sized, bedding parallel or downward oriented burrows elongate, oval or irregular in outline. They resemble *Skolithos* burrows but are smaller. Many of the burrows are filled with a dark sediment and burrow walls are indistinct, suggesting an original high water content of the sediment (Walker, 1974). The dark stain is caused by pyrite crystals. Coniglio (1985) suggests that pyrite growth is the result of a different, probably organic rich, microenvironment created by the burrowing organism (Pl. 7.1, fig.2). Another set of burrows are completely or partly filled with microspar. They may represent a different later generation than the mud filled burrows (Pl. 7.1, fig.3).

A.1.5 Limestone plates

Angular and lenticular plates of lime mudstone comprise the most abundant type of local clasts in Bed 10. They are of variable size and thickness and

composed of homogenous, laminated or bioturbated mudstone. The presence of disrupted limestone rafts (Fig. 7-2) indicates that the plates are derived from disintegration of the bedded sediments during transport. This is confirmed by the similar composition of mudstone layers in the rafts and the plates. The parting material probably contributed to the conglomerate matrix.

Interpretation: The parted and ribbon limestones are deposits of the slope environment and similar to rocks of the underlying bedded sequence. They form either through suspension settling of hemipelagic fines (peri-platform muds) or are a result of mud- or silt turbidites. Sedimentology and diagenesis of the parted and ribbon-limestones in the CHG have been studied in detail by Coniglio (1985; in press). He agrees with other workers (e.g. R.O.C.C. Group, 1986) that the rhythmicity of these sediments reflects changes in carbonate production on the shelf which is in turn probably climatically controlled. Accordingly the calcite rich layers correspond to times of high productivity and the siltite layers to times of reduced productivity. The carbonate rich layers were preferentially lithified by calcite cement during early diagenesis. The presence or absence of bioturbation most likely depends on initial organic content of the sediments and degree of bottom aeration.

A.2 Calcarenites

Description: Clasts of grainstone interbedded with dark brown shale, marl and wackestone are common in Bed 10. The grainstone layers are dark brown and 2-10cm thick. They consist of fine grained, ungraded massive or graded lime sands with parallel or cross laminations. The base of these layers is commonly irregular and appears to have been deposited in scours into underlying packstones or wackestones. Interbeds of alveolar or white weathering calcareous marls, 1-10cm thick, are commonly associated with this lithology.

Grainstones are composed of well sorted peloidal sands or silts with variable bioclasts, such as *Girvanella* rafts and tubules, pyritized or calcitic monaxone

sponge spicules (Pl. 7.1, fig.4), small indeterminable shell debris and echinoderm fragments. The peloids are oval, round or irregular in shape with well defined grain boundaries. Lithoclasts composed of coarse neomorphic calcite spar occur in some coarser grainstones. They are generally rounded and oval in shape (Pl. 7.1, fig.5). and were probably originally of a different, now obliterated, composition. Peloids, lithoclasts and skeletal grains form laminated or ripple laminated sands (Pl. 7.1, fig.4). Laminae may also be formed by mm to cm thick pelmicrite or mudstone layers which show little evidence of bioturbation and contain scattered peloids, oriented sponge spicules and calcified radiolarians.

Dark brown wackestones or packstones which commonly over- and underlie the grainstones are either massive or show mm spaced dark laminae. The main components are peloids and oriented sponge spicules. An original micrite matrix may have been present but appears to have been altered through aggrading neomorphism to an inclusion rich microspar or pseudo-spar. Skeletal components comprise *Girvanella* rafts and tubules, rare *Nuia* grains and small trilobite fragments. Some peloids can be identified as small algal clasts suggesting that algal debris is a major source for the peloids. The clasts are never soft-deformed, but always brittly fractured with calcite filled or open fractures, fracture surfaces are locally overgrown by quartz crystals.

Interpretation: The calcarenites associated with bedded finer grained sediments are most likely turbidite deposits. This interpretation is suggested by the presence of graded to ungraded sands and parallel or ripple laminations. Similar sediments are typical in the arenitic divisions of Bouma-sequences (Bouma, 1964). The calcarenite clasts found in the conglomerates are somewhat coarser than the turbidites described from the bedded sequence (Coniglio, 1985; in press) suggesting a more proximal origin.

A.3 Conglomerate

Description: Conglomerates are oligomict and composed of subangular to

subrounded clasts ranging in size from pebbles to cobbles. Matrix is characteristically argillaceous or limy mud. Clasts are limestone plates and a few grainstones. Fossils are rare, with only some echinoderm fragments scattered throughout the matrix. The matrix:clast ratio is commonly between 1:9 to 2:8. Fabric appears to be chaotic.

Interpretation. The conglomerates are comparable to similar deposits in the bedded sequence of the CHG which have been interpreted as debris flows (Hiscott and James, 1985; their Facies B).

A.4. Dolostone.

Description: Small fragments of buff weathering dolostone are present but not common. They are formed by silt sized dolomite crystals which usually have a detrital core (Coniglio, 1985).

Interpretation: Similar laminated dolostones occur in the bedded sequence of the CHG. The detrital origin of the dolomitic cores suggests that they were partly eroded from an area were dolomite formed, possibly a shallow water peritidal environment. Wind or water transported the grains downslope where they acted as cores for dolomite precipitation relatively early on the seafloor before erosion and resedimentation. (Coniglio, 1985; James and Stevens, 1986).

A.5 Chert

Description: These clasts are brown to yellow weathering pebble to cobble sized and are either homogenous or show relict structures of grainstone or laminated mudstone.

Interpretation: The relict structures indicate that the chert formed through silicification of limestones. The homogenous cherts are probably also a replacement possibly of a fine grained lithology. Silicification occurred prior to erosion (James and Stevens, 1986).

PLATE 7.1

All samples are from Bed 10 on CH Peninsula except for Figure 8 which is from St. Pauls Inlet. Figures 3-8 are thin section photo micrographs in plane light. Scale bar is 0.8mm.

Figure 1. Local clast of parted thickbedded limestone (book for scale is 23x29cm).

Figure 2. Polished slab of bioturbated parted thin bedded limestone with dark burrows filled with pyrite crystals. Scale is in mm.

Figure 3. Photomicrograph in plane light of burrows in parted thin bedded limestone filled with light coloured microspar.

Figure 4. Calcarenite composed of peloidal sand and oriented, pyrite replaced, monaxone sponge spicules (arrows).

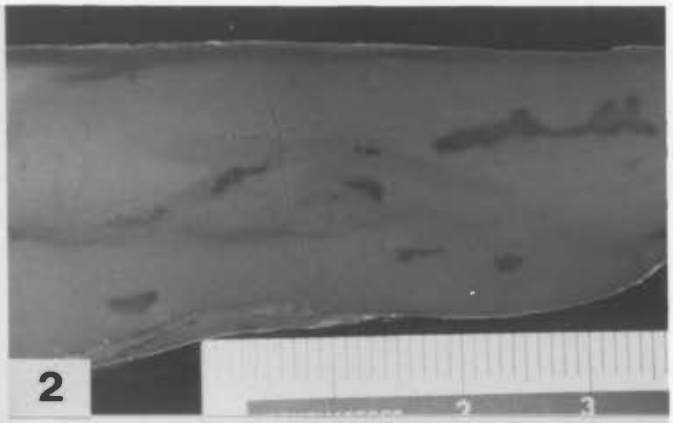
Figure 5. Calcarenite showing cross lamination (outlined in white) and coarse rounded lithoclasts composed of neomorphosed calcite spar, (arrow).

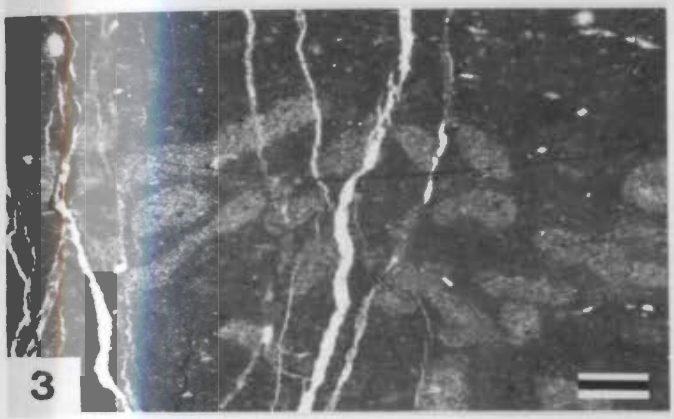
Figure 6. Lithoclast of semilithified pelsparite in B.1.1. calcirudite.

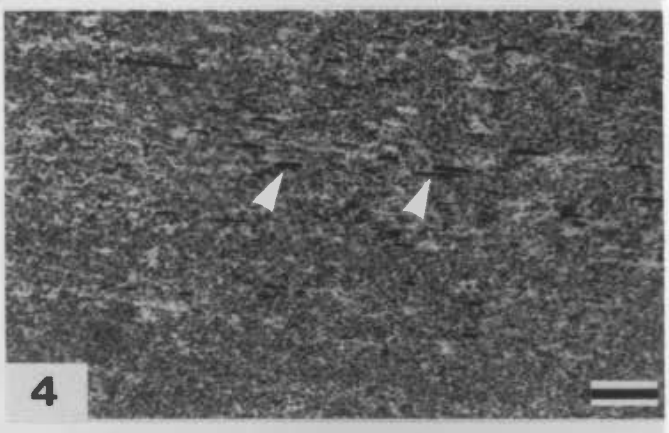
Figure 7. Soft deformed wackestone lithoclast (arrow) in B.1.2. calcirudite.

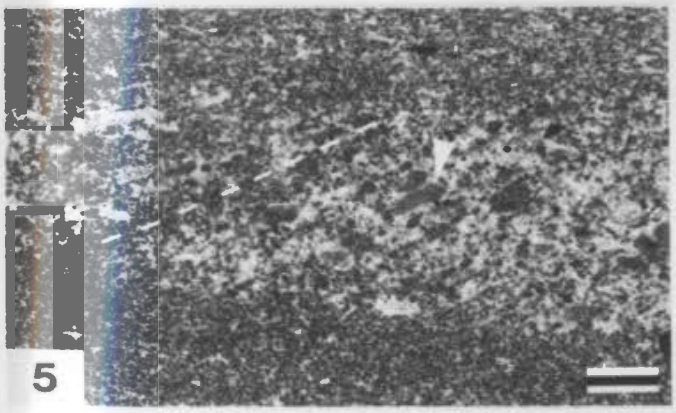
Figure 8. Mudstone lithoclast with lime sand pressed into soft surface. (B.1.3. calcirudite).

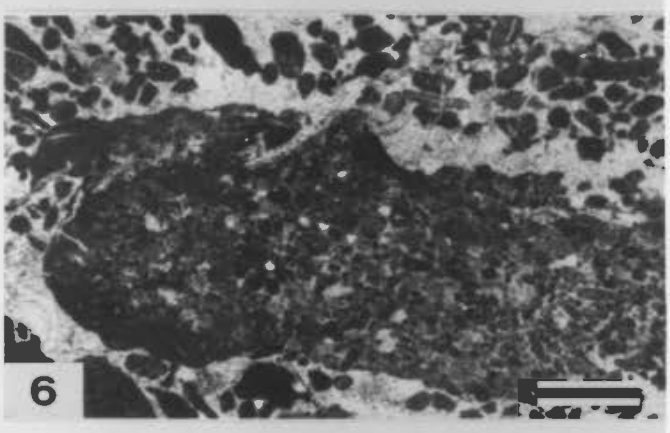

1

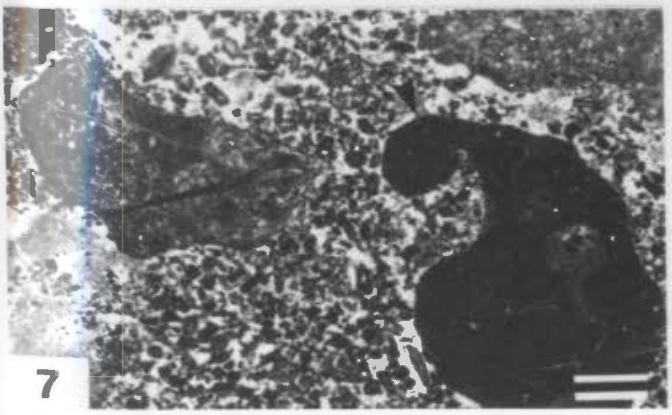

2

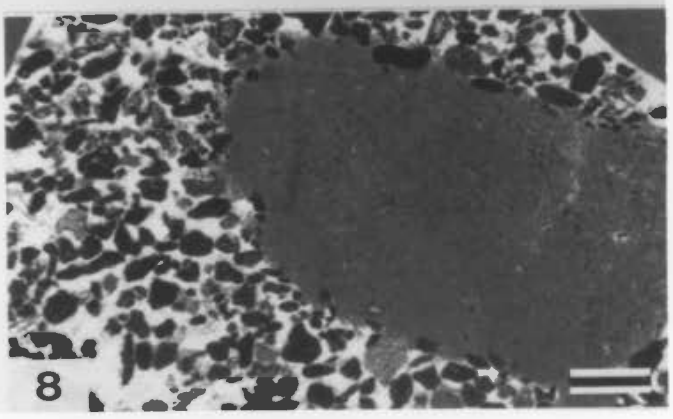

3


4


5


6


7


8

7.3. B. Foreign penecontemporaneous lithologies

B.1 Foreign massive wackestone

Description: This unbedded limestone comprises the most common foreign lithology in Bed 10. It can be subdivided into four different lithologies:

B.1.1. Grey *Girvanella* boundstone; B.1.2 burrowed peloidal microbioclastic wackestone; B.1.3 spiculitic wackestone; B.1.4 bedded microbioclastic peloidal wackestone.

All four lithologies grade into one another. The boundstone and bedded wackestone are less abundant than the massive wackestone. Most particles in the four sub-types are derived from the problematic organism *Girvanella*. Nicholson and Etheridge (1878) who first described the form thought that it was a foraminifer. Later workers generally agreed that it belongs to the Porostromata (Pia, 1927) which resemble calcified Cyanophyta, now Cyanobacteria. Because of the uncertainty of affinity of Paleozoic algae (e.g. *Epiphyton, Girvanella, Renalcis, Nuia* etc.) the approach of Pratt (1984) and Riding and Voronova (1985) is followed herein, who regard the microorganisms as algae and sub-divide them into morphological groups. Although *Girvanella* is not a reliable depth indicator (Riding, 1977) and its dependence on light equivocal, its absence in life position in lower slope sediments suggests that it grew in relatively shallow water. It was probably autotrophic and light dependent and is therefore referred to as alga herein. *Girvanella* contributes to the sedimentation in various ways in the form of intraclasts, lumps and peloids. Disintegration of algal filaments and the boring habit probably adds to the mud sized fraction (Klement and Toomey, 1967). *Girvanella* appears to provide at least 70% of the sediment in all samples, possibly more than 90%. Swinchatt (1965) noted that algae commonly attain their greatest significance in particle alteration and break down following mechanical reduction of the skeletal and nonskeletal grains to sand size particles. This observation also applies to *Girvanella*.

B.1.1 Gray *Girvanella* boundstone

Clasts of this boundstone show abundant *Girvanella* in growth position (Pl. 7.3, fig. 6) with preservation ranging from excellent to poor. (Pl. 7.5, fig. 2). Where preservation is poor wackestone and boundstone facies cannot be clearly separated. Boundstones are rich in fossils which are commonly clustered. They also contain abundant subhorizontal stromatactoid voids and sporadic true stromatactis with flat floors. Fossils include silicified trilobites (asaphids), brachiopods, orthocone nautiloids, *Nuia* grains, echinoderm debris, rod- and cup shaped sponges. Sponge spicules of various kinds are present both in thin section and acid insoluble residues. They are oxeas, lithistid desmas, and triactine and octactine based spicules indicating the presence of lithistid sponges (desmas) and heteractinid sponges (triactine and octactine based spicules, oxeas.) Due to their calcitic nature spicules are rare in the acid insolubles although they are abundant in many thin sections. The diagenetic replacement of silica is suggested by the mosaic pattern of the calcite. Microscopically the boundstones show a clotted fabric which in well preserved rocks can be identified as being formed by tangled *Girvanella* filaments. The algae form two types of fabric: (1) common clotted fabric with fenestrae-like structures filled by blocky calcite spar, (2) uncommon laminoid, composed of subparallel sheets.

B.1.2 Burrowed peloidal microbioclastic wackestone

This wackestone has fossils, sedimentary structures (i.e. fractures and stromatactoid voids) and sponge spicule assemblages similar to the boundstones. The peloidal to clotted fabric also grades laterally into peloidal wackestone with abundant relict *Girvanella* filaments. Small pockets of pebble sized intraclasts are common in geopetal mud matrix (Pl. 7.3, figs. 2,4).

This lithology is coextensive with boundstones in the same boulder and also with the bedded grainstones (B.3), judging from the grain composition, similar spicule assemblage and rich fossil content.

PLATE 7.2

All samples are from Bed 10 on CH Peninsula except Figure 8 which is from St Pauls Inlet. All figures except Figure 7 are thin section photomicrographs. Scale bar is 0.8mm unless otherwise indicated.

Figure 1. *Girvanella* rich bedded wackestone (Gw) intersected by cavity filled with bedded peloidal wackestone (cf) oriented at an angle to older sediment.

Figure 2. Grainstone (B.3.) with abundant algal debris (*Girvanella* lumps and -peloids) and aggraded neospar.

Figure 3. Stromatactoid cavity with flat bottom and roof supported by large shell fragment. Cavity is lined with fibrous calcite cement whose crystal terminations have been replaced by silica. Centre is filled with blocky calcite spar.

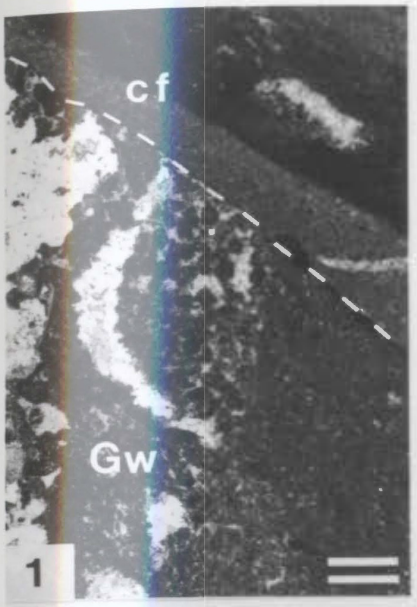
Figure 4. Light coloured burrows in dark lime mud; dark sediment is micrite, light sediment is microspar.

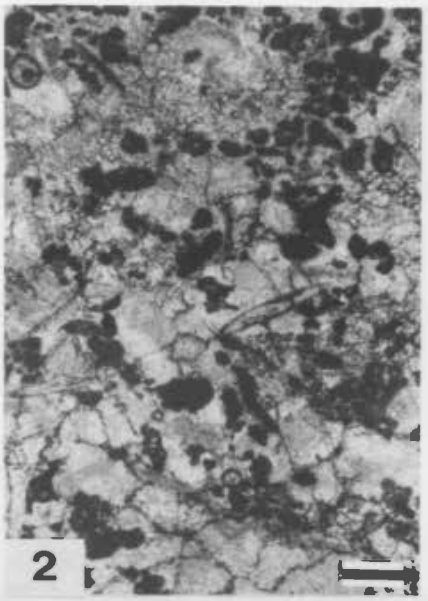
Figure 5. Bedded microbioclastic wackestone. Note alignment of sponge spicules.

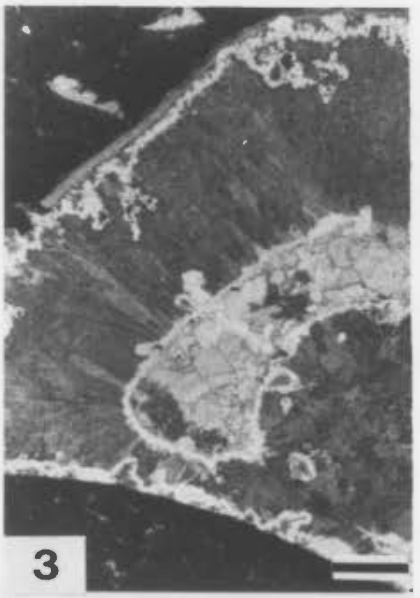
Figure 6. *Girvanella* boundstone with thrombolitic fabric (tf) and cavity (c).

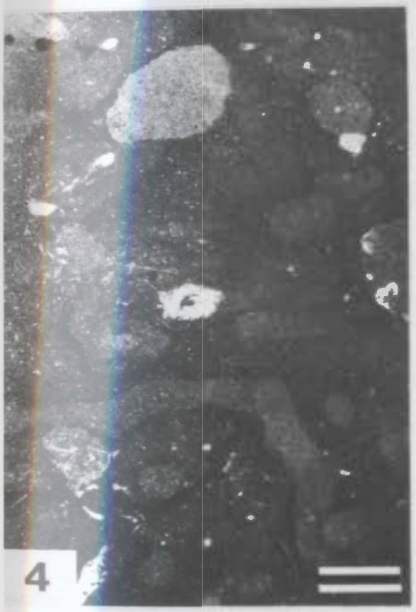
Figure 7. Polished slab of burrow mottled wackestone (B.1.). Note large silica rimmed spar- or sediment filled burrows in center of some dark motties.

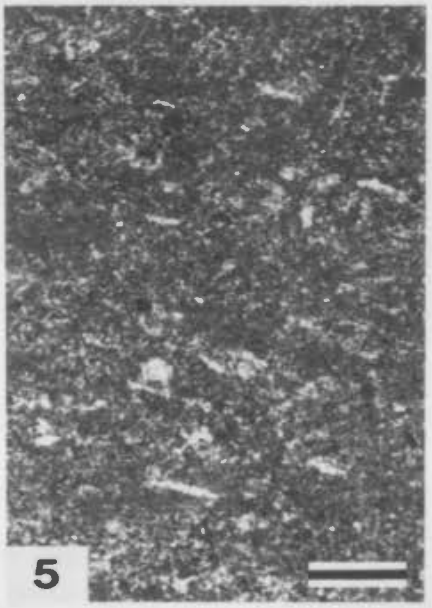
Figure 8. Influence of burrowing activity on sediment texture indicated by the alteration of spiculitic wackestone (sw) to peloidal wackestone to packstone (pw) inside of the burrow.

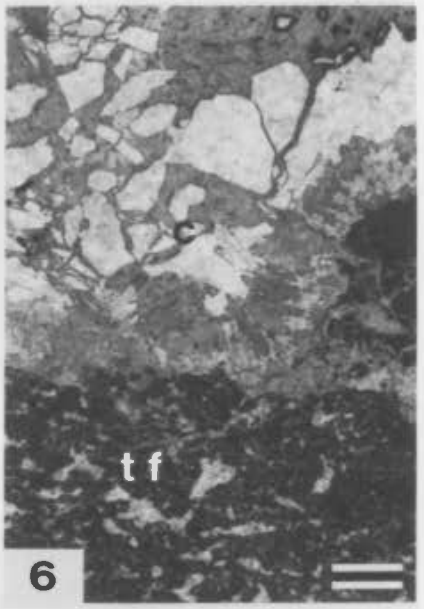

cf
Gw
1

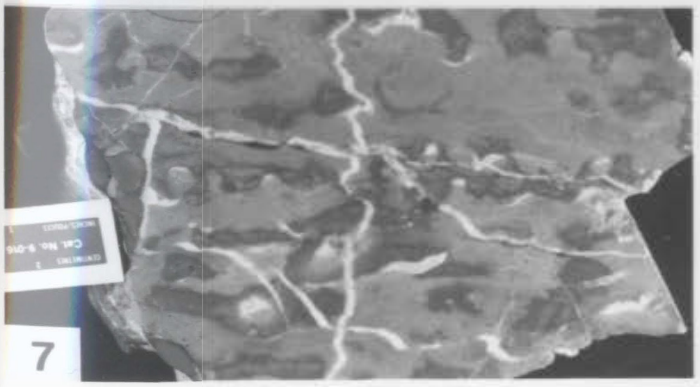

2

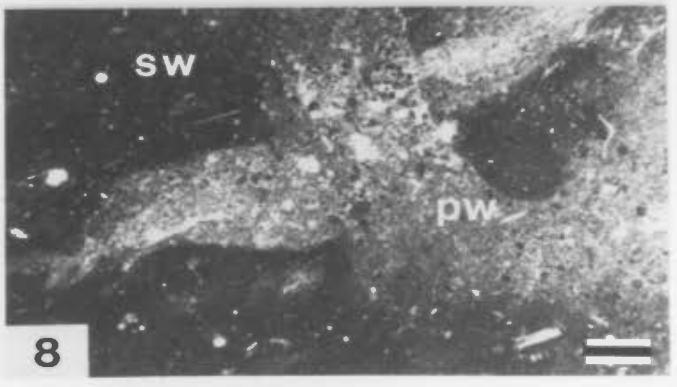

3


4


5


tf
6


7


sw
pw
8

B.1.3 Burrowed spiculitic wackestone

Burrowed spiculitic wackestone commonly co-occurs with the microbioclastic peloidal wackestone (B.1.2) and also consists mainly of algal mud. In some cases the peloidal wackestone appears to be the result of the pelletizing effect of burrowing organisms in the spiculite rich wackestone (Pl. 7.2., fig. 8). Burrows are conspicuous structures in both of the massive wackestones.

Most commonly the burrows are arranged in small vermiculate systems with round, oval or longitudinal cross sections of 1 mm or less (Pl. 7.2, fig.4). They have defined walls and are filled with microspar. Another type of burrow is larger in diameter (about 0.5 cm) with poorly defined walls and is filled with greenish homogenous lime mud devoid of the peloids which are so common in the surrounding matrix. A sparite filled core is commonly present near or in the center of the burrow. The most abundant structures are burrow mottles which have irregular "cloud shaped" or elongate patches of darker sediment in a light coloured matrix (Pl. 7.2, fig.7). The mottles may comprise to 40% of the rock volume. The central parts of the burrows are light coloured, suggesting several generations of burrowing activity. The mottles are commonly associated with a small cavity or with a round (cm sized) silica rimmed structure either completely filled with sparite or partly filled with sediment. In the latter case only the sparite filled part of the void is lined with silica. These cores are cross sections of siliceous tubes, up to 5cm long which have been found in the acid insolubles. Their origin is enigmatic; possibly they represent the silicified walls of a late stage type of burrow (O. Dixon, pers. com., 1986).

Bedded peloidal microbioclastic wackestones are uncommon and occur associated with both the massive lithologies and with calcirudites (see section B.1). (Pl. 7.2, fig. 5).

All four lithologies are characterized by abundant silica-rimmed cavities, voids and fractures. The clasts are lumpy weathering, gray and cut by yellow

weathering silica crusts which outline or replace a whole array of different sedimentary structures and fossils including: 1. shell debris (especially trilobites, brachiopods and echinoderms); 2. walls of large spar-filled "burrows", nautiloid siphuncles and ?spongiocoels; 3. small pore spaces and bedding parallel voids (Pl. 7.3, fig. 5); 4. walls of cavities and fractures; 5. large crystals of calcite spar are also preferentially silicified.

Extensive stromatactoid voids are a distinct feature of the rocks. Voids are oriented parallel or sub-parallel to one another. They are of variable length ranging from a few cm to several dm and form thin (mm-high, cm long) cavities which may widen to cavities several cm in height (Pl. 7.3, figs. 3-7). Bottoms and tops are irregular and silica-lined (Pl. 7.2, fig. 3), flat bottoms which are typical of stromatactis are rare, indicating that these structures may be related to but are not identical to the true stromatactis of Waulsortian mounds. The structures are lined with fibrous calcite whose crystal terminations or central parts are commonly replaced by silica. The remaining cavity is filled with an iron-poor calcite cement (Pl. 7.3, fig. 3).

Fractures form irregular, usually extensive networks throughout the rock. They are either cm thick fissures lined with fibrous calcite and silica or widen to several cm to dm wide cavities. Larger cavities are filled with different types of internal sediment which is unlike sediment from the overlying slope sequence and so must have been acquired from a different source. A common cavity fill is bedded mudstone or peloidal packstone. These sediments are typically stained pink, blue gray or green (Pl. 7.2, fig. 3). The bedding of the cavity fill is usually at an angle with that of the surrounding rock, suggesting filling after rotation of the block (Pl. 7.2, fig. 1). Nautiloid nests are also abundant.

Local bedded fine grained or coarse peloidal wackestones and grainstones are associated with the massive lithologies. They usually occur near the top or at the sides of larger blocks or as single boulders. Gray peloidal packstone layers, commonly fragmented, alternate with light gray layers of calcite spar. The beds

PLATE 7.3

All illustrations are from clasts found on CH Peninsula (The Ledge) except for figs. 5-6 which are from Shoal Cove (CH Peninsula).

Figure 1. Field sketch of massive wackestone with silica lined stromatactoid voids and fractures (CH Peninsula, The Ledge).

Figure 2. Photomicrograph of intraclastic portion in rock shows spiculitic wackestone lithoclasts in lime mud (see Figure 4). Matrix illustrates geopetal structures and anastomosing fabric (at) which may be attributed to collapsed peloids or sponge fragments. Scale bar is 0.8mm.

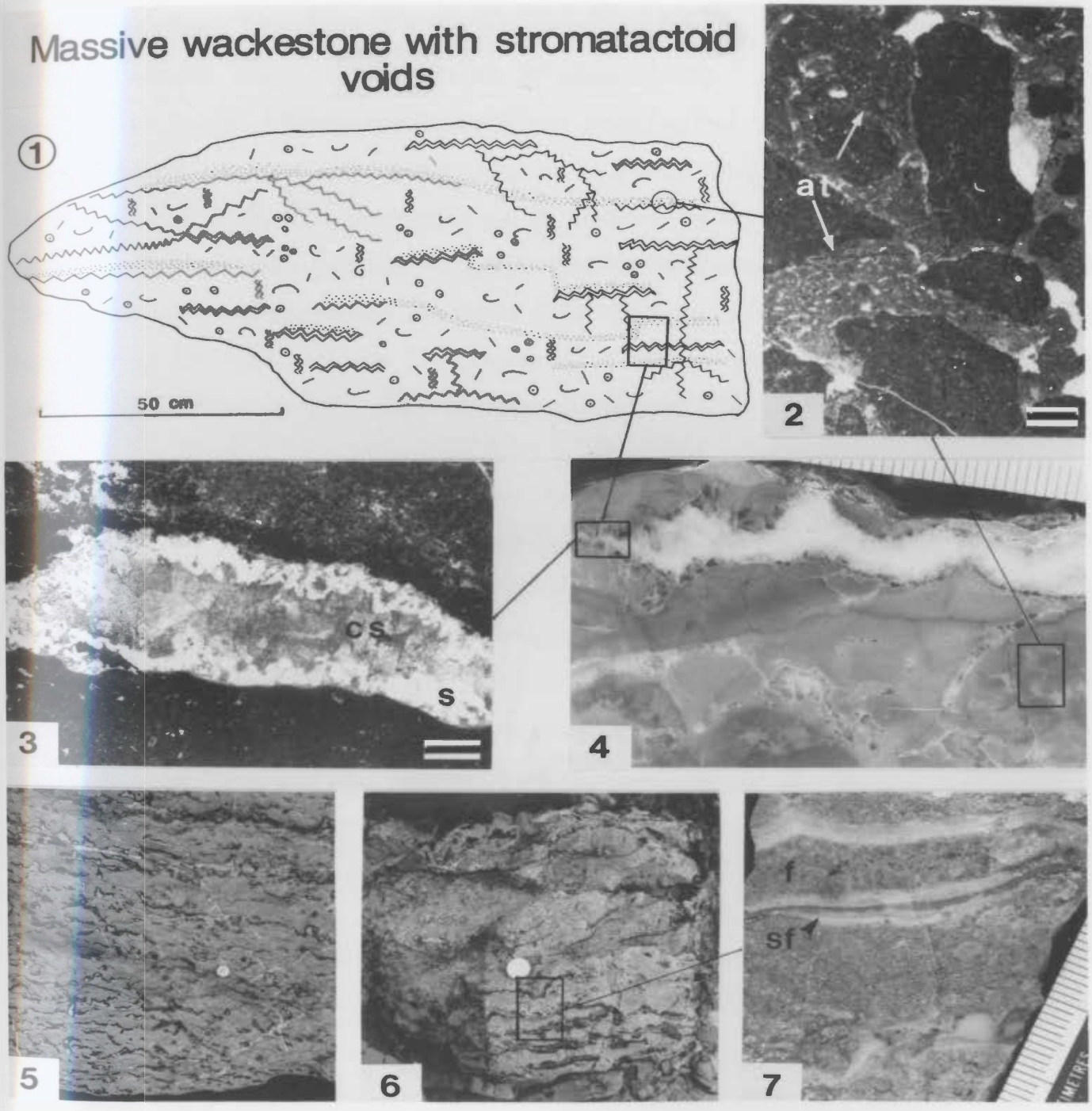
Figure 3. Thin section photomicrograph of stromatactoid silica rimmed void (s) filled with fibrous calcite spar (cs) (see Figure 4). Surrounding sediment is spiculitic wackestone. Scale bar is 0.8mm.

Figure 4. Polished slab of massive wackestone. Scale is in mm.

Figure 5. Clast of massive wackestone with small sub-parallel oriented stromatactoid voids resembling a large scale fenestrate fabric. Coin for scale is 2cm in diameter.

Figure 6. Clast with large crust-like, silica-lined voids resembling zebra-limestone. Coin for scale is 2.3cm in diameter.

Figure 7. Polished slab cut from clast in Figure 6. Void is at bottom filled with internal sediment (sf). Remaining cavity is lined with silica and filled with fibrous calcite crystals. Scale is in cm.


Massive wackestone with stromatactoid voids
1
50 cm
at
2
cs
s
3
4
5
6
f
sf
7

are 0.5-1cm thick. Another associated bedded lithology is light brown peloidal grainstone interbedded with brown peloidal wackestone in layers 0.5-1cm thick separated by thin silica partings. The bedding may be disrupted by vertical or obliquely oriented silica lined small cavities (1cm to several cm in size).

Interpretation: The four lithologies described above are obviously genetically related because they occur together in some clasts. The gradation of massive wackestone facies, *Girvanella* boundstone and bedded wackestone indicates that the sediment was partly physically and partly organically accreted. The significance of inorganic precipitation of micrite cannot be evaluated. The large amount of *Girvanella* peloids, lumps and rafts indicates a nearby source because the fragile components would not have survived long transport. The source area is represented by clasts of the fossil rich algal boundstones which are dominantly formed by *Girvanella* with thrombolitic and laminoid growth forms.

The spiculitic wackestones together with the spicule assemblages of the acid insolubles indicate that sponges represent important faunal elements. The sponge spicule assemblage is similar to that described by Rigby and Toomey (1978) from the Lower Ordovician Kindblade Formation (Oklahoma). The spicules are oxeas, lithistid desmas, and triactin- and octactine-based spicules indicating the presence of lithistid sponges (desmas) and heteractinid sponges (triactine- and octactine-based spicules, desmas) (K. Rigby, pers. comm., 1986) The same sponge spicule assemblage has also been found in the Lower Ordovician of the El Paso Group (Mc Kelligon Canyon Formation, West-Texas) (Toomey, 1970).

In their overall composition the sediments resemble mud mound facies described from other upper slope settings (Pratt, 1982) (Table 7.4). Several features are found in the CH-facies that are typical of such limestones including stromatactoid voids and early lithification. The abundant stromatactoid voids rimmed with fibrous calcite are probably genetically related to true stromatatis which is characterized by the presence of relatively flat bottoms of the cavities (Dupont, 1892). They have been varyingly interpreted: (1) as voids formed upon decay of

TABLE 7-4. COMPARISON OF LITHOLOGICAL CHARACTERISTICS OF MOUND FACIES AND MASSIVE WACKESTONES OF BED 10.

Sedimentary features of mound facies (summarized from Pratt, 1982 and Ross et al., 1975).	Sedimentary features found in massive wackestones in Bed 10.
1. Primary sediment mudstone or wackestone;	Primary sediment wackestone or boundstone;
2. lime mudstone matrix commonly clotted;	clotted fabric abundant;
3. packstones and grainstones rare;	rare but present;
4. fossils clusterd in nests;	trilobite and nautiloid nest;
5. firm bottom suspension feeders dominant;	sponge spicules are remains of suspension feeders;
6. infauna and bioturbation rare;	burrows common;
7. no evidence of compaction;	no evidence of compaction;
8. no borings;	no borings;
9. mud is not a precipitate, indicated by admixture of bioclasts;	mud mixture of microbioclastics and *Girvanella* filaments;
10. primary sediment may show faint bedding;	bedded sediment rare but present;
11. occasionally desintegration of calcareous algae is visibly mud source (Lees et al, 1977);	90% of mud probably *Girvanella* derived;
12. dilational fractures abundant, commonly filled with bedded sediment;	fractures probably dilatational, filled with bedded coloured sediments or fossils;
13. bedded stromatactis and zebra limestone common;	bedded stromatactoid voids with irregular bottom, true stromatactis rare;
14. reticulate primary cavity systems;	rare but present (Pl. 7.5., fig. 5);
15. cavities filled with geopetal internal sediment (commonly microspar or peloidal grainstone)	rare in bedded stromatactoid voids, abundant in reticulate cavity systems;
16. fossils commonly complete;	complete in boundstone facies.

soft bodied organisms such as algal mats (Bathurst, 1959; Philcox, 1963; Lees, 1964; Ross et al., 1975), or sheet like organisms such as sponges (Bourque and Gignac, 1983), or bryozoans (Textoris and Carozzi, 1964); (2) as recrystallized colonies of microorganisms (algae, cyanobacteria, bacteria, Tsien, 1986); (3) as voids in framework of a) anorganic origin: submarine cement crusts (Bathurst, 1980, 1982; Burchette, 1981); creep or slumping, (Schwarzacher, 1961); internal erosion (Wallace, 1987) or b) organic origin: algal supported framework (Pratt, 1982). No evidence (i.e. relict structures) has been found to ascribe the formation of stromatactoid cavities in the Cow Head wackestone to any of the above mentioned interpretations. Abundance of *Girvanella* suggests that organic buildups or debris may be involved in formation of stromatactoid cavities. An interesting observation has been made by Wiedenmayer (1978) who described early lithification of sediments underlying the base of certain sponge species of the Great Bahama Bank. Klappa and James (1980) pointed out that occurrence of stromatactoid mounds coincides with the first appearance of sponges as significant contributors to carbonate buildup facies in the geological record. Decayed sponges underlain by early lithified sediment may account for some of the cavities in the CH lithologies. Wallace (1987) pointed out the common association of stromatactis and sheltered cavities in wackestone. He suggested that the structures develop from a precursor cavity system by internal erosion just below the water sediment interface. In the CH material stromatactoid voids are commonly found associated with large shell fragments (Pl 7.2, Fig. 2). Internal erosion is indicated by the presence of voids filled with intraclasts (Pl. 7.3, fig. 2). The common occurrence of stromatactis in mounds which formed in deeper water at the shelfedge or on the upper slope suggests that the hydraulic forces which act in this environment have an influence on the formation of these voids.

Several generations of fracturing may be interpreted as dilatational crevices which opened during settling of semilithified mud. No evidence of exposure that would explain the fractures as solution cavities is present. The fissures must have formed before mound growth had ceased because they are filled with different

types of sediment which is not comparable with any type of lower slope facies and therefore must have been acquired before resedimentation occurred.

That the mounds were not lithoherms with a hard surface as defined by Neumann et al. (1972) is obvious from the lack of borings and from the abundance of burrow traces in the Cow Head facies.

The mounds preserved in the CHG were probably formed by soft lime mud which was partly accreted physically (B.1.2 and B.1.3) and partly stabilized by patchily distributed algal colonies (i.e. *Girvanella*) (B.1.1). The bedded wackestones (B.1.4) probably represent flank or intermound sediments which are also reported from other mound facies (Gwinner, 1976). The sediment was lithified early but not at the sediment water-interface. Water depth is difficult to determine because the significance of *Girvanella* as depth indicator is unknown (Riding, 1975) and other algae are absent. Garret (1970) observed that algal mats do not form in the deep subtidal because they are destroyed by burrowing organisms. This may explain the lack of biogenic structures in the massive wackestones which owe their formation nevertheless to algal growth. Gaetani and others (1981) who studied Triassic carbonate buildups found that the upper part of the slope was predominantly bound by encrusting organisms such as blue-green algae and porifers.

B.2. Foreign brown algal-sponge boundstone

This limestone is typically light brown, and contains abundant yellow weathering, silicified, shell debris. It differs from the gray *Girvanella* boundstone (B.1.1) in colour and lack of large cavities and fractures. The rock surface commonly weathers in a fashion similar to flasers. Fresh surfaces show a dark brown, dense, packstone to wackestone texture. Closer inspection of the rock surface reveals abundant shell debris and in situ organisms, such as sponges, suggesting that this is a mound lithology (Pl. 7.4, fig. 1). The main constituent is the alga *Girvanella* which forms: stromatolites, oncoids, lumps and peloids, mud?,

tubules(?) and/or overgrowth on bioclasts. The stromatolitic portions of the mound rock are formed by dense sheets of *Girvanella*. They are thin, several cm high, laminated colonies with a height to width ratio of about 3:1. Abundant skeletal debris and intraclasts are trapped between the layers. This interlayer sediment may be replaced by neospar so that the *Girvanella*-laminae are left behind (Pl. 7.4, fig.4).

Oncoids are formed by loosely or densely packed *Girvanella*-lumps which in turn are enveloped by *Girvanella*-filaments (Pl. 7.4, fig. 5).

Algal lumps and peloids occur in packstone adjacent to the stromatolites and in grainstone lenses. The irregular shaped lumps are swirled aggregates of algal filaments which were probably eroded from larger colonies before they were completely lithified (Pl. 7.4, fig. 5).

Micritized areas below *Girvanella* overgrowth on shell fragments suggests that the influence of algal growth caused formation of fine grained sediment which may add to the mud fraction of the rock. Upon death and decay of the algae the delicate filaments likely disintegrated contributing to the mud fraction.

Small spar filled "burrows" (about 0.1mm in diameter) occur together in large numbers forming conspicuous patterns in some clasts. They can at least in part be attributed to *Girvanella* whose filaments apparently formed a spongy network around an open pore space or grew around a structure (worm tube?) which is not preserved. Most of these structures are embedded in dense micrite and therefore difficult to interpret (Pl. 7.5, fig. 6). A single boulder from Bed 10 at Lower Head is composed of these *Girvanella* aggregates in a skeletal wackestone matrix and dissected by a network of cm wide sediment filled cavities (Pl. 7.5, fig. 5). The *Girvanella*-structures comprise about 60%-70% of the components. The remainder of the sediment is rounded micritic intraclasts (*Girvanella*-derived?) and peloids in a grumulose microspar matrix. The cavities are irregular shaped, one to several cm high and wide and commonly silica-rimmed. They form a

PLATE 7.4

Brown *Girvanella*-sponge boundstone

All figures are from the same boulder. (CH Peninsula, The Ledge)

Figure 1. Field sketch of brown *Girvanella*-sponge boundstone illustrating small algal stromatolites and archaeoscyphid sponges surrounded by skeletal burrowed mud with shell debris, silicified nautiloid siphuncles and occasional grainstone pockets.

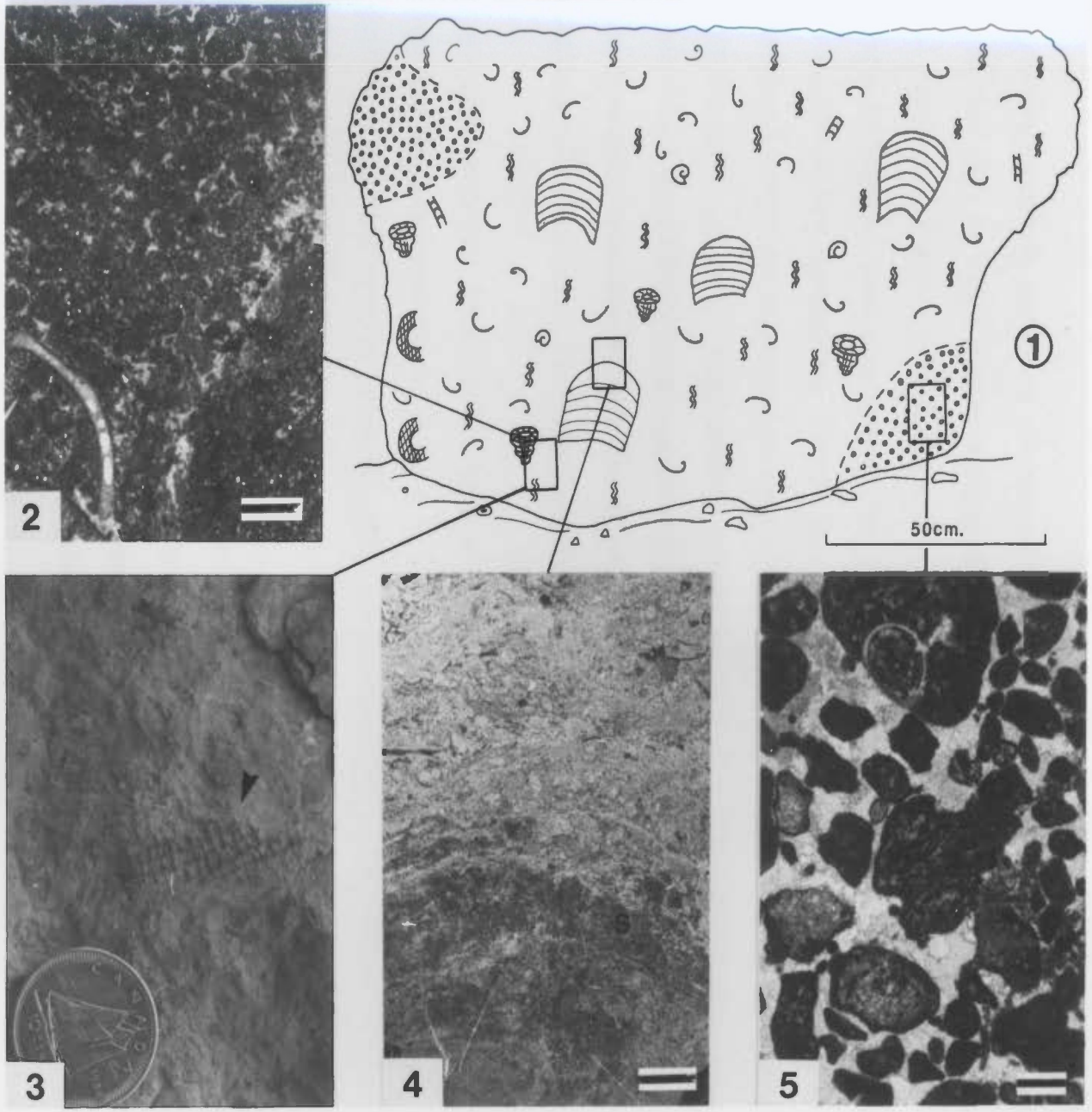
Figure 2. Photomicrograph of archaeoscyphid sponge. Scale bar is 0.8mm.

Figure 3. Reticulate pattern of silicified wall of archeoscyphid sponge on rock surface (arrow). Coin is 2cm in diameter.

Figure 4. negative print of partly recrystallized *Girvanella* stromatolite. Scale bar is 1mm.

Figure 5. Thin section photomicrograph of grainstone found in pockets: the grains are *Girvanella* intraclasts and other components which typically show an additional rind of *Girvanella* overgrowth forming a hybrid between cortoid and oncoid. Scale bar is 0.8mm.

Brown Girvanella–sponge boundstone



reticulate network which makes up about 30% of the rock volume and are filled with several layers of bedded sediments. In their overall composition these structures are similar to those previously described from the massive wackestones. The cavities resemble the reticulate frameworks described by Pratt (1982) who interpreted them as primary structures indicating presence of a supported thrombolitic network.

The puzzling growth forms of *Girvanella* in this rock possibly demonstrate the ability of the alga to build larger aggregates other than stromatolites by forming an algal supported framework of "pseudo-tubules" (i.e. the vermiform structures) which are enveloped and overgrown by additional algal filaments. Remains of these structures are commonly found in other lithologies (e.g. Coniglio, 1985 mentioned spar crystals surrounded by *Girvanella* filaments in fine grained deep water sediments). Another explanation would be that the tubules are remains of a now vanished organism which was overgrown with *Girvanella* threads. It is not obvious, however, whether or not the *Girvanella* aggregates are in a life position representing a bindstone or bioclasts forming a wackestone.

The unique conodont fauna contained in this lithology suggests a slightly older age than for the youngest clasts in Bed 10 and a derivation from the shelf edge or the shelf itself. The muddy matrix and preservation of the delicate tubules suggests a tranquil depositional environment.

Archaeocyphid sponges are abundant as fragments of cups up to 8cm wide. (Pl. 7.4, figs. 2,3; Pl. 7.5, fig. 4). Unfortunately most sponges are poorly preserved due to obliteration of the sponge body through decay or diagenesis. Interstices of the lithistid framework are filled with peloids and intraclasts, and the spicules are encrusted with *Girvanella* (Pl. 7.5, fig. 1). In other cases sponge fragments are filled with burrowed mud (Pl. 7.5, fig. 3). This biological activity probably destroyed many of the sponge skeletons soon after death. Sponges appear to have grown on the sediment stabilized by the algae or on skeletal debris (Pl. 7.5, fig. 4). Other (rare) constituents of the buildups are *Epiphyton* (only observed in

intraclasts), *Nuia* grains and problematic structures which resemble the "anastomosing tubes" described by Ross et al. (1975), who thought they might be cement between peloids (Pl. 7.2, fig. 2). Tsien (1986) suggested that "spongy or sponge-like structures" are spaces left by uncalcified algal filaments or micro organic tubes, while Klappa and James (1980) speculated that the reticulate pattern represents the remains of decayed sponges. These fossils are embedded in a dense packstone or skeletal wackestone matrix with abundant sponge spicules, trilobites, brachiopods, gastropods, echinoderm plates and a few partly chert replaced chitons(?). Silicified spar filled siphuncles of orthocone and coiled nautiloids are also abundant. The wackestone matrix is mottled light and dark brown as a result of intense bioturbation.

Texturally the clasts are silty, intraclastic skeletal wackestones to stromatolitic boundstones. Small amounts (between 1 and 2%) of quartzitic silt and dolomite crystals with dusty cores are distributed throughout the rock.

Interpretation: The presence of abundant small laminated *Girvanella*-stromatolites which form scattered hemispheres throughout the rock together with archaeoscyphid sponges indicate that these clasts represent fragments of an organic buildup facies. The capability of this association of organisms to form buildups has been demonstrated by Toomey (1981). Structures resemble the lower mound horizons described from the Lower Ordovician Kindblade Formation in Oklahoma (Toomey and Nitecki, 1979) which presumably represent subtidal shelf deposits of similar age.

The CH mound facies lacks *Calathium* which may indicate a deeper water setting of the CH-mounds if *Calathium* is indeed an alga as suggested by Nitecki, (1969). However, *Calathium* is also absent or rare in some of the sponge mounds in the lower Kindblade Formation.

These boundstones differ from the previously described *Girvanella* boundstones to wackestones (B.1.) by lacking stromatactoid voids and extensive fractures.

PLATE 7.5

Samples are from CH Peninsula unless otherwise indicated. Figures 1 to 6 are of *Girvanella* sponge boundstone. All figures except for Figure 5 are thin section photomicrographs.

Figure 1. *Girvanella* filaments encrusting calcite replaced sponge spicule (s). Pore space in sponge framework is also filled with algal threads (G). Scale bar is 0.2mm.

Figure 2. Well preserved *Girvanella* threads grading laterally into micospar suggesting that much of the finegrained sediment is derived from breakdown and diagenetic alteration of algal filaments. Scale bar is 0.2mm.

Figure 3. Framework of archeoscyphid sponge filled with burrowed mud. Scale bar is 1mm.

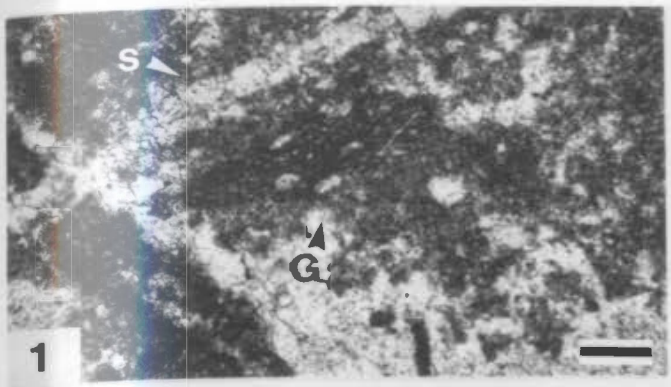
Figure 4. Reticulate pattern of sponge network with underlying microspar rimmed burrow in dolomitic silt-rich wackestone matrix. Scale bar is 0.8mm.

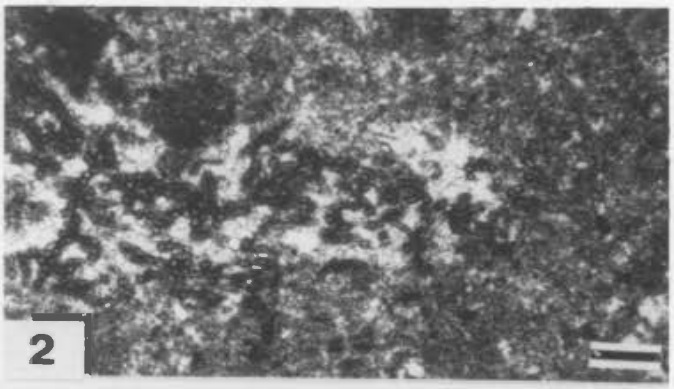
Figure 5. Clast from Lower Head West with reticulate cavities filled with bedded sediment. Arrow indicates "up" direction.

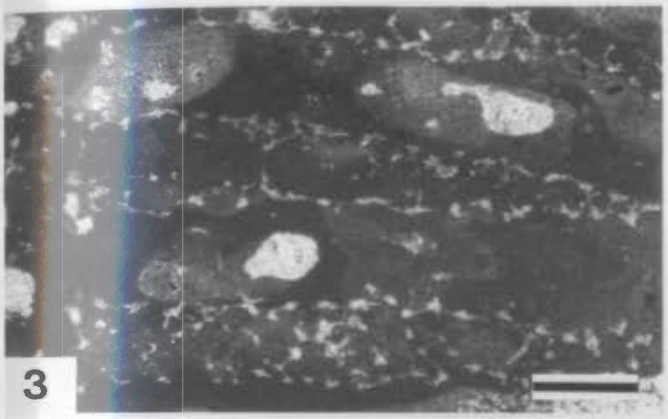
Figure 6. Photomicrograph of *Girvanella* boundstone of Figure 5. *Girvanella* aggregates form or surround small tubes. Scale bar is 0.3mm.

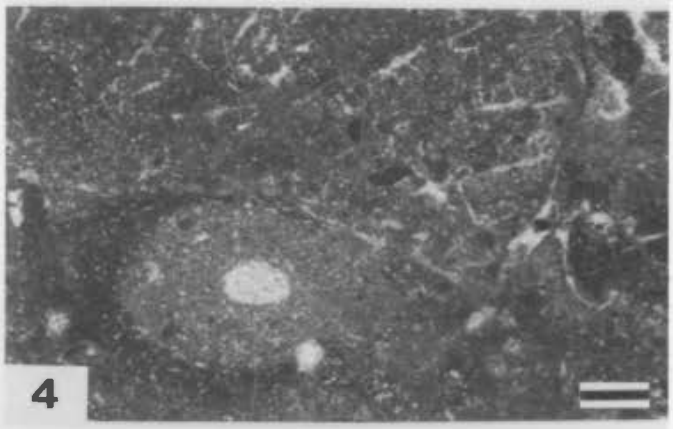
Figure 7. Lumpy mudstone. Book for scale (arrow) is 19x23cm large.

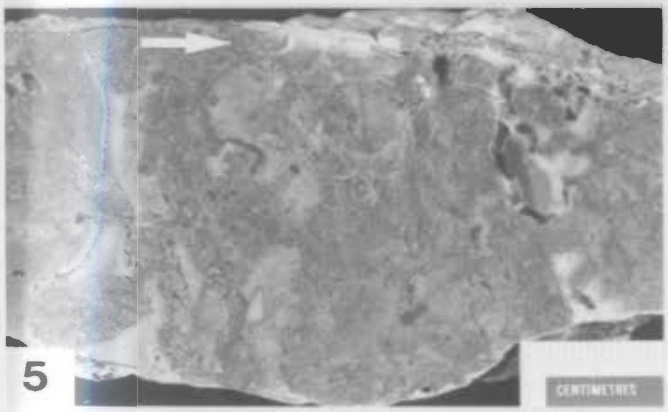
Figure 8. Old calcarenite clast with well rounded quarts grains and ooid (at far right) in dolomitic ground mass. Scale bar is 0.8mm.


S
G
1

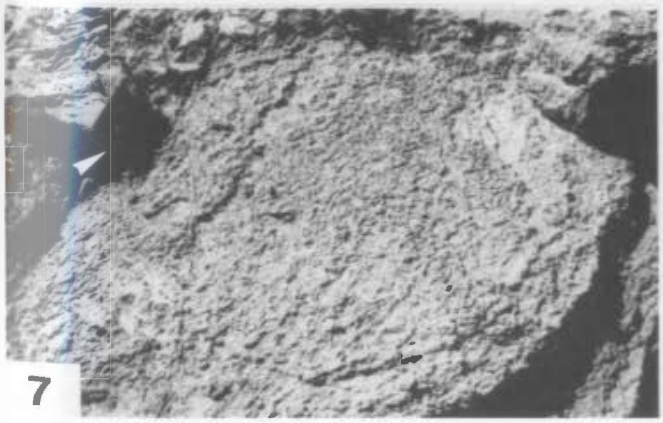

2

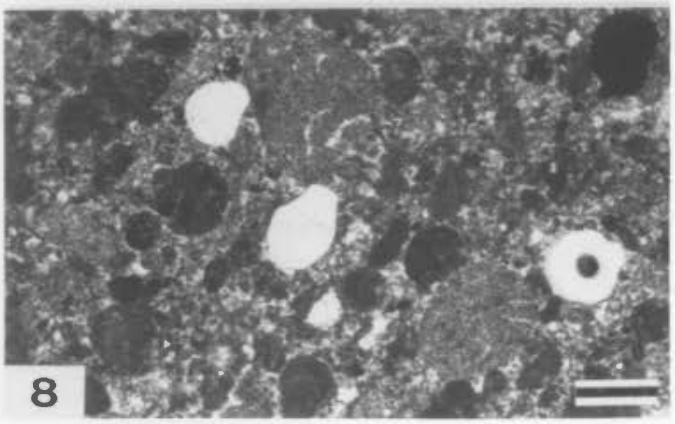

3


4


5
CENTIMETRES


6


7


8

They are generally darker in colour, more grainy and rich in silt sized quartz and dolomite. A gradational relationship with other facies has not been observed.

B.3 Bedded grainstone

Description: This lithology is bedded, light brown grainstone with abundant intraclasts, peloids, coarse brachiopod shells and minor trilobite fragments, gastropods, *Nuia* grains and variable amounts of echinoderm fragments. Acid insoluble residues yield a sponge spicule assemblage with elements similar to those described below from the massive algal boundstones. Grains are more than 90% algal derived with most being irregular shaped, poorly rounded algal lumps and peloids of fine to very coarse sand size (Pl. 7.2, fig. 2). Some larger grains appear to be deformed and were probably not completely lithified when eroded. Grains float in a very coarse neomorphic calcite spar with dusty inclusions or in silica. Neomorphism also affected brachiopod fragments, some of which can only be recognized by dusty outlines which are probably the remains of micrite envelopes seen in better preserved fragments.

Interpretation: Bedded grainstones differ from calcirudites with shallow water derived lithoclasts because they are composed of smaller grains, coarser fossils and are better sorted. The conodont fauna indicates an upper slope origin. Large size and poor rounding of the fragile algal lumps and the shell debris suggests that the rock was formed in a low to medium energy environment although it should be kept in mind that skeletal particles commonly show peculiar hydraulic behaviour which can make environmental interpretations questionable (Jindrich, 1969). The grain composition dominated by *Girvanella* sands resembles that of grainstone lenses found in algal boundstone (B.2.). This evidence together with the presence of a similar sponge spicule assemblage implies a similar source for the bedded grainstone. As for some of the B.4.2 calcirudites they, too, may represent talus sediment of carbonate banks or buildups. Bottom hugging submarine currents can also enhance formation and sorting of coarse grainy sediments in otherwise low energy environments.

B.4 Calcirudite.

Description: Calcirudite clasts are composed of 0.5-5cm sized lithoclasts in a grainstone matrix. Clasts are of moderate size (up to 25cm in length), light gray brown or blue gray, sporadically dark brown and subrounded to subangular in shape (Pl. 7.6, fig. C.3). No soft-deformation has been observed. Yellow weathering grains and patches on the clast surfaces (blue on fresh surfaces) are the result of partial silicification of components and pore space filling cement.

Calcirudites are composed of a variety of different sand to pebble sized bioclasts and lithoclasts embedded in either early cement or microspar to pseudospar. Different bio- and lithoclastic components together with different conodont faunas indicate three types of calcirudite with:

B.4.1. Lithoclasts and conodonts mostly shelf derived; B.4.2. lithoclasts and conodonts mostly derived from the upper slope; B.4.3. lithoclasts mostly derived from the lower slope.

B.4.1. Shelf derived calcirudite

Calcirudite with shelf derived lithoclasts is rare (only one clast has been identified) and the conodont fauna retrieved indicates that the clast is slightly older than most others and originated from the shallow platform. These calcirudites contain granule to small pebble sized lithoclasts in a sand matrix. The clasts are irregular shaped, commonly elongated peloidal packstones and wackestones together with numerous *Girvanella* clasts (Pl. 7.1, fig. 6). The sand sized fraction is composed of bioclasts and peloids many of which are algal in origin. Peloids comprise the largest number of grains. Skeletal grains are mostly *Nuia* and echinoderm fragments, the latter commonly bored and/or with syntaxial cement overgrowths. Other bioclasts include *Girvanella* remains (e.g. tubules and lumps), together with brachiopod and trilobite shells. Pore spaces are filled with a clear blocky calcite spar.

B.4.2 Upper slope derived calcirudite

This most common type of calcirudite yields dominantly upper slope derived lithoclasts and conodonts. Calcirudite clasts are occasionally found interbedded with bedded and massive grainstone, wackestone (Pl. 7.6, figs. A.1, A.2, B.1) and parted lime mudstone (Pl. 7.6, figs. C.1, C.2). The lithoclasts range in size from 0.5cm to 4cm. The sand:clast ratio ranges from 70:30 to 30:70. Most of the lithoclasts are microbioclastic wackestone, commonly rich in sponge spicules, echinoderm plates and small shell debris and comprise between 20% and 80% of the total lithoclasts. *Girvanella* clasts characterized by loosely packed or densely crowded clusters of *Girvanella* are next in abundance. They are generally smaller than the wackestone clasts and make up 20% to 40% of the clast total. Micritized *Girvanella*-clasts may not have been recognized and in this case the clast type may be more abundant than is obvious. Some wackestone clasts are deformed (Pl. 7.1, fig. 7) reflecting the semi-consolidated nature of the clasts prior to transport. The soft nature of the lithoclasts during transport is also indicated by: (a) deformed lithoclasts enveloping grains; (Pl.7.1, fig. 7); (b) disintegrated clasts of peloidal wackestones; (c) "rip-up" or loadcasts in underlying wackestones (Pl. 7.6, fig. A.1, A.2); (d) pitted irregular surfaces of lithoclasts; (e) indistinct grain boundaries.

A fourth, rare type of lithoclast is peloidal packstone to wackestone which usually comprises less than 10% of the clast total.

The sand fraction of the calcirudites is polygenetic comprising algal peloids(?), small lithoclasts and fine grained skeletal debris composed of echinoderm plates, brachiopod and trilobite shells, all of which have micritic envelopes. Sedimentary structures observed in some clasts include a) bedding parallel orientation of elongate lithoclasts; b) mm-thick beds of coarse lithoclast layers alternating with finer grained sand-rich horizons; c) geopetal fillings with sand at the bottom of otherwise spar filled pores between lithoclasts, shelter pores and perched sand on top of lithoclasts. Some *Girvanella* fragments as well as other indetermined

intraclasts are preferentially replaced by neomorphic calcite spar and form coarse crystalline lithoclasts with well defined boundaries and intercrystalline paste (sensu Coniglio, 1985). Lithoclasts show all stages of transition between original clast and replaced end-product. Locally clast and/or matrix are replaced by silica (Pl. 7.6, fig. B.2). Spar between grains and clasts is the same coarse neospar that replaces micrite rich lithoclasts suggesting that it is neomorphosed micrite (Coniglio and James, 1985) (Pl. 7.6, figs. B.2, C.3). The presence of an aggraded matrix is indicated because: (1) the majority of interfaces between the crystals are curved; (2) intercrystalline clay is present between the crystals; (3) patches of micrite are preserved; (4) star shaped radial fibrous crystal aggregates fill large pore spaces; (5) floating grains are abundant; (6) between 10% and 20% of the lithoclasts are completely replaced by coarse neospar. This evidence suggests that much of the "grainstone matrix" is a diagenetically altered wackestone with an original mud matrix.

B.4.3 Lower slope derived calcirudite

Calcirudites with mixed shallow and deep water clasts contain the largest clasts (up to 5cm long) with an average size of 5-10mm. They are bimodal with very coarse lithoclasts in a medium grained calcarenite matrix. Some clasts are associated with bedded mudstones indicating a genetic relationship with these lower slope deposits. The lower slope lithoclasts are flat mudstone pebbles with some silt sized peloid layers. Some mudstone lithoclasts are armoured, i.e. sand grains were pressed into the surface while it was still soft. (Pl. 7.1, fig. 8). They range in abundance from 10% to 60% of the lithoclast total. Rare phosphate pebbles are restricted to this calcirudite type. The other components are similar to upper slope derived lithoclasts described from type B.4.2. The lithoclasts are crudely graded. The sandy matrix is locally cross laminated.

Interpretation: Most calcirudite lithologies are similar to "fore slope breccias" described by Hopkins (1977) and derived from different sources on the slope and transported over variable distances. Figure 7.3 summarizes inferred relationships between different types of calcirudites.

The calcirudites with sands, lithoclasts and conodonts derived from the shelf (Type B.4.1) closely resemble fore slope breccias described from the Miette and Ancient Wall buildups in Alberta (Hopkins, 1977). The source rocks there were differentially cemented (nodular) bedded carbonate sands deposited on the upper slope. Downslope movement by hybrid sediment gravity flows mixed nodules with uncemented sands and ended after relatively short distance transport resulting in breccia deposition. Stricker and Carozzi (1973) described similar deposits with rip-up clasts and sheltered pore spaces from shallow water sediments of the Pogonip Group (Nevada) and interpret them as storm deposits. Storm deposits have been reported from the western Newfoundland shelf sequence (Catoche Formation, Knight and James, in press) and may have functioned as triggers for sediment movement. Similarity of composition between sands in B.4.1 and B.4.2 calcirudites suggests that the sands in both types originated high on the fore slope or on the shelf. When the supply of sand to the fore slope was relatively high, rapid loading and unstable packing of sediments could result in failure and sediment gravity flows which then incorporated the muddy sediments further down slope mixing soft sediment clasts with mud and sands and resulting in the formation of B.4.2 calcirudites. A somewhat similar mechanism has been concluded for the formation of "pebbly mudstones" in Lower Cretaceous sediments in California (Crowell, 1967) which are interbedded with deepwater limestones. Gwinner (1976) described intraformational breccias with similar characteristics from Jurassic deposits in West Germany where the clastic limestones are found intercalated with bedded marls and lime mudstones downslope from algal sponge mounds. The calcirudites interbedded with parted lime mudstone are probably of similar origin.

Selwood (1978) comments on the presence of slumped flank beds in Waulsortian mud mounds, and suggested that they provide evidence of periodically mobile slopes of the mounds. Similarly the B.3.2 calcirudites may in part be coarse talus sediments which formed around banks or buildups on the upper slope. This explanation seems to be particularly applicable to types which are intercalated

ORIGIN OF CALCIRUDITE CLASTS

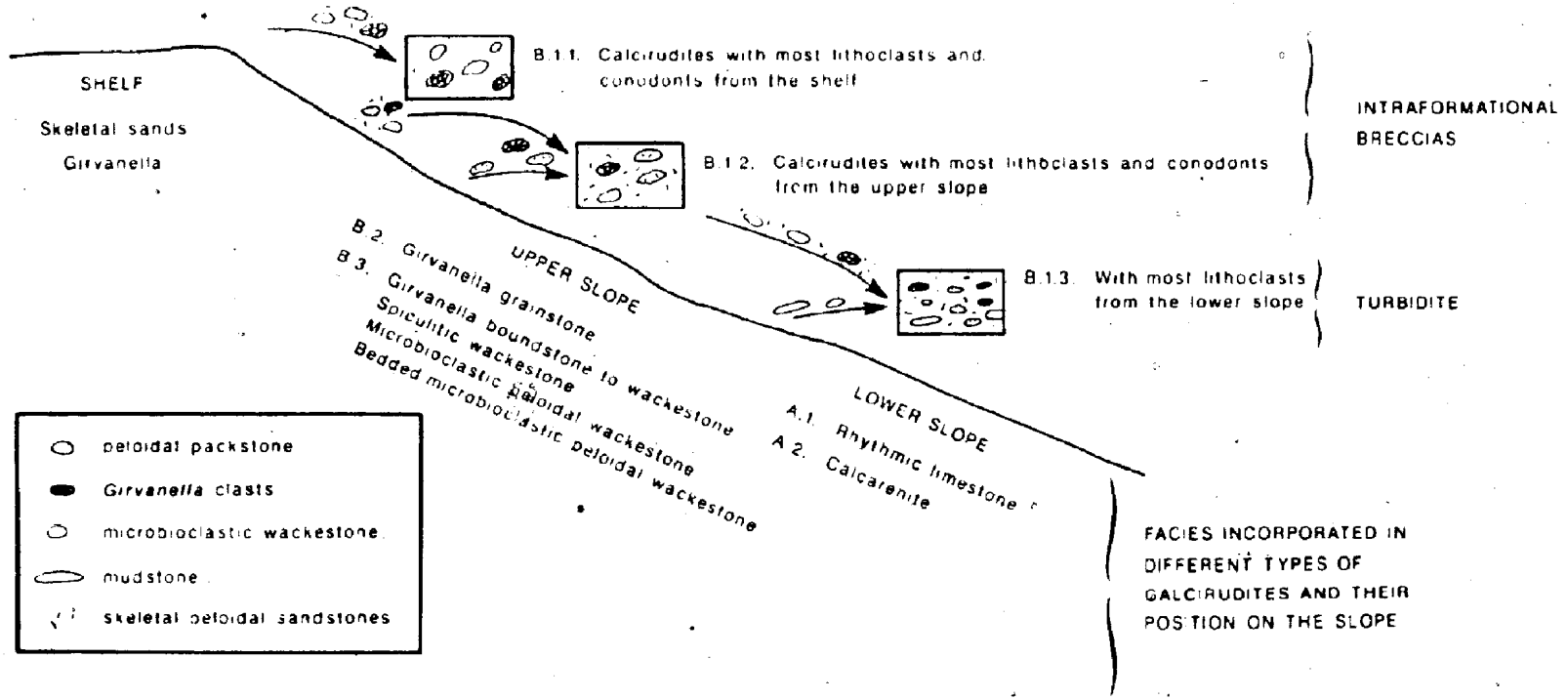


Figure 7-3: Diagram illustrating inferred relationships between different types of calcirudite.

PLATE 7.6
Calcirudites

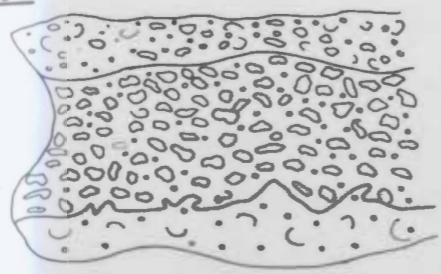
Figure A.1. Left, field sketch of calcirudite clast from Bed 10 (CH Peninsula, Shoal Cove) with 1. bedded wackestone (ws) showing possible evidence of basal scouring and beginning of rip-up which seems to be caused by erosion through 2. the overlying calcirudite (cr). Calcirudite is overlain by 3. coarse grainstone (gs). The clast is about 30cm long; right, Figure A.2. Photograph of clast A.1 in the field. Hammer handle about 4cm thick.

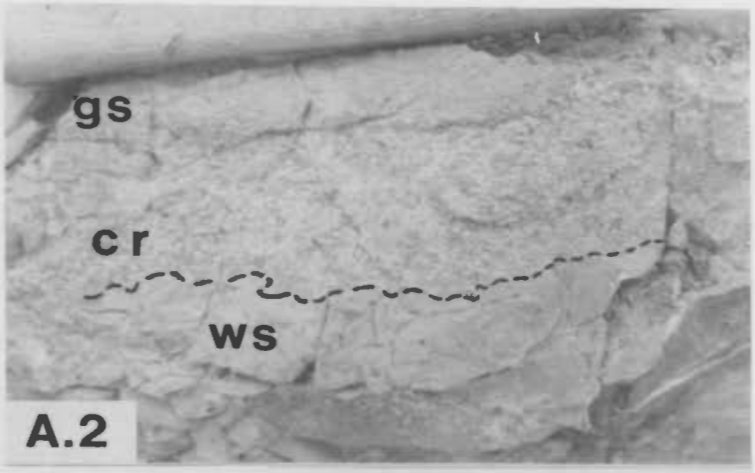
Figure B.1. Left, field sketch of calcirudite clast from Bed 10 (CH Peninsula, The Ledge) composed of interbedded calcirudite, pelsparite and bedded skeletal wackestone indicating the genetic relationship between the different facies. Clast is about 30 cm long. 5x enlarged section of lithoclastic layer is shown in circle to the left; right, Figure B.2. thin section photomicrograph of clast illustrating neomorph spar (ns); silica replaced clast (sc) and possibly geopetal sediment fill (gs) between the two replacement structures. Scale bar is 0.8mm.

Figure C.1. Left, field sketch of calcirudite clast from Bed 10 (Lower Head West) with overlying parted limestone. Clast is about 35cm long; right, Figure C.2. detail of contact between mudstone and calcirudite. Coin is 2.5cm across. C.3. Polished slab of calcirudite clast with irregular lithoclasts in mud or neospar matrix.

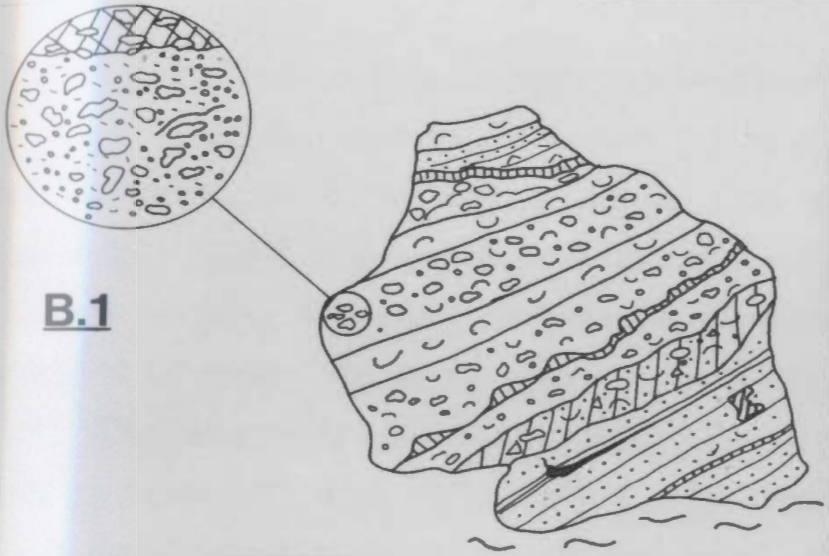
Calcirudites

A.1

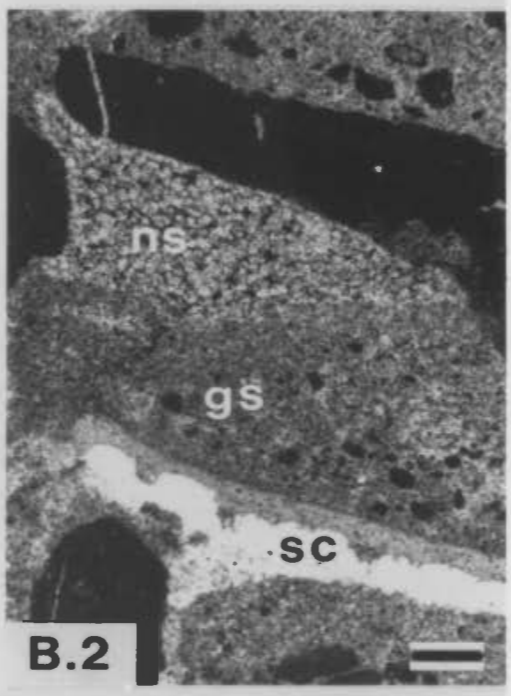




A.2

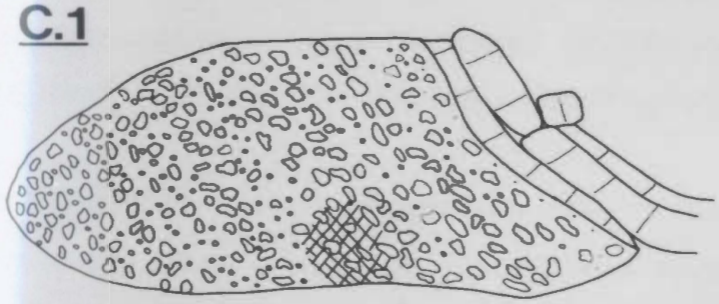


B.1



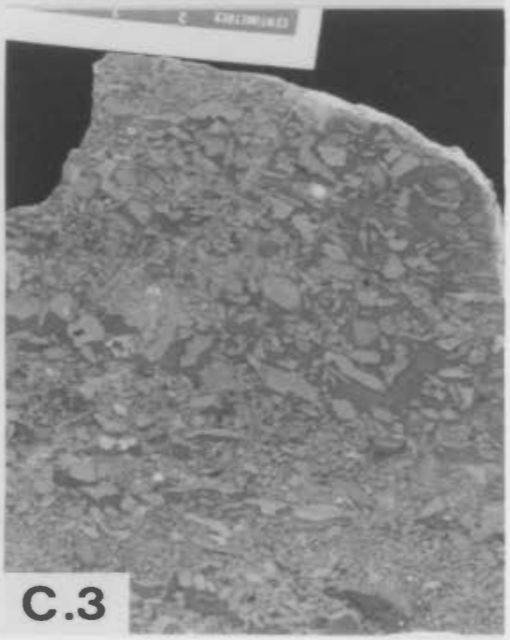
B.2

C.1





C.2



C.3

with bedded wackestones and grainstones (Pl. 7.6, figs. A.1, B.1) which are also interpreted as intermound sediments (see B.1 and B.3).

The lithoclasts in Type B.4.3 are of mixed origin and derived from shelf, upper and lower slope suggesting that during transport different clast lithologies were incorporated. The gradation of the components and the presence of cross bedding suggests deposition from turbidity currents.

B.5 Lumpy wackestone

Description: Clasts of this lithology are bedded wackestones and mudstones with cm sized limestone nodules separated by argillaceous dolomitic partings of variable thickness. A boulder found on Cow Head Peninsula displays facies relationships which are usually only encountered in separate clasts (Pl. 7.7). A sequence of three different lithologies is present: a lower bed (40cm thick) is composed of lumpy limestone with yellow weathering dolomitic partings 1-5cm thick. The interbedded mudstone layers form single nodules or, more commonly, wavy nodular beds with little shell debris. They are overlain by a massive to rubbly fossiliferous wackestone (10 cm thick) with minor dolomite (5%-10%), followed by another bedded sequence (40cm thick) composed of light gray, slightly nodular mudstone (0.5-1cm thick) interbedded with yellow brown weathering dolomites (1-4cm thick). No fossils have been observed in this upper part.

Texturally the lumpy limestones are mostly skeletal wackestones. The rubbly fabric is the result of limestone nodules of variable size (commonly 0.5-1cm across) surrounded by an argillaceous dolomitic matrix. The ratio of dolomitic matrix to limestone is highly variable ranging from 8:2 to 2:8. The nodules commonly grade into the matrix but also clearly defined limestone lumps may be present which are occasionally bordered by fractures or stylolites.

Most of the dolomite crystals possess a cloudy core and are probably detrital in origin (Coniglio, 1985) (Pl. 7.7, fig. 3). The centers of some rhombs are calcitic

indicating replacement of the dolomitic core. Matrix as well as clasts show traces of intense bioturbation. Skeletal remains are echinoderm fragments (up to 1cm in size), *Nuia*-grains, brachiopods, trilobites and occasional nautiloids (Pl. 7.7, figs. 1,2). Bioclasts are generally angular and range between 10% and 20% in abundance. Echinoderm fragments are the most common grains followed by *Nuia*, a problematic microfossil, usually assigned to algae (Guibault et al., 1976).

The lumpy wackestones with variably pronounced argillaceous dolomitic partings occur commonly in Bed 10 as well as in younger beds. Conodont faunas indicate the clasts are in most cases slightly older than other clasts found in Bed 10. In addition, some clasts are barren or yield only indistinct single or broken conodonts and cannot be assigned with certainty to any stratigraphic position.

Interpretation: Lumpy wackestones are muddy sediments which were probably deposited in quiet water below the wave base where deposition was not disturbed by turbulence. The rapid change from bedded mudstones with impoverished biota to bioturbated, fossiliferous wackestones observed in one boulder probably records shifts in the depositional environment such as bottom aeration or other factors that influence benthic life. The abundance, coarseness and angularity of the echinoderm debris suggests the presence of a suitable growth environment nearby (Ruhrman, 1971). The presence of brachialia and columnalia indicates derivation from stemmed echinoderms which probably grew attached to a hard substrate. No traces of holdfasts or borings were observed and the sediment surface was probably muddy implying that the echinoderms were most likely attached to brachiopod shells in the soft mud. A soft water-rich substrate can also be inferred from the diffuse outline of the burrows (Walker and Alberstadt, 1975). The good preservation of the burrows reflects only minor compaction and possibly early lithification in shallow subsurface depth (Mullins et al., 1980). The formation of nodular limestones has been variously interpreted. It maybe the result of concretional growth of calcite crystals caused by interaction between clay-rich and carbonate-rich material (Schindewolf, 1925; Coniglio, 1985, in press).

PLATE 7.7
Lumpy wackestone facies

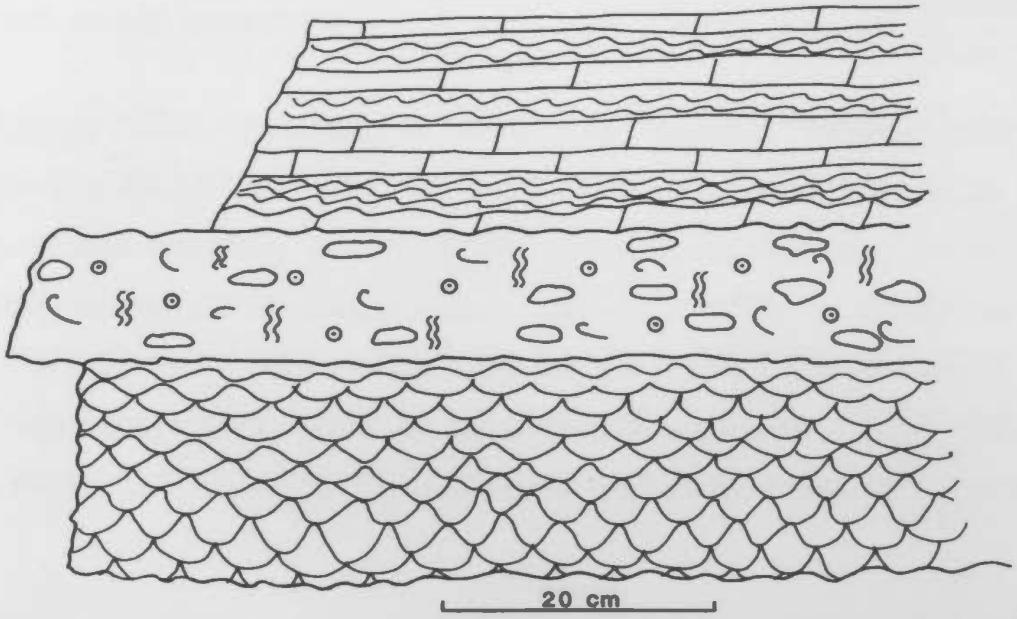
Drafted figure is field sketch of lumpy wackestone seen at Shoal Cove on CH Peninsula. Lumpy wackestone at bottom is overlain by burrowed skeletal wackestone followed by bedded limestone with fitted fabric and with dolomitic argillaceous partings.

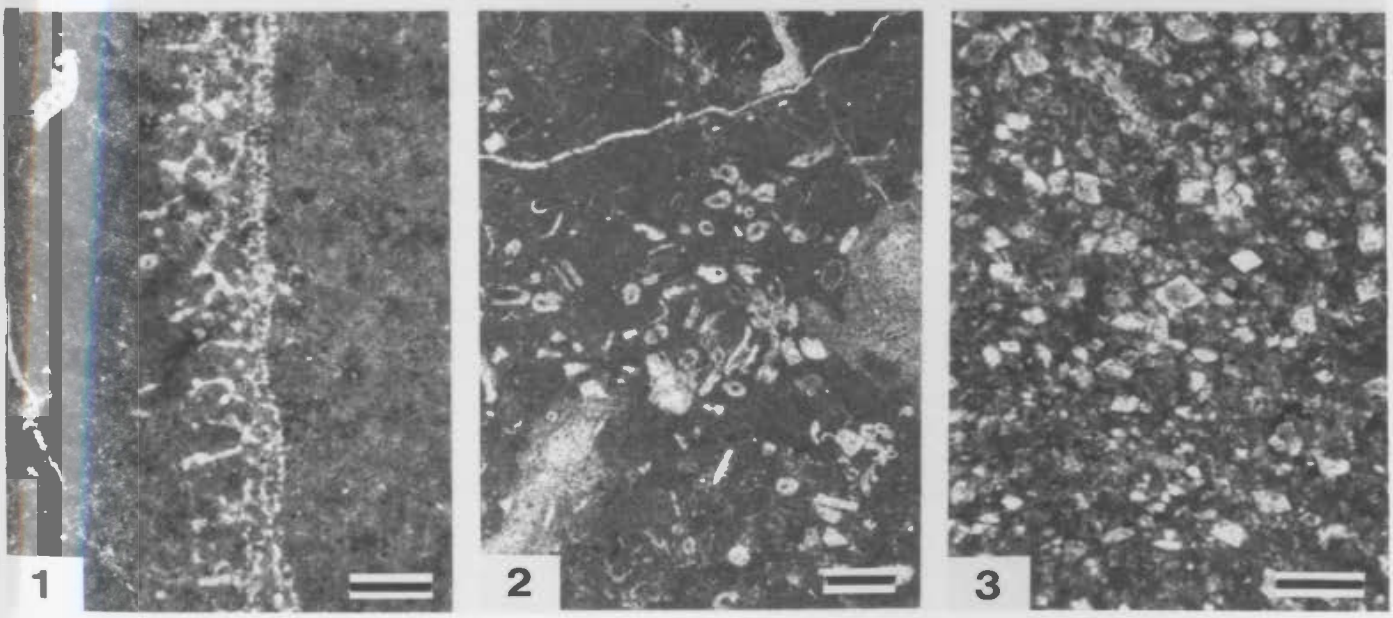
Figure 1. Thin section photomicrograph of echinoderm fragment in lime mud matrix. Scale bar is 0.2mm.

Figure 2. Thin section photomicrograph of *Nuia* grains and echinoderm debris in burrowed lime mud matrix. Scale bar is 0.8mm.

Figure 3. Thin section photomicrograph of cored dolomite rhombs from argillaceous partings. Scale bar is 0.4mm.

Lumpy wackestone





B.6 Lumpy mudstones

This limestone is bedded lumpy lime mudstone with mm thick greenish argillaceous siltstone partings. Limestone layers are formed of separate or coalescent limestone nodules surrounded by variable amounts of parting material (Pl. 7.5, fig. 7). Rocks of this lithology are typically barren of conodonts. The rock surface is commonly white wheathering. Larger rafts are always soft deformed but rarely preserved.

Interpretation: This lithology is similar to nodular hemipelagites from the bedded sequence (A.1), however, the lumpy fabric is never present in those rocks. Lumpy limestones typically occur on the upper slope and may be comparable to peri-platform ooze of Schlager and James, (1978). They are probably hemipelagites and the lumpy fabric may be the result of preferential lithification of calcite-rich layers as a result of intensive bioturbation. They differ from the lumpy wackestones (B.5) in the sparse fossil content and lack of a conodont fauna

7.4. C. OLDER CLASTS

C.1. *Epiphyton* boundstone:

The *Epiphyton* boundstone is an uncommon lithology which can be readily recognized by the high silica content which causes orange weathering and obliteration of much of the boulder surface. A large number of white *Epiphyton* colonies in growth position are, however, surrounded by small fibrous calcite rimmed cavities. The lithology has been described in detail by James (1981). The dense micritic *Epiphyton* colonies are intercalated with sheets of *Girvanella*. Fine grained micritic sediment, possibly derived from algal breakdown envelops many of the *Epiphyton* colonies. A coarse peloidal packstone is locally present between the algae with many of the rounded well-defined peloids made up of several *Epiphyton*-branches. Other components are rounded quartz grains and rare ooids. Silicification is either pervasive or affects only the fine-grained sediments (i.e. *Epiphyton* peloids) leaving spar-filled pore spaces untouched.

Interpretation: The single broken conodont present in a sample from an *Epiphyton* boundstone suggests a Tremadoc or older age for these clasts. Clasts of *Epiphyton*- and *Girvanella* dominated boundstones occur abundantly in the Cambrian to Tremadocian conglomerates of the CHG (James, 1981) and in other Cambrian shelf edge facies (Pfeil and Read, 1980). They are interpreted as algal buildups which grew in shallow though tranquil environments along the platform margin of the North American craton. *Girvanella* appears to be the basic builder of the mounds with *Epiphyton* colonies attached to them. *Renalcis* and stromatolitic algae were minor components of the buildups which probably developed a low relief above the seafloor due to early cementation by calcite cements.

C.2 Oolite

A single light gray oolite clast occurs as a rounded and fractured boulder 40cm x

30cm. The oval and round sorted components are oriented bedding-parallel and many of the grains have a yellow weathering rim which probably stems from surficial silicification of outer ooid laminae. The fractures dissecting the clast are up to several cm in width and form a network in which larger fractures are connected by thin cracks. The larger fractures are filled with the typical bedded light grey to grey mudstone which also occurs in fractures in the massive wackestone lithology or with yellow weathering pelsparite. The cavity fills are bedded with a slight angle to the bedding of the oolite clast. The rock is an ooid grainstone composed to 90% of oval superficial ooids. One to two concentric laminae surround a core of variable composition. Most commonly the cores are formed by intraclasts composed of peloidal grainstones, but homogeneous mudstones, skeletal grainstones and packstones also occur.

Ooid types other than the superficial ooids are: poly-ooids, normal ooids (usually with large cores) and small radial ooids. Also "ooid ghosts" occur which are faint outlines of aggraded grains, presumably ooids judging from their shape, size and the presence of a better preserved outer cortex layer. Thin rims of isopachous cement are present around most grains and pore spaces are filled with sparite.

Interpretation: No conodonts are present in this boulder but oolites and other massive lithologies with abundant well rounded grains are typically found in the Cambrian to Tremadocian part of the CHG and the adjacent shelf carbonates of the Port au Port Group (Chow, 1986). Clasts of ooid grainstone with cavities containing green internal sediment also occur in Bed 8-conglomerates (James and Stevens, 1986). The ooid grainstones are interpreted as deposits of shallow marine environments which form under moderate to high energy conditions. In Recent sediments (e.g. the Great Bahama Banks) superficial ooids have been observed in deeper water environments (Newell et al., 1960) and the presence of large nuclei surrounded by only few thin cortex layers is generally regarded as an indicator for ooid formation in comparably quiet waters.

C.3 Calcarenite

A single orange to yellow weathering boulder found at Cow Head Peninsula is a coarse to medium calcarenite with well rounded quartz- and lime sand grains and sparse flat pebbles in a siliceous dolomite matrix (Pl. 7.5, fig. 8). The flat pebbles are composed of fine grained dolomite and up to 4cm long and 1cm thick. They are oriented parallel to the bedding and make up 10% of the whole rock volume. The fine to coarse sand sized components are mainly peloids, quartz grains and intraclasts which are composed of mudstones and pelsparites. All grains are rounded to well rounded. A few scattered ooids with radial cortexes are present. Skeletal components are echinoderm fragments.

Iron-rich euhedral dolomite crystals comprise the matrix. The dolomite rhombs typically show a round cloudy core suggesting a detrital origin followed by diagenetic growth of the crystals.

Interpretation: Similar calcarenites with floating tabular clasts and quartzose sands are present in the Cambrian part of Bed 8 in the proximal sections of the CHG (James and Stevens, 1986). No conodonts have been obtained from the clast and therefore the statigraphic level cannot be confirmed. Hiscott and James (1985) regard the upper Cambrian flat pebble conglomerates (their Facies A) and calcarenites as deposits of turbidity currents in contrast to the former interpretation by Hubert et al. (1977) as contourites.

Chapter 8
CLAST LITHOLOGIES OF BED 12

8.1. Introduction

Bed 12 is a megaconglomerate which is intermediate in age and clast size between Bed 10 with the smallest clasts and Bed 14 with the largest clasts and greatest variety of lithologies. The different lithologies are summarized in tables 8.1-8.3.

8.2. A. Local penecontemporaneous clasts

A.1 Rhythmic limestone

Description: These clasts are defined and described in detail from Bed 10 (Chapter 7). Parted and ribbon limestones in Bed 12 are similar in overall composition to those from Bed 10 and therefore only addressed briefly herein. Description will concentrate on the differences between Bed 10 and Bed 12 lithologies.

A.1.1 Parted and ribbon limestone

Most large rafts of lower slope lithologies in Bed 12 are parted limestones, ribbon limestones are rare. The parted limestones are composed of several cm thick dark grey to dark brown layers of unfossiliferous micrite interbedded with thinner parting material which is either shale or argillaceous siltstone with variable amounts of dolomite. Lime mudstone is generally a homogenous unfossiliferous micrite sporadically wholly or patchily aggraded to microspar.

TABLE 8-1. CLAST LITHOLOGIES - LOCAL PENECONTEMPORANEOUS CLASTS.

LITHOLOGY	LITHOLOGICAL INTERPRETATION	INTERPRETATION
A.1. Parted and ribbon limestones, plates	Dark grey to dark brown several cm thick limestone layers separated by shale or argillaceous siltstone with variable amounts of dolomite. Limestones are homogenous or bioturbated micrites; bioclasts are radiolarians and Girvanella filaments.	Hemipelagites Mud or silt turbidites
A.2. Calcarenites	Medium calcarenites composed of a) shallow water or b) deep water derived sands. Bedding present.	Turbidites
A.3. Conglomerates	1. Oligomict conglomerate with dolomitic matrix. Irregular shaped wackestone and mudstone lithoclasts, chaotic fabric, matrix support.	Debris flows
	2. Oligomict conglomerate with limestone matrix. Irregular shaped wackestone and mudstone lithoclasts, chaotic fabric, matrix support.	
	3. Polymict conglomerate with calcarenite matrix. Lithoclasts of flat mudstone pebbles, grainstone dolomite, chert. Oriented fabric.	Turbidites
A.4. Dolostone	Buff weathering laminated dolostone, silicified.	Detrital dolomite dolomitized on seafloor
A.5. Chert	a) Chert intercalated with limestone beds; b) dark brown angular chert plates; c) green and red chert clasts.	Limestone relaced by silica prior to erosion
A.6. Shale	Green laminated shale, softly deformed	Mud turbidite.

TABLE 8-2 CLAST LITHOLOGIES - FOREIGN PENECONTEMPORANEOUS CLASTS

LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
B.1. Massive wackestone and massive to bedded grainstone	Facies consists of three end members: 1. Burrowed wackestone and packstone; with a) microbioclastic wackestone, b) peloidal microbioclastic wackestone, c) peloidal microbioclastic packstone. Bioturbation alters sediment to form sub types 1a)-1c). 2 Massive grainstone to packstone; Poorly to well sorted medium to coarse calcarenite with variable amounts of mud preserved between grains. Commonly associated with burrowed wackestone and mudstone. Sometimes highly fractured. 3. Bedded grainstone to rudstone; elongated, subrounded to rounded mudstone and wackestone lithoclasts in calcarenite or mud matrix.	Upper slope mud accumulations Shelf edge sands Talus sediment and/or foreslope breccias
B 2 Boundstone	Light grey boundstones are dominated by algae (Renalcis, Epiphyton, Girvanella); brown boundstones are formed by algae together with sponges and enigmatic organisms. Colour stems from high detrital content. Associated facies are medium to coarse grainstones	Organic buildup facies
B 3 Calcirudite	1 Calcirudites with dominantly lower slope derived lithoclasts: soft deformed lithoclasts of mudstone and bedded wackestone, 2cm-4cm long in microspar matrix 2 Calcirudites with dominantly upper slope derived lithoclasts, irregular shaped mudstone and wackestone lithoclasts, 0.5cm-3cm in size microspar matrix	Talus sediment and/or intraformational breccias
B 4 Lumpy dolomitic wackestone	Correlates to lower Bed 11 in age, light grey lumpy wackestones intercalated with variable amounts of dolomite, sediment intensively burrowed, fossiliferous with brachiopods and trilobites, fractured.	Upper slope mud accumulations
B 5 Bedded mudstone to wackestone	Correlates to upper Bed 11 in age, bedded to rubbly mudstones and wackestones with irregular, poorly defined bedding planes, bioturbation common anastomosing tubes, spongiomorph fabric.	Algal-bound(?) mud deposits, in shallow water
B 6 Shelf derived grainstone	Bedded brown and light grey mudstone interbedded with light brown grainstone. Boulder cut by silica lined fractures filld with bedded sediment	Shelf derived sediment deposited under variable energy conditions
B 7 Lumpy mudstone	Bedded to rubbly mudstone with large spar filled burrow shafts and thin dolomitic argillaceous siltstone partings	Peri-platform ooze

TABLE 8-3. CLAST LITHOLOGIES - OLDER CLASTS.

LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
C.1. Brachiopod-rich wackestone to mudstone	Age equivalent to Bed 9 and older, mixed fauna. Mottled mudstone with wackestone layers. Discontinuity surface present.	Condensed sequence of shallow water limestone
C.2. Oolite	Superficial ooids intercalated with dolomite rich wackestone.	Shelf edge sands of Cambrian age
C.3. Calcarenite	Lithoclasts of wackestone and mudstone, limy matrix contains well rounded quartz grains. Clasts of flat mudstone pebbles oriented with long axis parallel to bedding plane.	Turbidites, equivalent to Bed 8
C.4. Calcirudite	Similar to calcirudites described from Bed 10 with lithoclasts mainly derived from upper slope.	Intraformational breccia or talus sediment reworked from Bed 10.

Pyrite crystals are dispersd throughout. Some limestone layers terminate in marginally aggraded crystals (Pl. 8.1, fig.1). Other components are rare and where present they are silt sized peloids and single *Girvanella* filaments. Some rocks contain up to 5% recrystallized radiolarians.

A.1.2 Bioturbated limestone

These are relatively rare light brown mudstones with dark blue stained, mm-sized burrows. Burrows differ from those in bioturbated limestones from Bed 10 in their smaller size and lower abundance.

A.1.3 Plates

Description: Limestone plates are the most abundant lower slope lithology. They are similar in composition to limestone layers in parted limestones. Thick (3-7 cm) subangular dark brown plates are particularly conspicuous.

Interpretation: Parted and ribbon limestones are hemipelagites and/or deposits of fine-grained turbidites like those in Bed 10. Lack of soft deformed ribbon limestone maybe due to their low preservation potential. Radiolarians are more abundant than in clasts from Bed 10.

A.2 Calcarenite

Description: Clasts of calcarenite are generally small plates composed of fine to coarse sand sized grains accompanied in some examples by lithoclasts of mudstone, 1 cm to several cm in size. Calcarenites are dominated either by shallow water derived grains or by deep water bioclasts (eg. spicules and radiolarians) indicating different sources for the components of the turbidites. Skeletal grains comprise from less than 1% to 30% of the components. Shallow water bioclasts comprise echinoderm fragments, *Nuia* grains, shell fragments (trilobites and brachiopods), *Girvanella* rafts and *Halisis* chains. Rounded to

subrounded peloids, probably of algal origin, comprise up to 90% of the grains, a coarser fraction are lithoclasts composed of lime mud (possibly *Girvanella*-derived), argillaceous dolomitic siltstone or phosphatic granules. Components are usually oriented parallel to bedding and alternating coarse and fine grained layers are present. The grains are embedded in a muddy matrix which is in places aggraded to microspar or neomorphic spar.

Interpretation. The calcarenites are deposits of turbidity currents which originated from different positions on the slope or at the shelfbreak. This is indicated by the variable composition of the main constituents which are derived from shallow and/or deep water sources.

A.3 Conglomerates

Description: Three types of conglomerates can be distinguished in Bed 12. They differ in composition of matrix and lithoclasts.

A.3.1 Oligomict conglomerate with dolomitic matrix. These conglomerates are composed of irregular shaped lithoclasts, up to 3cm long, surrounded by a dolomite rich argillaceous siltstone matrix similar in composition to the matrix of Bed 12 in general but sporadically silicified at the surface. Lithoclasts are subangular to subrounded wackestone and mudstone. The clast:matrix ratio is about 70:30 with few stylolitic contacts. Clast orientation is random.

A.3.2 Oligomict conclomerate with a carbonate matrix. These chaotic conglomerates contain subrounded to rounded clasts of homogenous and bioturbated mudstone and skeletal and peloidal wackestone up to 3cm long. The lithoclasts float in a carbonate matrix with scattered dolomite rhombs, quartz silt, peloids and skeletal debris of echinoderms and small unidentified shell fragments. The clast:matrix ratio is about 60:40 and stylolites are rare.

Interpretation: The oligomict conglomerate with carbonate matrix and oligomict

conglomerate with dolomitic matrix are probably deposits of debris flows indicated by matrix support, chaotic fabric and lithoclast diversity. Similar lithologies are present in conglomerate horizons in Bed 11 and their up-slope equivalents are probably the source for the clasts.

A.3.3 Polymict conglomerate with a calcarenite matrix.

These rare rounded boulders composed of subrounded lithoclasts, several cm in size and irregular in shape, are sporadically surficially silicified. The clasts are a mixture of flat mudstone pebbles, pelsparitic and intrasparitic grainstones, laminated dolomites, silicified grainstones and chert. The matrix is a medium to coarse grained calcarenite, cemented by calcite spar. No stylolites are visible. The clast:calcarenite matrix ratio is about 60:40. Elongate clasts are aligned with their long axis parallel to bedding.

Interpretation: The polymict conglomerates with a calcarenite matrix are probably the result of turbidity currents. This is suggested by oriented fabric of the flat pebbles and similarity to facies A turbidites of Hiscott and James (1985).

A.4 Dolostone

Description: Rounded blocks of buff weathering laminated dolostone are over 1m long (Pl. 8.1, fig. 2). The fresh surface is dark green and the rock is partly silicified. Clasts are similar in composition to dolostone beds found in the underlying Bed 11. Erosion of the Bed 11 dolostone can be seen at Point of Head.

Interpretation: Like dolostones in Bed 10 the dolostones are interpreted to be the result of submarine dolomitization of detrital dolomitic sands and silts.

A.5 Chert

Description: Chert occurs as layers in clasts of bedded fine grained lithologies intercalated with limestone beds. The contacts between limestone and chert are

usually gradational. The chert is commonly laminated and contains silt sized pyrite dispersed in the matrix (Pl. 8.1, Fig. 3).

Dark brown cm thick plates of chert with a grainy surface are conspicuous elements of the conglomerates especially at The Ledge on Cow Head Peninsula. The dark brown colour stems from an argillaceous cumulate between tenth of mm to mm sized chert layers which show fitted fabric or are lumpy. The fabric is probably the result of stylolitization. Clear round spheres dispersed throughout the rock are radiolarians. Other biogenic components are sponge spicules composed of ferroan calcite; ferroan dolomite is also present (Pl. 8.1, fig. 4).

In distal sections the conglomerate also contains small clasts of homogenous green and red chert.

Interpretation: Most cherts were probably originally limestones which were replaced early in their diagenetic history (i.e. before they were transported). (Coniglio, 1985).

A.6 Shale

Description: Clasts of laminated green shale up to 20cm x 30cm in size and soft deformed are found in some of the distal sections of Bed 12.

Interpretation: The laminated shales have been interpreted as fine grained turbidites in contrast to the massive shales, which are supposedly hemipelagic deposits (Coniglio, 1985). They are similar to the green shales in the distal facies of Bed 11.

PLATE 8.1

All pictures illustrate clasts and samples found in Bed 12 on Cow Head Peninsula.

Figure 1. Photomicrograph of parted limestone with contact of aggraded calcite crystals between lime mudstone and parting material. Scale bar is 0.3mm. Shoal Cove.

Figure 2. Rounded boulder of buff coloured bedded dolomite in conglomerate (Jim's Cove) which has been incorporated from the underlying Bed 11. Hammer (arrow) for scale is 35cm long.

Figure 3. Photomicrograph of laminated chert (Jim's Cove). Scale bar is 0.8mm. Arrow indicates "up" direction.

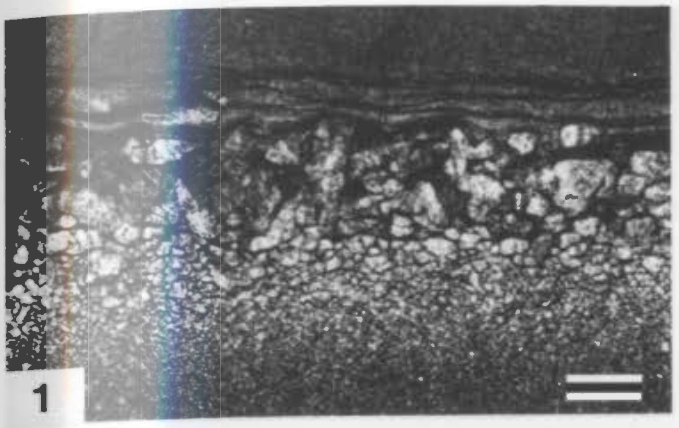
Figure 4. Photomicrograph of stylolitic chert with darkbrown residual sediment between sutures and abundant radiolaria (Point of Head). Scale bar is 0.8mm. Arrow indicates "up" direction.

Figure 5. Photomicrograph of calcirudite. Porespace between lithoclasts is filled half with microspar (gs) and half with aggraded neospar (ns). Floating grains indicate neomorph nature of porefilling cement (Jim's Cove). Scale bar is 0.8mm.

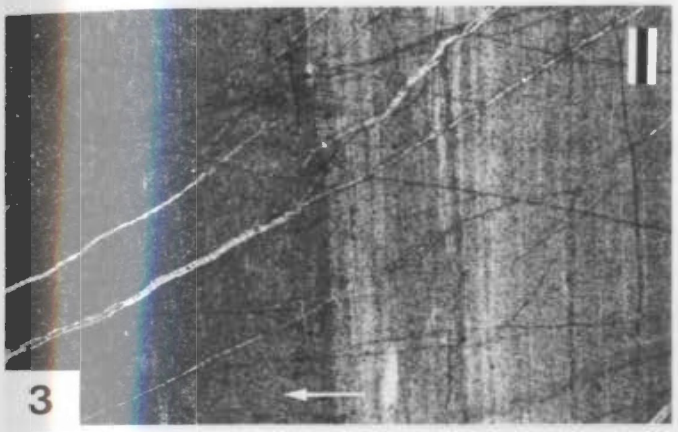
Figure 6. Photomicrograph of calcirudite with relicts of mud at bottom of pore spaces suggesting that sediment was filtered in between grains after lithoclasts were deposited (Jim's Cove). Scale bar is 0.8mm.

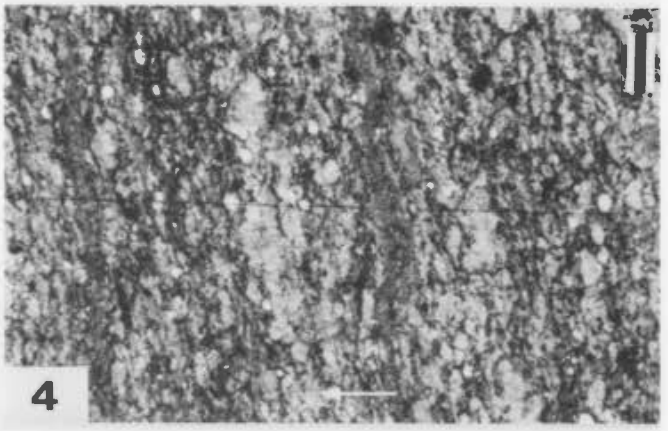
Figure 7. Void in wackestone to packstone is partly filled with peloids (vs) and lined with glaucony (Jim's Cove). Scale bar is 1mm.

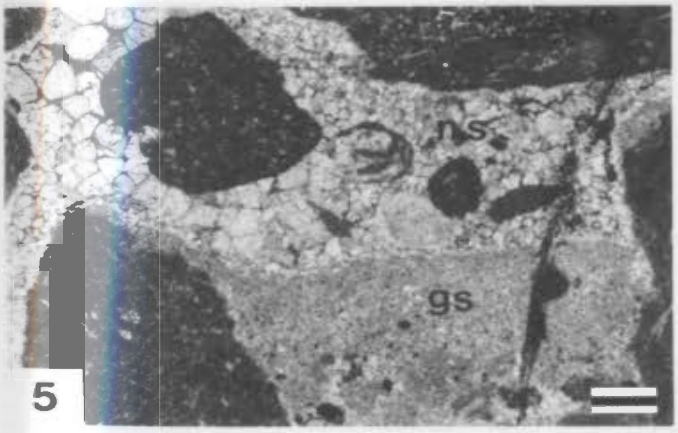
Figure 8. Chondrites-like burrow system in massive wackestone was actively filled with peloids by the burrowing organism (Jim's Cove). Scale bar is 4mm.


1

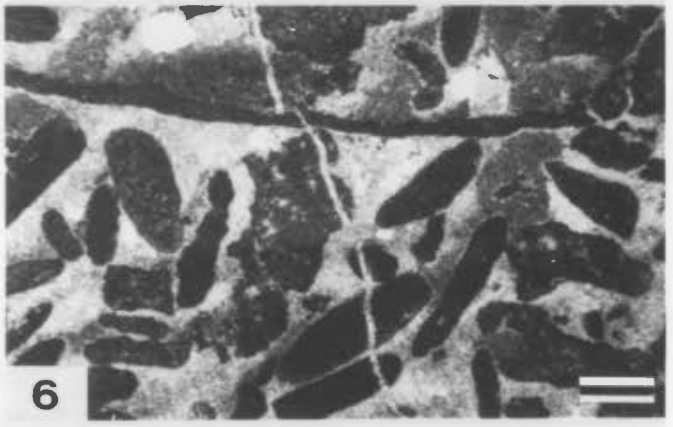

2

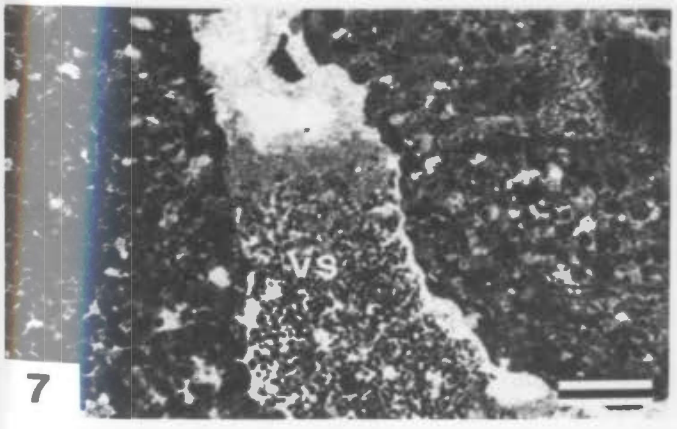

3


4

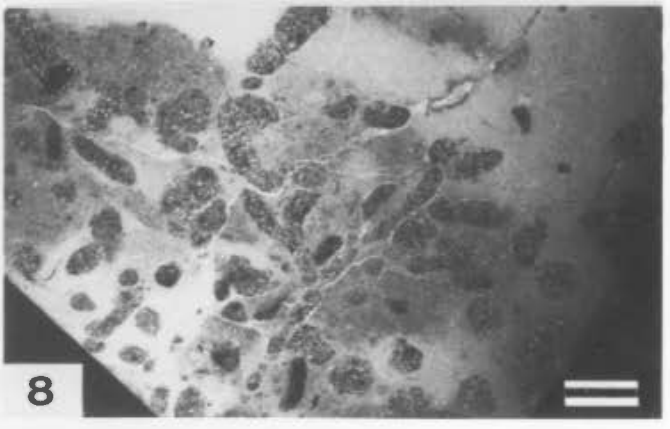


5


6



7


8

8.3. B. Foreign penecontemporaneous clasts

B.1. Massive wackestone and massive to bedded grainstone.

These facies represent the most abundant lithology in Bed 12 conglomerates and are characterized by three end members:

B.1.1 burrowed wackestones and packstones; B.1.2 massive grainstones to packstones; B.1.3 bedded grainstones and rudstones.

Both, bedded and massive grainy facies (B.1.2 and B.1.3) grade into fine grained wackestone and packstone (B.1.1) within the same clast. This intercalation of coarse and fine grained sediments is characteristic of Bed 12 lithologies (Pl. 8.2) and indicates a common source.

B.1.1 Burrowed wackestone and packstone

This end member is further subdivided, based on texture and compositional variation, into: a) microbioclastic wackestone, b) peloidal microbioclastic wackestone, c) peloidal microbioclastic packstone. The different sub-types appear to be controlled by the activity of burrowing organisms which differentiate the substrate. Microbioclastic wackestones represent relatively undisturbed sediment, microbioclastic peloidal wackestones are typically intensively burrowed and the most common type (Pl. 8.3, fig. 5). Removal of the finegrained mud between the peloids and skeletal grains may ultimatively result in formation of subtype c), a packstone (Pl. 8.2, fig. B.2). All three types may occurr within one thin section.

Microbioclastic sediments are characteristic of wackestones as well as packstones. They are composed of echinoderm fragments, shell debris from trilobites and brachiopods, disrupted *Halisis* chains, abundant sponge spicules (oxeas, desmas), rare gastropods (macluritids) and single *Girvanella* tubes. The skeletal grains are commonly preserved as clean angular fragments, but in some examples they are rounded and bored or coated with micrite. Complete shells of gastropods, brachiopods and trilobites are rare.

Peloids are abundant in most samples. They range in size from silt to medium sand and are usually irregular in shape, subrounded to rounded or have a fuzzy outline. Within one thin section they are usually poorly sorted and presumably multi-genetic. Several different sources can be determined. a) Many peloids are related to the activity of burrowing organisms and are found within these burrows, they may be fecal pellets in part and /or small intraclasts. In intensively burrowed wackestones larger angular intraclast are present presumably "carved out" of viscous mud. b) Peloids are also derived from breakdown of algal colonies notably *Girvanella* and *Epiphyton* (algal peloids of Coniglio & James, 1985). *Girvanella* derived peloids are highly variable in size ranging from silt to sand size and are commonly irregular in shape. *Epiphyton* derived peloids are round or oval and composed of dense micrite ("mini-micrite" of Folk, 1974). They are rare in the peloidal wackestone. c) A certain number of medium sand sized peloids are derived from break down of lithistid sponges. Their spicules were overgrown by algae and pores filled with mud upon death of the animal and subsequent transport or dissolution of the sponge skeleton may have set the porefills free. Early lithification during the decaying process of the sponge tissue may have stabilized the peloids. The process has been suggested for peloids from Jurassic algal sponge reefs (Flügel & Steiger, 1981) where porespaces in sponge skeletons were filled with *Rivularia* algae (Behr and Behr, 1976) which form algal peloids (or "tuberoids") upon disintegration of the sponge skeleton.

Most of the mud which forms the peloids is derived from algae (i.e. *Girvanella*) as indicated by relict structures and all these components are in this respect algal peloids but with different modes of formation.

The mud sized fraction is derived from breakdown of *Girvanella* algae indicated by numerous preserved clusters of algal filaments and single floating tubes. Burrowing activity leads to inhomogeneity of the mud with micrite in undisturbed sediments and microspar in bioturbated sectors. This influence of bioturbation on grainsize is particularly visible in some burrows which are rimmed by microspar in

an otherwise micritic matrix. (Pl. 8.2, fig. A.3). Burrows are conspicuous elements in all massive facies and several different types can be observed, indicating presence of different burrowing organisms as well as changes in the biogenic structures, possibly in response to changes in sediment consistency (Walker & Diehl, 1986). Most of the burrows are endichnia (Seilacher, 1964) that is, they were formed by organisms which lived within the sediment. A few burrows can be classified as epichnia, they are connected to the overlying sediment (Fig. 8-1).

Endichnia can be further sub-divided with respect to their complexity and different types of wall structures and casts.

A.1. Endichnia organized into burrow systems.

1. *Chondrites*-like burrows filled with peloids are feeding and dwelling burrows (Seilacher, 1964) found in massive wackestone (Pl. 8.1, fig.8; Pl. 8.3, fig.6; Fig. 8-1.1). They were actively filled with pellets by the burrowing organism.

2. Poorly defined burrows with mm-wide oval or round cross sections with poorly defined walls. Tunnels are only partly peloid filled or open. Maybe a similar structure as that described under 1. but formed in less suitable (soupy?) sediment or the animal formed no stable walls (Fig. 8-1.2).

3. Irregular to patchy bioturbation affecting areas several cm in size. Burrow mottles are commonly microsparitic with sharp to poorly defined boundaries and in some examples have a coarse crystalline core (Pl. 8.2, fig. B.3, Fig. 8-1.3). Burrows are open or passively filled with mud. The indistinct outline of the burrows suggests that they formed in soupy to soft sediment. This is also indicated by deformation halos around some of the burrows. This type of burrow is typical for *Planolites* (Ekdale et al., 1984).

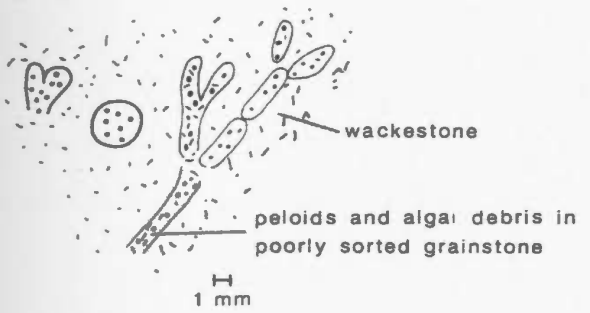
4. Burrow systems with 1-2mm wide tunnels, round in crossection and exhibiting well defined walls, are filled with microspar or calcite spar (Pl. 8.3, fig. 7; Fig. 8-1.4).

Figure 8-1: Types of burrows in foreign clasts of Bed 12.

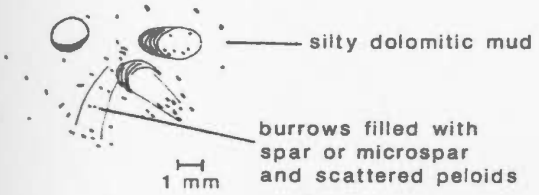
ENDICHNIA

Burrow systems

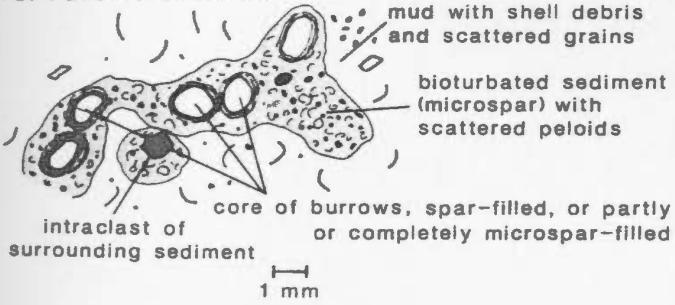
1. Active fill



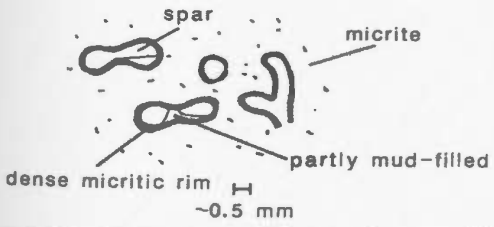
2. Active or no fill



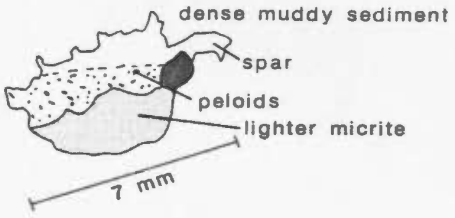
3. Passive or no fill



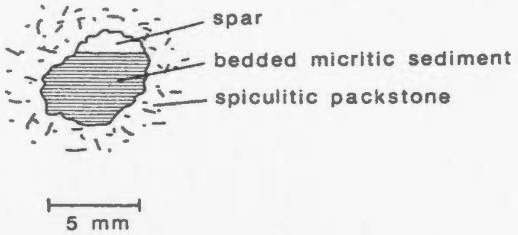
4. No fill and stabilized walls.



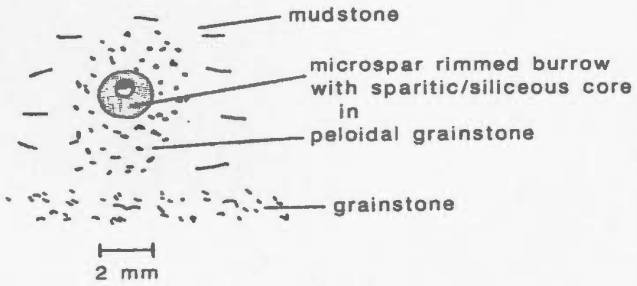
Burrow shafts



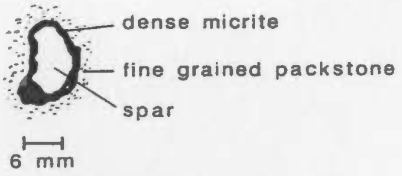
5. 6. Passive fills



7. Passive or no fill



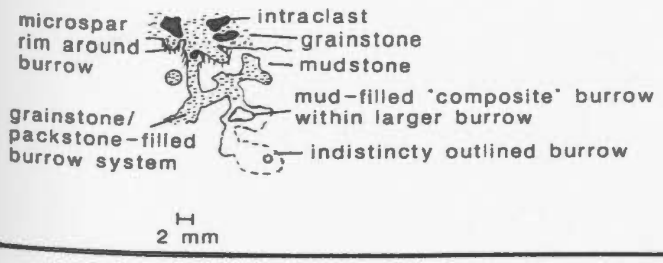
8. No fill and stabilized walls



EPICHNIA

Burrow systems with passive fills

9.



10.

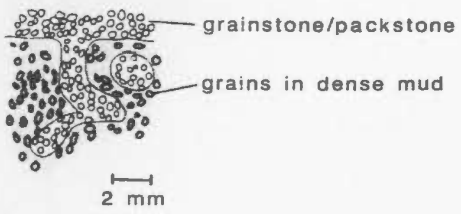


PLATE 8.2

Figure A.1. Field sketch of clast found at St. Pauls Inlet North illustrating a layer of burrowed mudstone over- and underlain by grainstone and burrowed wackestone.

Figure A.2. negative print of thin section from clast of Figure A.1. (box) showing the contact between burrowed mud and overlying grainstone. Burrow system is filled with grains derived from the overlying sediment. Scale bar is 1.5cm.

Figure A.3. Thin section photomicrograph showing close-up of burrows in Figure A.2. (box) with walls of aggraded micrite. Scale bar is 2mm.

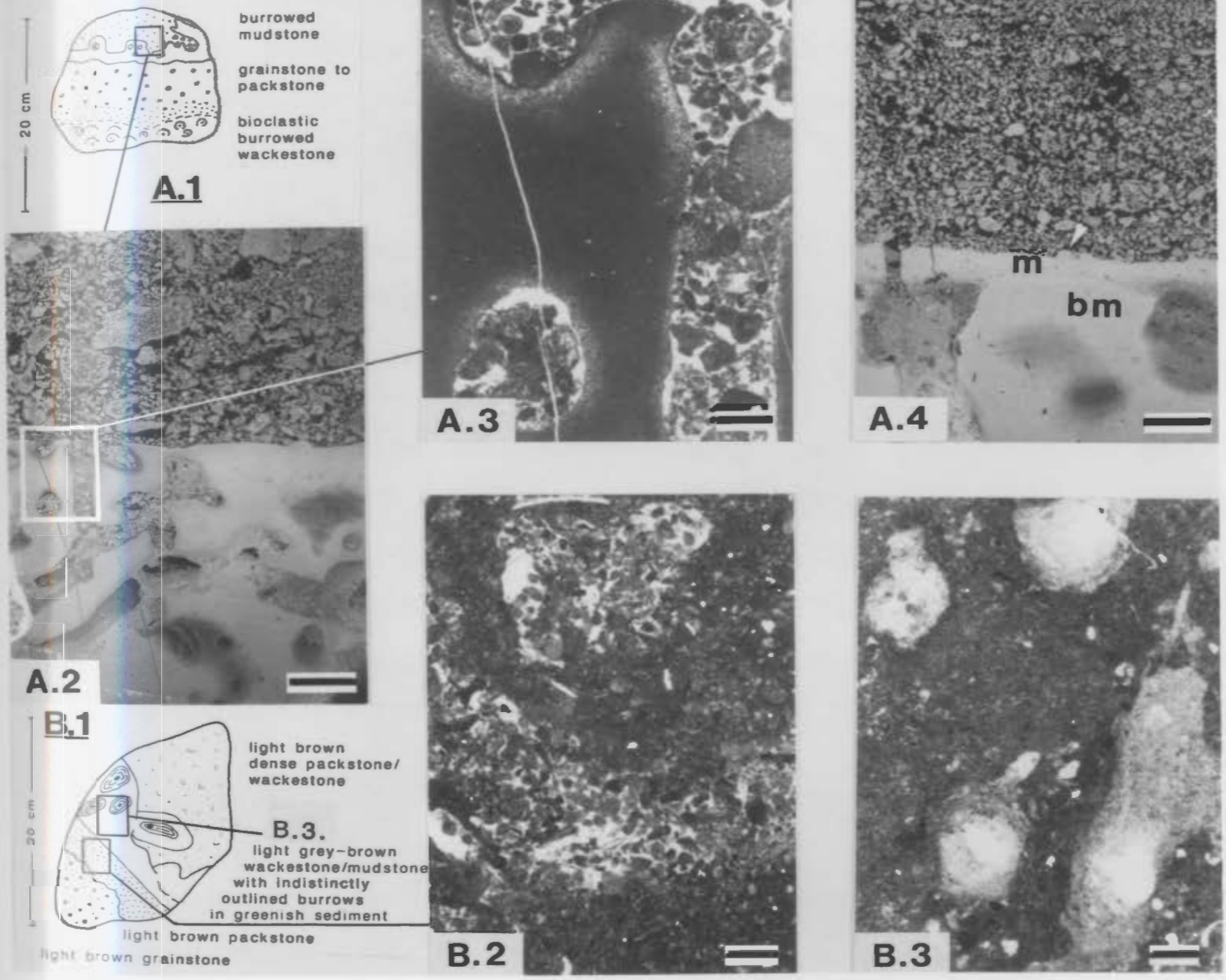
Figure A.4. negative print of mudstone and grainstone of similar composition to that of figs. A.1-A.3 (Martin Point North). Layer of bioturbated mud (bm) at bottom is overlain by thin layer of undisturbed mud (m). Grains of the overlaying grainstone are pressed into the mud surface (arrow). Scale bar is 1.5cm.

Figure B.1. Field sketch of clast found at Martin Point North illustrating relationship of grainstone, packstone and wackestone.

Figure B.2. Thin section photomicrograph of packstone layer from clast in Figure B.1.. Packstone is bioturbated with grainstone filling burrows. Scale bar is 1mm.

Figure B.3. Thin section photomicrograph from clast in Figure B.1. showing bioturbated wackestone with indistinctly outlined burrows. Scale bar is 1mm.

Relationships of mudstone/grainstone/wackestone.



A.2 Endichnia consisting of burrow shafts.

5. Large irregular shaped burrows filled geopetally with different types of sediment: wackestone at bottom, overlain by packstone to grainstone; remaining cavity is spar filled (Fig. 8-1.5)

6. Large oval cm-wide burrows filled with calcite spar and bedded peloidal wackestone which is finer grained than the surrounding sediment. The burrow fill was passive. The difference in grain size indicates that lime mud was present around during formation or subsequent infill of the burrow. The surrounding coarser sediment may thus be the result of grain aggradation or the original mud was washed away. (Pl. 8.3, fig. 8; Fig. 8-1.6).

7. A common phenomenon these burrows have a core of clear spar cement surrounded by a "halo" of microspar in an otherwise grainy sediment (Fig. 8-1.7; Pl. 8.7, fig.8).

8. Some burrows in peloidal packstone are irregular, measure up to 1cm in diameter and have well defined walls which are stabilized by a rim of dense micrite (Fig. 8-1.8; Pl. 8.3, fig.9). The rim may have been formed by the burrowing organism in order to stabilize the margin, similar to *Callianassa* which builds silt lined burrow systems (Tudhope and Scoffin, 1984). This burrow is likely a domichnia or dwelling structure.

B.1 Epichnia

9. These are mm-wide burrows filled with grainstone in a wackestone matrix composed of similar grains in a muddy matrix (Pl. 8.2, figs. B.1, B.2, Fig. 8-1.10). The burrows are connected to the surface.

10. A succession of different burrow generations in response to changes in sediment consistency is well displayed in a sample of a dense mudstone overlain

PLATE 8.3

All figures except figs. 1 and 2 are thin section photomicrographs from samples found in Bed 12 on Cow Head Peninsula.

Figure 1. negative print of grainstone with interbedded mudstone layers. Surface of grainstone is silicified (s) (Martin Point North). Scale bar is 2mm.

Figure 2. negative print of wackestone with silicified surface (arrow) and silicified areas (s) in the overlying packstone to grainstone (St. Pauls Inlet North). Scale bar is 2mm.

Figure 3. Photomicrograph of clast in Figure 2. shows close-up of indurated surface (arrow) between wackestone and grainstone and silicified area (s) in upper right corner. Scale bar is 0.8mm.

Figure 4. Bedded grainstone to packstone with algal-bound (?) mud between the grains (Point of Head). Scale bar is 0.8mm.

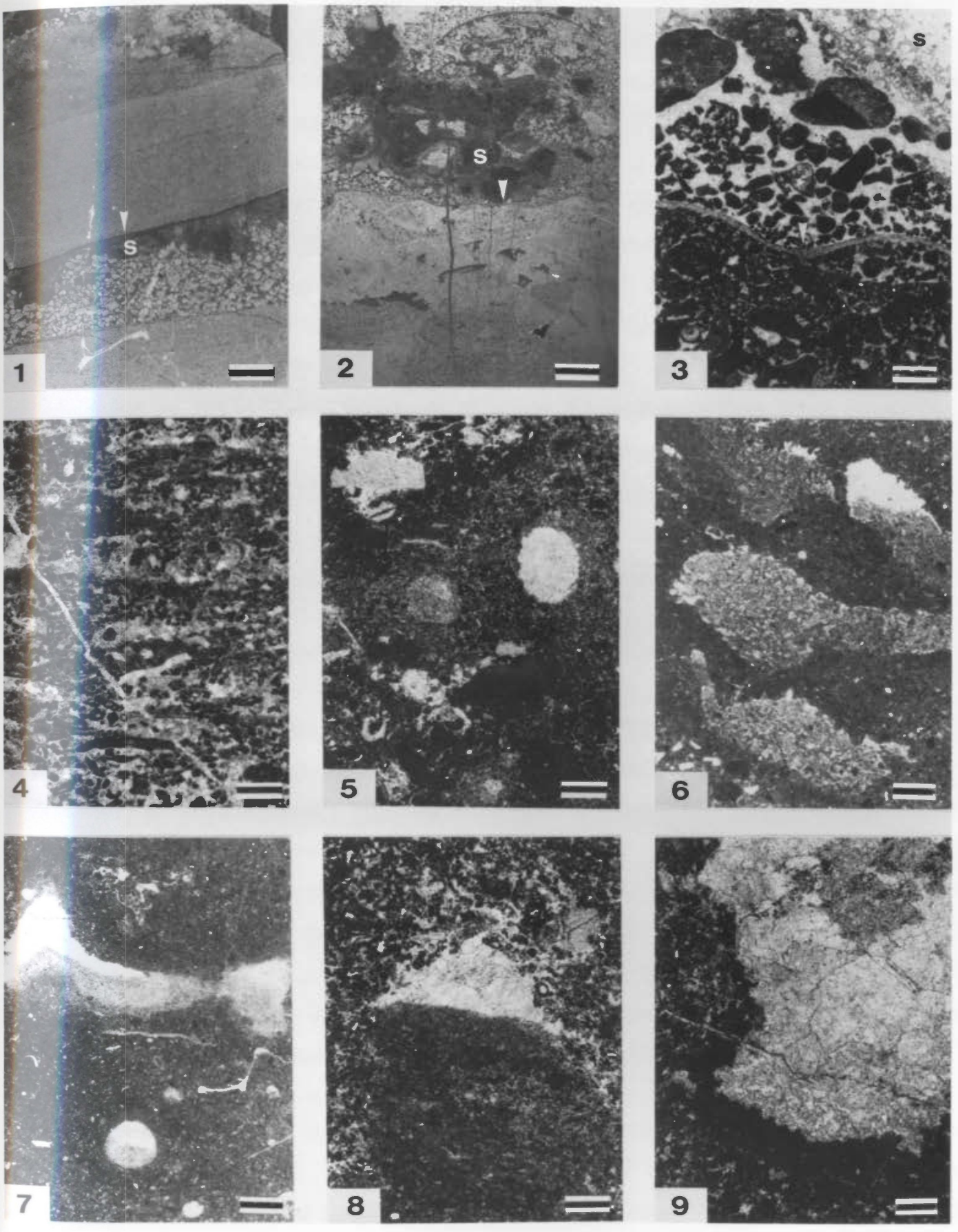
Figure 5. Spar filled burrows in packstone to wackestone (Jim's Cove). Scale bar is 0.8mm.

Figure 6. Burrow system in wacketone actively filled with peloids (Jim's Cove) Scale bar is 0.8mm.

Figure 7. Spar filled burrows in microbioclastic wackestone (Shoal Cove). Scale bar is 0.8mm.

Figure 8. Burrow shaft geopetally filled with bedded lime mud in packstone (Point of Head). Scale bar is 0.8mm.

Figure 9. Burrow shaft in packstone with walls stabilized by dense lime mud (Jim's Cove). Scale bar is 0.8mm.


S
1
S
2
S
3
4
5
6
7
8
9

by a grainy sediment (Fig. 8-1.9; Pl. 8.2., figs. A.1,2,4). The first generation is represented by undefined burrows filled with microspar which formed in an unstable "soupy" mud. With dewatering and compaction the deposit was transformed into a firm ground and small *Thalassinoides*-like burrow systems (domichnia) were excavated. They are filled at the bottom with peloidal microbioclastic wackestone followed by a grainy fill of grains from the overlying grainstone with addition of a finer fraction (silt sized algal peloids and mud). The fine grained sediment at the bottom of the burrow was reburrowed and refilled geopetally with a peloidal wackestone. The sediment filling the burrows is finer grained than the overlying grainstone suggesting that the finer fraction was washed away subsequently after infill of the burrow. A similar phenomenon can be observed in other samples where fine-grained sediment has been preserved under the cover of shells. This type of burrow may form in environments, where moderate erosion strips off loose surficial sediment to expose a more coherent layer, commonly a relict sediment that has already been dewatered. Domichnia are common in this type of deposit (Ekdale et al., 1984).

B.1.2 Massive and bedded grainstones and rudstones

The development of the grainstone facies is well displayed in a large fractured boulder at The Ledge on Cow Head Peninsula (Plate 8.4). This huge boulder measures over 80m in length and 4m in height; width cannot be estimated as the mass is covered by soil and conglomerate. Orientation of the boulder is difficult to determine because the masssive grainstone does not show any bedding and the different generations of fractures and their fills indicate 2 or 3 different up directions. The smooth surface of the boulder and the presence of pocket-like dm^2 to m^2 large patches of darkgrey mudstone suggests that a bedding plane is exposed while a layer of wackestone appears to be bedded (Pl. 8.4, fig. 5 at 20m).

The primary sediment is a medium grained calcarenite with finer and coarser areas (Pl. 8.4, figs. 1,2,4). The grains are subrounded to rounded and moderately to well sorted, better than in most other grainstone clasts. Grainstones associated

with mud rich sediment are generally less well sorted and rounded (Pl. 8.3, fig. A.3). The grainstones are composed dominantly of micritic peloids and intraclasts, subordinate components are echinoderm fragments, *Nuia* grains and undeterminable sparse shell debris. Many skeletal grains are corroded and coated. Grains are cemented by clear calcite spar or embedded in muddy matrix, signs of extensive neomorphic aggradation are not present.

Abundant fractures form an irregular network dissecting the boulder surface. These fractures can be found in many smaller clasts of this lithology as well (Pl. 8.1, fig. 7; Pl. 8.5, fig. A.2). In the large boulder they reach several meters in length and several cm to dm in width. They are mainly oriented perpendicular and parallel to the base of the boulder and are lined with a rim of fibrous calcite crystals and/or silica. Cavities are filled by: (1) Bedded orange and blue-stained mudstone alternating with grey mudstone with bedding oriented parallel to the base of the boulder. (2) Laminated gray mudstone oriented perpendicular to base of boulder (this sediment may not be a cavity fill but part of the depositional sediment indicating that bedding is oriented perpendicular to base of boulder). (3) Nautiloid coquinas. (4) Zebra-limestone with mudstone and peloidal packstone layers alternating with silica lined crusts of fibrous calcite cement. Some fractures contain broken calcite crusts floating in a muddy matrix or with with coarse subangular lithoclasts cemented by fibrous calcite cement and rimmed with silica (Pl. 8.4, fig. 3). (5) Gray, bedded peloidal packstone with silt sized peloids. The differently oriented fracture fills, their variable composition, broken crusts of calcite cement and complicated cross cutting relationships imply that several generations of fractures are present each of which was filled following a separate phase of disruption and/or transport.

Gray mudstones associated with the grainstone facies are highly fractured and unfossiliferous with the exception of a few single *Girvanella* tubes and echinoderm fragments. No evidence of bioturbation is visible in the block, in contrast to most other clasts of this lithology where massive grainstones are associated with

bioturbated mudstones and wackestones. These burrows are *Skolithos*-like single large tubes, mm to cm in diameter and are surrounded by mud in an otherwise grainy sediment. The patches of muddy sediment associated with burrows suggest that the burrowing organism was able to stabilize the fine grained mud amidst the sand.

B.1.3 Bedded grainstone

These sediments are composed of alternating mud-rich and -poor layers, they show gradation of calcarenite to calcirudite and interbedding with mudstone or wackestone (Pl. 8.2, figs. A.2.4; Pl. 8.3, figs. 1-3). These features suggest frequent alternations in water agitation and possibly presence of omission surfaces. Several lines of evidence suggest that periods of slowed sedimentation occurred: 1. surfaces separating different sediment-types are indurated with silica or dolomite (Pl. 8.3, figs. 1-3); 2. voids are lined with glaucony (Pl. 8.1, fig.7); 3. sediments are intensively bioturbated and some of the mudstone layers were sufficiently compacted to support tunnels connected to the sediment-water interface (Pl. 8.2, fig. A.2); 4. conodont faunas are reworked (see paragraph C.1). 5. Bored shells are present at omission surfaces (Pl. 8.9, fig. 4). In addition deposits of the underlying Bed 11 also indicate starved sedimentation (James and Stevens, 1986): the surface of Bed 10 is silicified and corroded, phosphatic conglomerates are common. Bed 11 is thin (starved) considering the time span covered.

Massive grainstones may also yield coarse lithoclasts but these are generally irregular in shape and subangular. This difference may indicate that bedded rudstones and grainstones were transported while massive grainstones and rudstones remained more or less stationary. In some cases the observed bedding of grainstones and alternation of mud rich and -poor layers may be the result of algal binding. (Pl. 8.3, fig. 4) (Neumann et al., 1970).

Interpretation: Massive fractured grainstones probably represent shelf edge sand facies which typically form along carbonate margins (Ball, 1967; Hine et al., 1981;

PLATE 8.4

Lithology of a large boulder found on Cow Head Peninsula, Point of Head section. All figures shown on the plate are from this boulder. Scale bar on all thin section photomicrographs is 1mm.

Field sketch of over 70m long boulder mainly composed of grainstone, packstone and cavities. (Legend: cav=cavities, dg=darkgray, fg=fine grained, g=gray, gast=gastropods, gs=grainstone, lg=lightgray, ls=limestone, ms=mudstone, ost=ostracods, ps=packstone, w=with, ws=wackestone, .=silica-rimmed).

Figure 1. Thin section photomicrograph from packstone to wackestone area of clast with abundant algal debris.

Figure 2. Thin section photomicrograph of grainstone to packstone with *Halysis* chain.

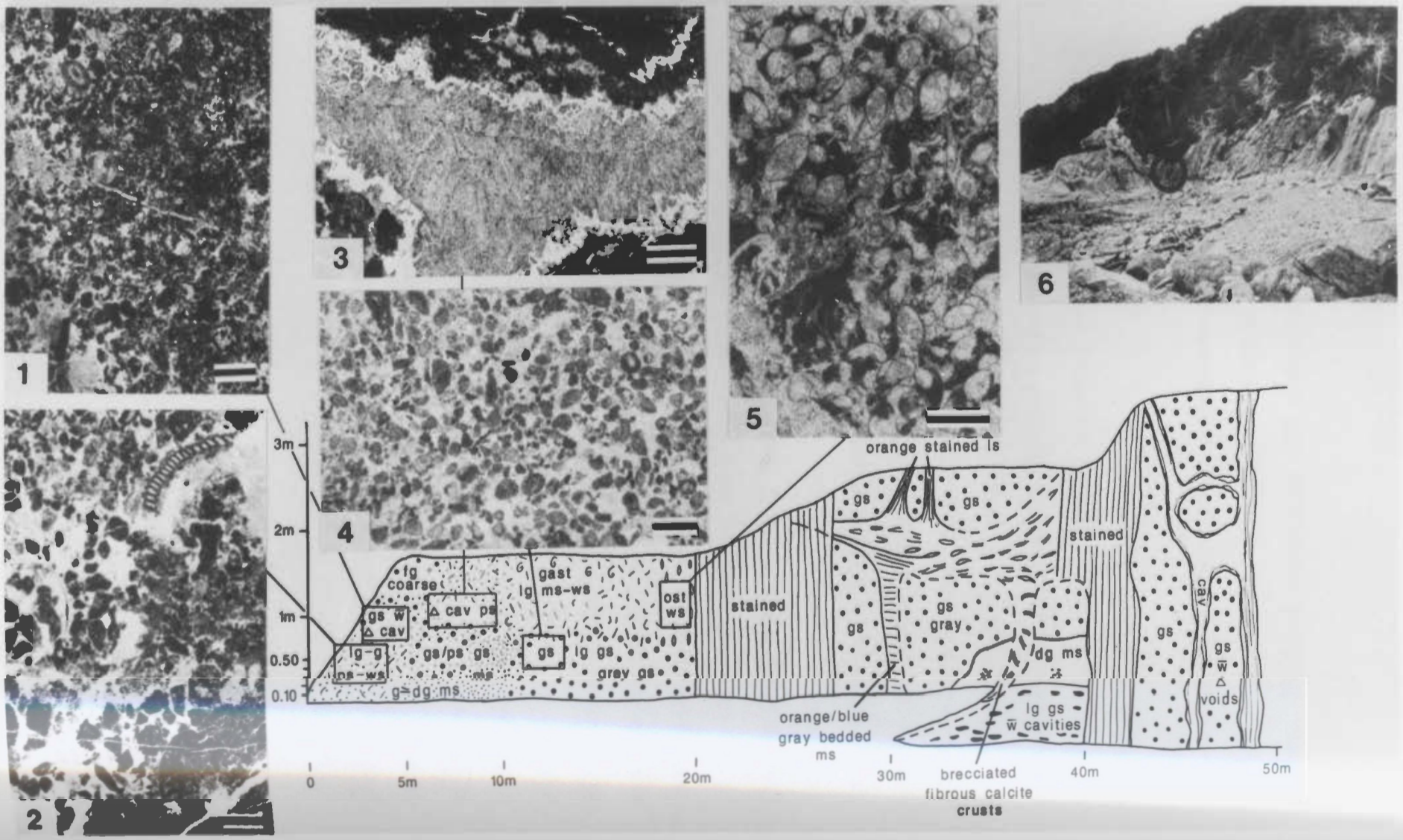
Figure 3. Thin section photomicrograph from area of clast with algal packstone dissected by silica-lined fibrous calcite filled cavities and voids.

Figure 4. Thin section photomicrograph of light gray grainstone facies.

Figure 5. Thin section photomicrograph of ostracod(?) wackestone which appears to be bedded within boulder.

Figure 6. Photograph of part of the boulder in the field. Person stands where mapping began. Boulder continues to the left but is interupted by fault. The stained smooth surface to the right of picture which is figured on boulder map at 40m.

Relationships of massive grainstone/packstone/wackestone.



Halley et al., 1983) Deposition in a transitional environment with frequent changes in water agitation is indicated by the presence of poorly washed grainstone with muddy sediment intercalated with clean spar cemented sands. The intensive fracturing may have two explanations: a) shelf edge sands were exposed at some stage of Bed 11 deposition and karst surfaces developed or, b) early lithification and fracturing occurred on the sea floor as in the formation of Neptunian dykes (Playford, 1984).

The preservation of the mud may have been aided by binding activity of algae and stabilization of fine grained sediment by tube building burrowers (Watson, 1903). Fraenkel and Meade (1973) reported on presence of extensive biogenic sediment stabilizing systems in estuarine sands. Accumulation of mucilaginous materials which probably are products of organisms living on grains and in interstices fostered sediment stability. A study of Shark Bay sediments (Davies, 1970) showed that lime-mud and sand banks develop as largely self propagating systems provided a baffling agent is present. Mainly locally produced skeletal carbonate may accumulate in an area of relatively high turbulence through action of an external baffling and stabilizing mechanism which may not be preserved. Davies points out, that if the rock contains large proportion of silt and clay sized sediment of skeletal origin, this benthonic community should be considered as being an organic baffle. *Girvanella* debris together with stabilized burrows would qualify as binders and bafflers forming banks near the shelfedge. Lime sand banks which formed under the influence of marine bottom communities have also been described by Ginsburg and Lowenstam (1958). It is therefore conceivable that mud-rich grainstones formed under the relatively high energy conditions of a shallow water shelf edge, in contrast to the clean sands which comprise other edge deposits (e.g. Bahamas).

Some of the poorly sorted grainstones and rudstones may also be talus sediments which accumulated around mud slopes and boundstones or just in slightly deeper water. Bedded rudstones and grainstones with rounded lithoclasts and abraded

skeletal grains are probably transported talus sediments or fore slope breccias transitional in character to the calcirudites described below (B.3).

Microbioclastic wackestones and packstones probably represent upper slope mud accumulations with the mud fraction derived from the break down of algae.

B.2 Boundstone

Clasts of organically or inorganically bound limestone can be subdivided based on differences in colour into : a) light gray boundstone and b) brown boundstone (Pl. 8.6, fig. 1). The lighter coloured boundstones are dominantly composed of algae (eg. *Girvanella*, *Renalcis*, *Epiphyton*) and mud, while the darker limestones yield a larger variety of different organisms and are higher in detritus (sedimentary and skeletal grains, dolomite rhombs and quartz silt). The colour alteration may be related to different amounts or utilization of organic matter.

Similar to Bed 10 the boundstones are thought to represent *Girvanella* buildups. Some of the algal boundstones are thrombolitic with mm-sized irregular fenestral fabrics comprising open spaces filled with geopetal lime mud and calcite spar. *Girvanella* in Bed 12 are accompanied by moderately abundant *Renalcis* and *Epiphyton*. The alga *Halysis* and a problematic *Pulchritamina*-like organism are also present for the first time (Pl. 8.6, figs. 3,4).

Anthaspidellid sponges are common (Pl. 8.6, figs. 2,6). They are difficult to detect in thin section and outcrop because only the algal mud, which filled pore spaces in the sponge framework is preserved as peloids, while the sponge skeleton was dissolved. The abundance of sponge spicules suggests that many sponges were not preserved but completely disintegrated (Pl. 8.5). Their role as framebuilders is therefore difficult to evaluate.

Several problematic tubular organisms occur in Bed 12 boundstones:

PLATE 8.5

All figures illustrate clast lithologies found in Bed 12 on Cow Head Peninsula.

A.1. Field sketch of mottled bioturbated wackestone associated with massive skeletal wackestone to packstone, (Point of Head).

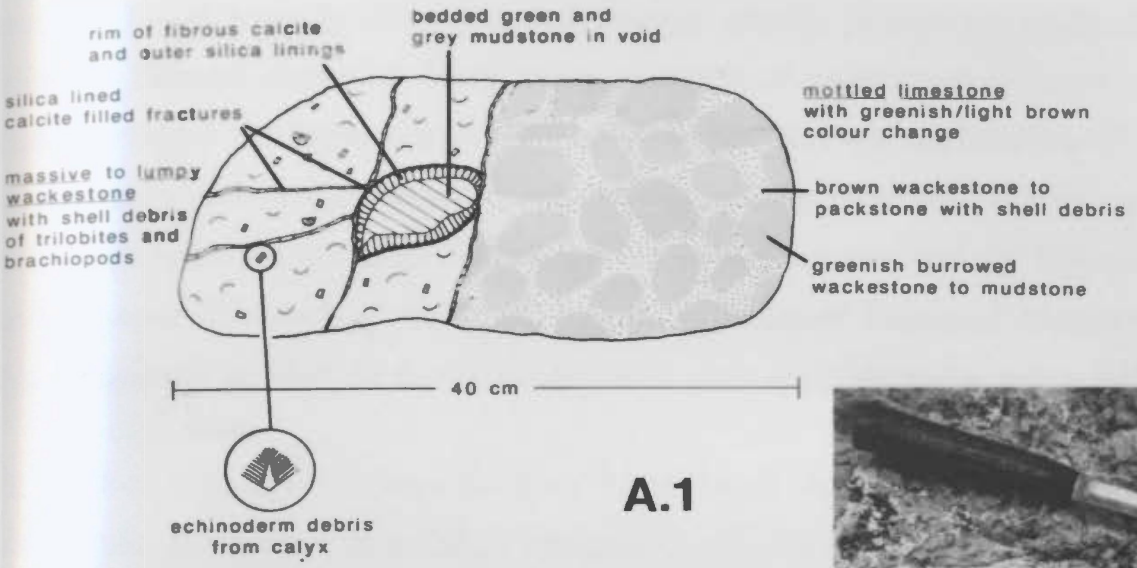
A.2. Photograph of similar clast lithology with fracture filled with bedded green mudstone at bottom, remaing space is lined with silica and several generations of fibrous calcite. Surrounding sediment to left is skeletal packstone to wackestone, to right is mottled wackestone. Hammer for scale is 30cm long.

B.1. Field sketch of a clast illustrating the relationship between boundstone and burrowed wackestone, (Jim's Cove).

B.2. Thin section photomicrograph of clast in Figure B.1. showing bioclastic burrowed wackestone. Skeletal components are trilobites, gastropods and enigmatic "tubes" (t). Scale bar is 1mm.

B.3. Thin section photomicrograph of clast in Figure B.1.. Sediment is a spiculitic wackestone with poorly preserved sponge spicules (arrow). Scale bar is 1mm.

MOTTLED LIMESTONE / MASSIVE WACKESTONE

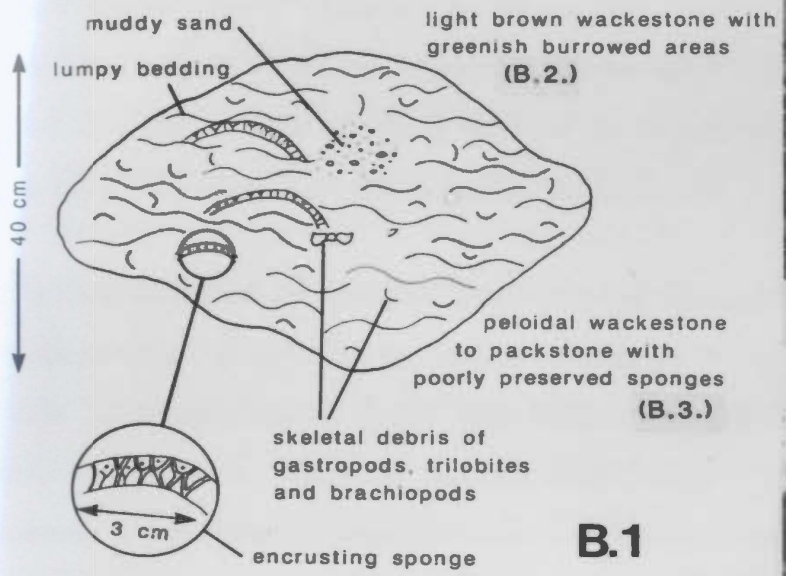


A.1

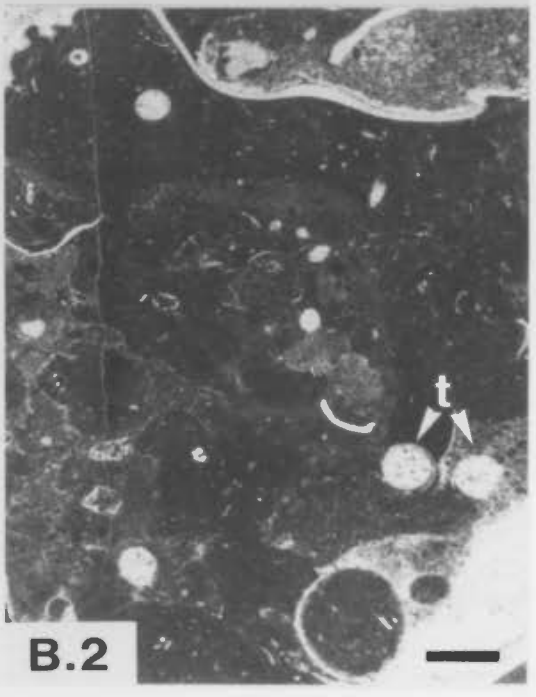


A.2

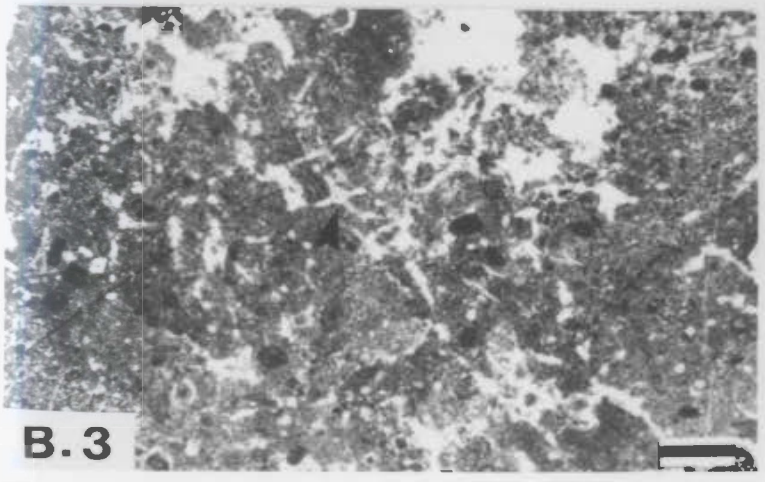
RELATIONSHIP OF BOUNDSTONE / BURROWED WACKESTONE



B.1



B.2



B.3

1. *Wetheredella* like tubules with round or oval cross sections and sausage shaped longitudinal sections are commonest (Pl. 8.6, fig. 5). The structures measure 0.1-0.2mm in diameter and possess poorly preserved walls of centripetally oriented fibrous crystals. They form clusters of overlapping tubes with different cross sections. In some cases they appear to encrust underlying (?) algal sheets, but usually their relationship to the surrounding sediment is not apparent. They may be encrusting foraminifers like *Wetheredella* described by Copper (1976) from the Upper Ordivician of Anticosti Island or tubes of infaunal burrowers. They are also abundant in Bed 14 boundstones and discussed there in more detail.

2. Tubes with round cross sections form fused clusters with crescent shaped tops that grade downward into large irregular outlined burrow cavities filled geopetally with peloidal mud. Single tubes appear to be double walled or to have a "cone-in-cone" structure but this may be the result of dissolution of a central part with different mineralogy. Spaces between the inner and outer walls are filled with micrite, the core is filled with clear calcite spar. The walls are formed by radially oriented fibrous calcite crystals similar in construction to the previously described tubules (Pl. 8.6, figs. 7,8; Pl. 8.5, fig. B.2).

3. Etched samples of boundstones reveal the presence of large colonies (several cm in diameter) of tubules or tubes which form intertwined vermicular systems or protrude as single tubes from the sediment. The structures possess partly acid resistent walls as a result of partial silicification and are characteristically found associated with green argillaceous sediment and crusts. The greenish colour probably indicates a reducing micro-environment around the burrows. These tubules and vermicular boxworks appear to be remains of burrow systems formed by infaunal organisms, possibly polychaetes which are known to form tubes and burrow systems with stabilized walls. Silicification of burrows is a well known though poorly understood diagenetic phenomenon (Joysey, 1959; Ekdale et al., 1984).

The organic buildups in the boundstone facies are commonly surrounded by

medium to coarse sands of detritus derived from the different organisms especially *Girvanella*. Darkbrown as well as light grey boundstone are commonly found grading into massive wackestones (Pl. 8.5).

Interpretation: Light gray and brown boundstones represent organically bound limestones which probably formed at or near the shelf edge in shallow water. Deposition within the photic zone is indicated by the abundance of algae such as *Renalcis*, *Epiphyton* and *Halisis*.

B.3 Calcirudite

B.3.1 Calcirudites with dominantly upper slope derived lithoclasts are composed of 0.5-3cm large irregular shaped subrounded to rounded mudstones and subordinate wackestone- and *Girvanella* clasts. Clasts float in an aggraded microspar matrix with sparse silt to sand sized peloids (Pl. 8.1, fig. 5). In some clasts a geopetal muddy matrix is preserved between grains suggesting that mud filtered in after deposition of the lithoclasts (Pl. 8.1, fig.6). Different calcirudites show variable size of lithoclasts. The matrix is partly replaced by silica. The calcirudites are interbedded with grainstone, mudstone and wackestone more commonly than in Bed 10.

B.3.2 Calcirudites with dominantly lower slope derived lithoclasts comprise 2cm-4cm long and up to 1cm thick flat pebbles of mudstone and bedded finegrained peloidal wackestone. Some of the lithoclasts are soft-deformed and of the same composition as the matrix of Bed 12 implying a similar origin for these clasts and the groundmass. The matrix is an aggraded microspar with 10-15% silt to sand sized peloids and sparse coarser irregular shaped pelsparite lithoclasts up to 5mm long.

Interpretation: Like similar lithologies in Bed 10 these sediments are probably talus sediments and intraformational breccias which were deposited on the upper slope.

B.4 Lumpy dolomitic wackestone (Lower Bed 11-age)

Description: This lithology is characteristically a light gray limestone with buff to greenish weathering dolomite-rich partings grading into cm-sized lenticular or roundish limestone lumps. (Pl. 8.7, figs. 1,3). The amount of dolomite is variable and accounts for 30% to 70% of the rock. In some cases dolomite is not confined to the partings but is scattered throughout the matrix and may comprise up to 90% of the sediment (Pl. 8.7, fig. 2).

Gradation from a relatively dolomite-poor to a dolomite-rich sediment or even dolostone can be observed within a single boulder. Many of the dolomite crystals in the parting material have cloudy detrital cores which are frequently replaced by calcite. Minor amounts of silt sized quartz are also present. Weathered boulder surfaces and etched samples show that the dolomitic partings are intensively burrowed with burrows preserved as intertwined mm-sized tubes.

The sediment is fossiliferous with variable amounts of trilobites and brachiopods which are commonly silicified at the boulder surface. One large boulder of this lithology found at The Ledge yielded at least 5 different trilobite and 4 brachiopod genera (R. J. Ross Jr., pers. com., 1984) (Pl. 8.7, fig. 1). Other bioclasts are single *Girvanella* tubules and -rafts. Silt- to sand sized peloids may account for 15% to 20% of the components in some samples, but they are generally absent

The mud fraction of the sediment is commonly also intensively burrowed. Different types of burrows occur, including: 1. Large burrowed areas with "cloudy" indistinct outlines; the burrowed mud is coarser in size (microspar) than the surrounding material and therefore appears to be lighter in colour. 2. Acid insoluble residues commonly yield cm sized tubes of pyrite which are probably previous burrow fills. 3. As mentioned before visible in the greenish partings are burrows which wheather out in form of vermicular networks with tubes 0.5-1mm in diameter. 4. Several cm long burrow shafts, occasionally branching (1-1.5cm in

PLATE 8.6

All figures illustrate Bed 12 lithologies from Cow Head Peninsula.

Figure 1. Chest of brown *Girvanella*-sponge boundstone with coiled nautiloid cross section (arrow) (Jim's Cove). Book edge for scale is 20cm long.

Figure 2. Negative print of brown *Girvanella* boundstone with sponge remains outlined by dashed line. Surrounding sediment is bioturbated mud. (Point of Head). Scale bar is 1cm.

Figure 3. Photomicrograph of boundstone with *Halysis* chains. Scale bar is 0.8mm.

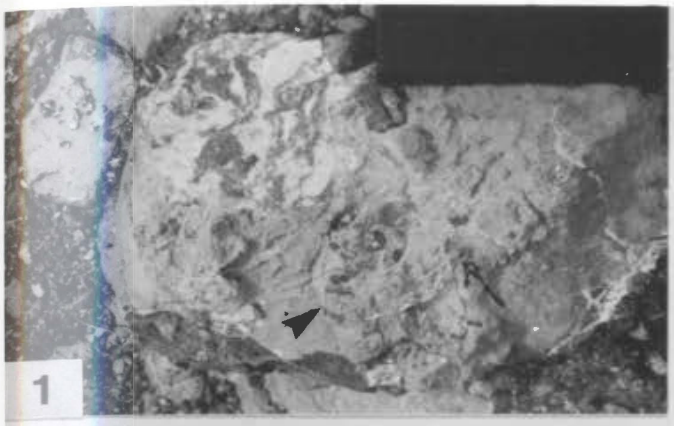
Figure 4. Photomicrograph of *Pulchrilamina*-like organism. Scale bar is 0.8mm.

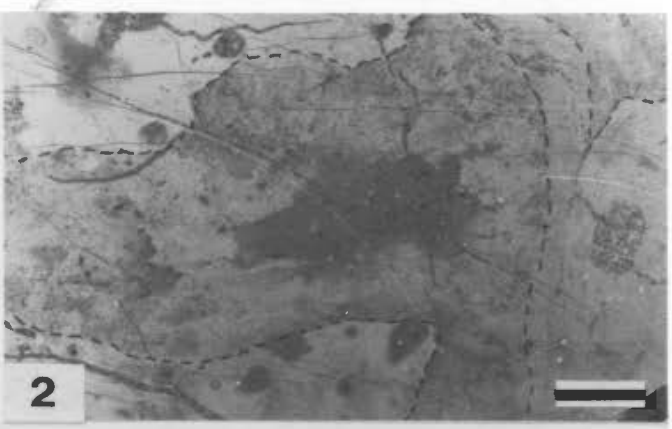
Figure 5. Photomicrograph of *Wetheredella*-like organisms. Scale bar is 0.8mm.

Figure 6. Photomicrograph of sponge fragment with poorly preserved sponge spicules and pores filled with peloids ("tuberoids"). Scale bar is 0.8mm.

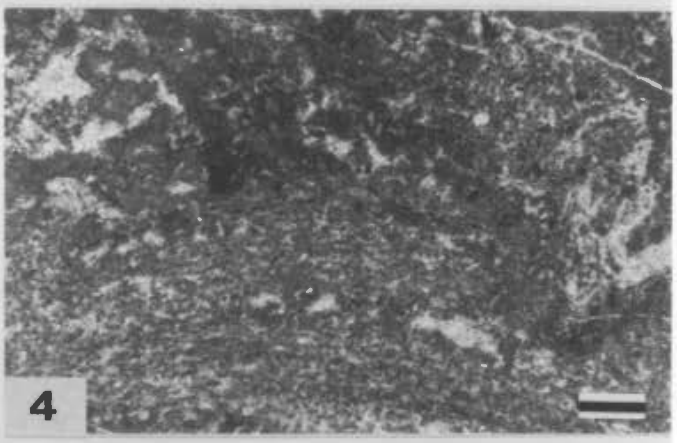
Figure 7. Photomicrograph of enigmatic double walled tubes shown in Figure 8. Space between walls is filled with sediment. Scale bar is 0.5mm.

Figure 8. Double walled tubes in wackestone. Scale bar is 1mm.

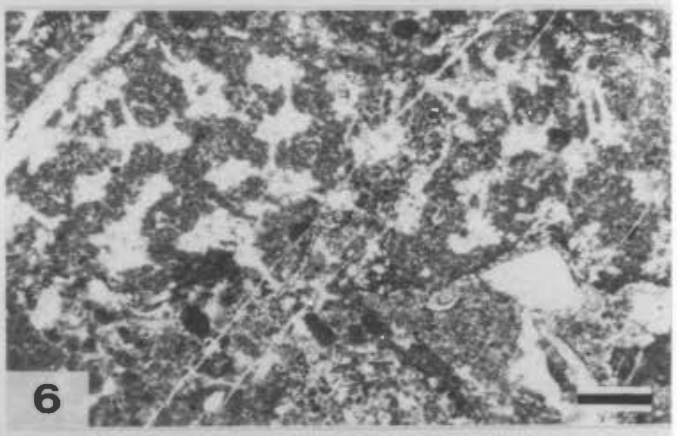

1

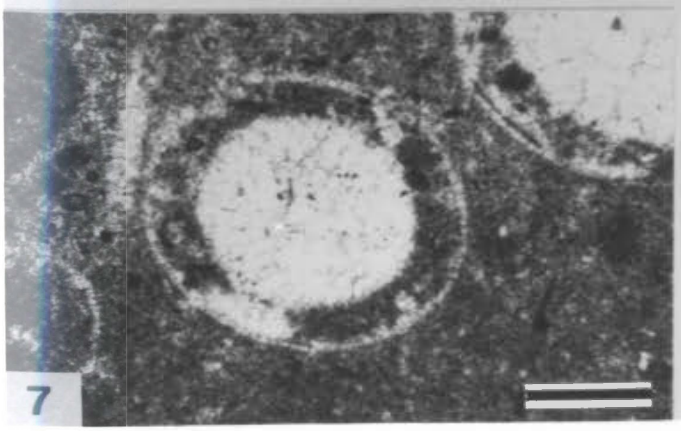

2


3


4


5


6


7


8

diameter) with spar filled cores and rims of dense micrite weather out in a clast of lumpy wackestone at The Ledge. Shafts were broken into short segments indicating that they were originally long stabilized tubes which were disrupted during transport of the semilithified sediment (Pl. 8.7, fig. 4).

Clasts show complex patterns of synsedimentary fractures which healed with several generations of fibrous calcite cement and then fractured again, also indicating that sediment was only partly lithified when moved. Dm-long and cm-wide crusts of fibrous calcite with yellow weathering siliceous rims float in the muddy matrix of some of the large boulders. Some of the fractures are filled with synsedimentary mud or peloidal grainstone.

Interpretation: The fine grained nature of the sediment, the lack of shallow water conodont faunas and scarcity of sedimentary features indicative of vigorous continuous agitation, suggests that deposition was below wave base. Calcareous algae are only present as disintegrated fragments (i.e. *Girvanella* rafts and single tubes) suggesting deposition below the photic zone. Trilobites and brachiopods along with abundant burrows reflect activity of epifaunal and infaunal benthos in well aerated water. Similarity of the lithology to lumpy burrowed mudstone suggests that both lithologies were deposited in neighbouring environments on the deep upper slope. Sediments of this type have been abundantly described from the slope environment (McCrossan, 1958; Wilson, 1975; Flügel, 1978; Pickering et al., 1986). Conodont faunas indicate an age equivalent to the lower part of Bed 11 for clasts of this lithology.

B.5 Bedded mudstone to wackestone (upper Bed 11 age)

Description: These sediments are bedded to rubbly mudstones and wackestones with irregular and poorly defined bedding planes, but no parting material. Bedded sediment may grade into massive wackestones and packstones described earlier (B.1). Beds are cm thick and alternating light gray and gray (Pl. 8.7, fig. 6). The sediment is composed of alternating layers of homogeneous faintly

laminated mudstone, burrowed mudstone to wackestone and peloidal packstone with fine to medium sand-sized peloids (Pl. 8.7, figs. 7,8). They show a vermicular pattern when densely packed similar to the anastomosing tubes described by Ross et al. (1975) who also interpreted this as a peloidal fabric. Fenestrate fabric is present in some clasts suggesting shallow water deposition. Small cm sized cavities are filled with neomorph calcite spar or are rimmed with fibrous calcite cement and filled with a clastic debris of calcite crystals. Fossil content includes fragments of trilobites, brachiopods, echinoderms, poorly preserved calcified sponge spicules, single algal filaments and unidentifiable microbioclastic shell debris. Acid insolubles yield rare phosphatic tubes and ornamented arthropod fragments in addition to abundant phosphatic brachiopods. Burrow traces are common. (Pl. 8.7, fig. 8). In some cases clasts were not completely lithified before transport occurred and small pebbles are pressed into the surface. Some of these clasts obviously disintegrated during transport on a cm scale into subangular fragments and fractures which are filled with mud and small lithoclasts. Stylolites are common forming irregular networks.

Interpretation. Clasts of this lithology usually yield conodont faunas correlative to the uppermost part of Bed 11 indicating that they are younger than most others. Presence of bedding, lamination, and fenestrae together with the fine grained nature of this lithology implies deposition in quiet shallow water or stabilization of the sediment with help of binding organisms (algae). Abundance of burrows argues for physical accretion of the sediment in quiet water, which may have been aided, however, by algal growth. Lateral gradation into massive wackestones indicates genetic relationship to this sediment type which cannot be distinguished from earlier described older burrowed wackestones and packstones. This relationship argues for deposition in deeper water of the upper slope, while presence of abundant algae and fenestrae is more indicative of sheltered shallow lagoonal environments (Wilson, 1975). In the context of a shallow water conodont fauna, the latter interpretation seems to be more favourable.

PLATE 8.7

All figures are of Bed 12 lithologies from Cow Head Peninsula. Scale bar on thin section photomicrographs is 0.8mm.

Figure 1. Large boulder of lumpy wackestone at The Ledge. The central part of the clast is dolomitic. Top of boulder is to the left (arrow). Book for scale (ring) is 23x29cm.

Figure 2. Photomicrograph of lumpy wackestone in Figure 1 with brachiopod shell and silt-sized dolomite rhombs in lime mud matrix.

Figure 3. Photomicrograph of limestone lump with crossection of brachiopod surrounded by sediment rich in dolomitic silt typical for lumpy wackestone.

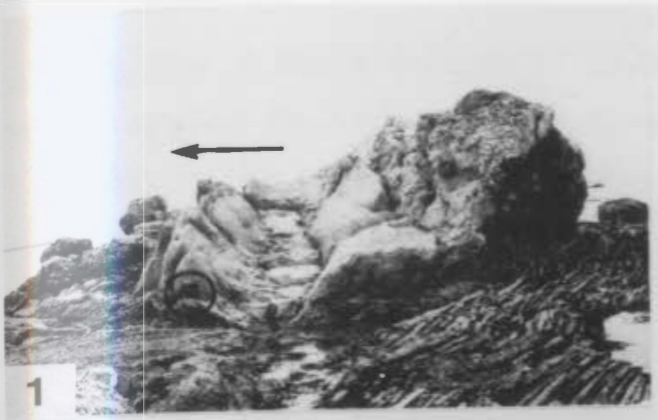
Figure 4. Burrow tubes (1-2cm in diameter) (arrow) with spar filled cores. Lumpy wackestone clast at Point of Head. Hammer blade for scale is 20cm long.

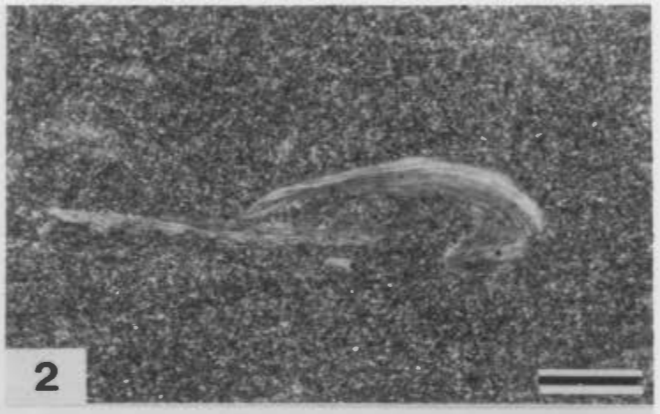
Figure 5. Lumpy wackestone with burrow tubes with spar filled cores (arrow). Sediment is lime mudstone interbedded with argillaceous dolomite rich parting material; Jim's Cove. Scale bar is 10cm.

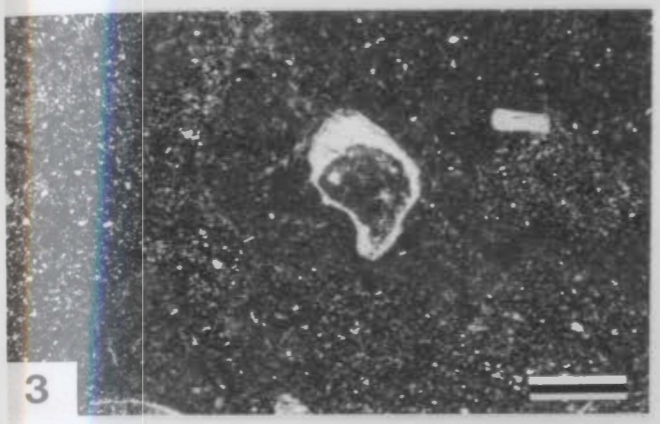
Fig 6. Bedded peloidal wackestone with interbedded laminated and massive layers (Jim's Cove). Coin is 2cm in diameter.

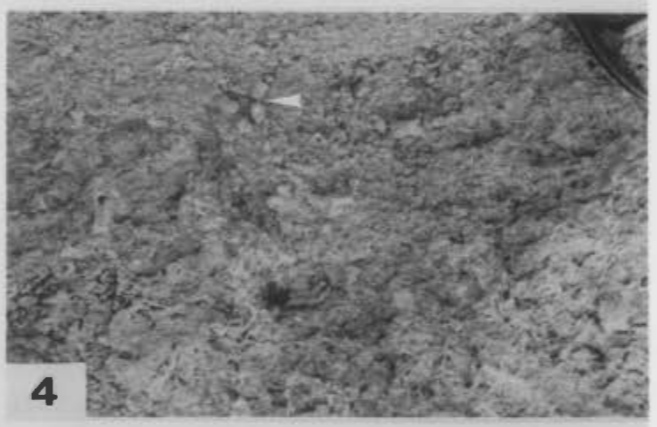
Figure 7. Photomicrograph of interbedded peloidal packstone and mudstone with fenestra-like voids at top. (Jim's Cove). Scale bar is 0.8mm.

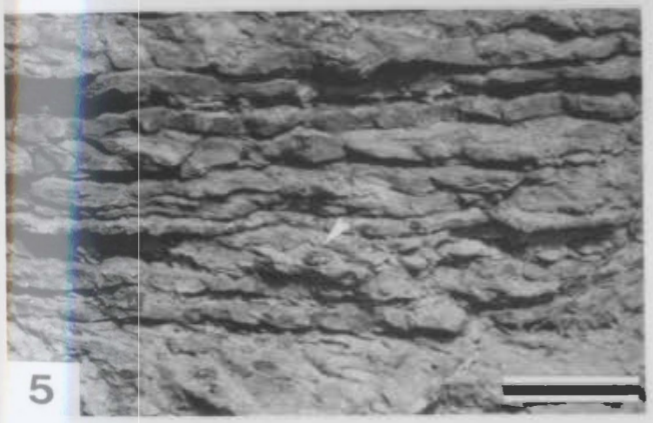
Figure 8. Burrow surrounded by halo of microspar in peloidal grainstone. Photomicrograph shows thin section of peloidal grainstone to packstone with fenestrate fabric.


1

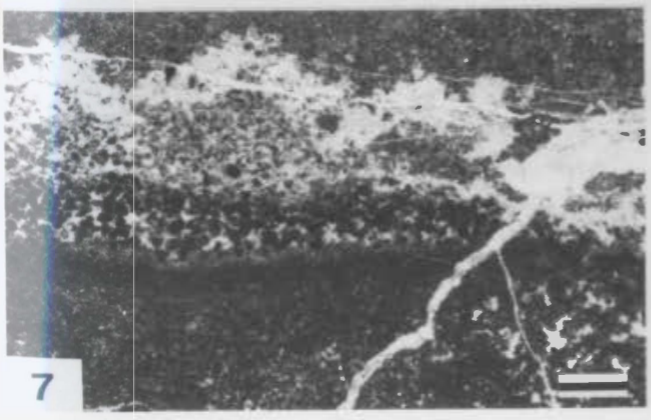

2

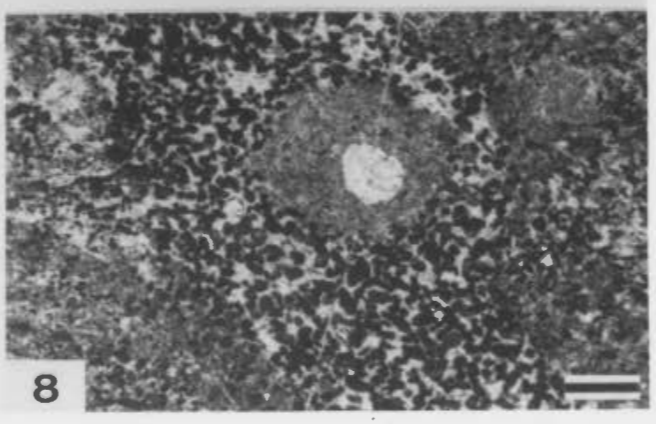

3


4


5


6


7


8

B.6 Shelf derived grainstone

Description: A single boulder of about 30cm diameter found at Shoal Cove yielded a shelf derived conodont fauna correlative with the upper Catoche Formation or the base of the Aguathuna Formation. The sediment is a bedded brown and light gray mudstone intercalated with several cm thick light brown grainstone layers which are composed of intraclasts up to 1 cm long, peloids and skeletal grains, dominantly echinoderm debris, trilobite and brachiopod fragments (Pl. 8.8, figs. 2,6). Some of the beds are coarsely crystalline and completely replaced by neomorphic calcite spar. The bedded primary sediment is cut obliquely by several generations of silica lined fractures which are filled by bedded mudstone or pelsparite of gray, brown, pink or greenish colour.

Interpretation: Conodont faunas derived from the clast indicate deposition of the sediment on the shelf. Interbedded mud-rich and sand-rich layers indicate variable energy conditions on the shelf with quiet and agitated periods.

B.7 Lumpy mudstone

Description: This lithology is very similar in composition to equivalent clasts described from Bed 10 but is homogenously bedded with less lumps. It is characterized by large burrows which form large tubes parallel to bedding plains in distance of about 20-30cm. Burrows are preserved in the form of *Skolithos*-like tubes several cm in diameter composed of micrite with a cm-wide core of clear calcite spar (Pl. 8.7, fig. 5). They resemble burrows described from the lumpy wackestone facies but are larger.

Interpretation: Like clasts of this type in Bed 10 the lumpy burrowed mudstones are interpreted as peri-platform ooze.

8.4. C. Older clasts

C.1 Brachiopod-rich wackestone to mudstone.

Description: This limestone is a gray and light gray mottled mudstone with highly fossiliferous wackestone layers with abundant brachiopods (Pl. 8.8, fig.4). Conodonts from these clasts are of Bed 9-age and older (i.e. a mixed fauna) suggesting the fauna is reworked.

Sediment is muddy with 5% or less bioclasts including *Nuia* grains, trilobites and brachiopods. Wackestone layers or coquinas interrupt the relatively fossil poor sequence. In some examples the mud-sized fraction can be identified as composed of micritized *Girvanella* threads. The sediment is pervaded with burrows several mm in diameter. They are filled with geopetal sediment consisting of a vermicular peloidal packstone overlain by a coarser grained peloidal sand; clear calcite spar fills the remaining cavity (Pl. 8.8, fig. 5). The presence of a discontinuity surface is marked by a irregular wavy seam of laminated, brown, hyaline limonite(?), 0.1-0.3mm thick. It truncates shells and impregnates the underlying sediment. (Pl. 8.8, fig. 1). The overlying sediment is a coarse light gray wackestone with abundant *Nuia* grains.

Interpretation: The presence of mixed faunas, conspicuous colour changes parallel to bedding, irregular (limonitic or phosphatic) sutures and truncated and bored bioclasts indicate a discontinuity probably as a result of slowed sedimentation leading to a condensed sequence. Water depth is difficult to determine but abundance of calcified algae *Girvanella* suggest deposition in shallower water within the photic zone.

C.2 Oolite

Description: Like the oolite clasts in Bed 10 this lithology is composed to 90% of superficial ooids (0.2-1mm in diameter) in a clear blocky calcite cement. A few radial ooids are also present. The outer layers of the ooids are commonly replaced

by silica and so are 5% or less of the calcite cement. Replacement of the cement appears to originate around quartz sand grains. A layer of dolomite rich wackestone with irregular boundaries is intercalated with the oolitic sediment separating a finer grained more densely packed oolite with about 30% - 40% sand sized peloids from a coarser part with larger ooids and only 10-20% peloids (Pl. 8.8, fig. 7). Another sample is composed of well rounded moderately sorted sand sized lithoclasts of pelsparite, wackestone and rare skeletal debris. These sands resemble the ones associated with the oolites and are probably genetically related, i.e. they formed in a similar environment.

Interpretation: The interpretation of the oolites in Bed 10 is applicable to those from Bed 12. The presence of dolomite rich mud and different sizes of ooids within the sand probably records changes in water energy which allowed mud and finer grained sediment to settle. This is consistent with the interpretation of superficial ooids as beeing formed in a somewhat lower energy regime than "normal" ooids (Chapter 7 C.2).

C.3 Calcarenite

Description: Calcarenites are somewhat similar in composition to those found in Bed 10, but lack the diagenetic overprint of dolomitization. Dominant components are lithoclasts composed of rounded to sub rounded fragments of skeletal wackestone, mudstone and peloidal wackestone. Many of the mudstone lithoclasts appear to be micritized *Girvanella* intraclasts. Next in abundance are medium sand-sized peloids. Bioclasts are minor constituents and mainly derived from echinoderms, trilobites and brachiopods. *Nuia* grains are rare. Other particles are coarse sand sized phosphatic granules which are either oval or irregular in shape and rounded dolomitic grains in which dolomite rhombs replaced former mudstone(?) lithoclasts. Conspicuous particles are the well rounded quartz grains characteristic for Bed 8 calcarenites (Pl. 8.8, fig. 3).

Interpretation: The calcarenites are most likely derived from Bed 8 and represent turbidite deposits (Hiscott & James, 1985).

C.4 Calcirudites

Description: Calcirudites found in Bed 12 are similar to those described from Bed 10 with lithoclasts dominantly derived from the upper slope. Conodont faunas contained in these rare clasts confirm this assignment.

Interpretation. Talus and intraformational breccias similar to those found in Bed 10.

PLATE 8.8

All figures illustrate old or shelf derived clast lithologies found on Cow Head Peninsula.

Figure 1. Photomicrograph of lumpy *Nuia*-rich wackestone with omission surface marked by bored shell fragment (arrow) (Jim's Cove). Sample is from clast illustrated in Figure 4. Scale bar is 0.8mm.

Figure 2. Photomicrograph of shelf derived grainstone. Dark areas are silica replacing calcite spar. (Point of Head). Scale bar is 0.8mm.

Figure 3. Negative print of oolitic grainstone with wellrounded quartz grains. Scale bar is 3mm.

Figure 4. Clast of *Nuia*-rich wackestone with omission surface (arrow) marked by dark suture. Figure 1 shows omission surface of same clast in detail. Book edge for scale is 29cm long.

Figure 5. Thin section photomicrograph of burrow mottled lower part of clast in Figure 4. Scale bar is 0.8mm.

Figure 6. Clast of shelf derived grainstone with interbedded lime mud and grainstone layers. Grainstone is partly silicified. Coin for scale is 2cm in diameter

Figure 7. Photomicrograph of oolite with dolomite-rich mud in lower part of picture. Scale bar is 0.8mm.

1
2
3
4
5
6
7

Chapter 9
CLAST LITHOLOGIES OF BED 14

9.1. Introduction

Bed 14 megaconglomerates yield the largest clasts and greatest variety of different lithologies of all 3 debris flow horizons. This variety is the result of a large number of older clasts incorporated into the debris flow. Clast lithologies of Bed 14 are summarized in tables 9.1-9.3.

9.2. A. Local penecontemporaneous lithologies

A.1 Rhythmic limestones

A.1.1 Penecontemporaneous ribbon limestone

Description: Thinbedded marly limestone beds (1-3cm thick) alternate with thick interbeds of argillaceous, dolomite-rich siltstone (2-5cm thick). The terrigenous parting material is of greenish colour (fresh surface) and weathers buff or brown. Limestone beds are gray (fresh surface) and weather white indicating clay content. Limestone beds are typically homogenous with up to 3% pyrite dispersed throughout or forming clusters in the mud fraction. Mudstones are typically laminated with layers of peloidal wackestone rich in sponge spicules and algal filaments. In some samples the lime mud is rich in dolomite rhombs with cloudy cores and silt sized quartz (up to 3%). These minerals are also abundant in the parting material which in some cases is entirely replaced by coarse dolomite rhombs. Contacts between limestone and silty material are usually gradational. Rafts of ribbon limestone are usually small (10-30cm long in average) and occur in

TABLE 9-1. LOCAL CLASTS OF BED 14.

LITHOLOGY	SEDIMENTOLOGY	INTERPRETATION
A.1. Parted and ribbon limestone	Thin bedded marly limestone beds alternating with interbeds of argillaceous, dolomite-rich siltstone. Clasts commonly softly deformed.	Hemipelagites or fine grained turbidites.
A.2. Calcarenite.	Clasts of fine grained fossiliferous and unfossiliferous calcarenites reworked from rocks equivalent in age to beds 9, 11, 13.	Turbidites
A.3. Conglomerate.	Six different types of conglomerates: 1. penecontemporaneous conglomerate with mudstone/siltstone matrix; 2. dolomitized cgl.; 3. cgl. with silicified lithoclasts; 4. cgl. with phosphate clasts; 5. cgl. with a) bedding parallel and b) randomly oriented flat mudstone pebbles in calcarenite matrix; 6. chip cgl..	All conglomerates are debris flow deposits except 5.a), which was deposited by turbidity currents.
A.4. Dolostone.	Laminated dolostone similar to that described from Bed 11.	Dolomitic sand which was dolomitized on sea floor, reworked from Bed 11.
A.5. Chert.	All of lower slope lithologies cited above were affected by pervasive silicification.	Pervasive silicification of a variety of local lithologies, occurred preferably during deposition of Bed 11.

TABLE 9-2. CLAST LITHOLOGIES OF BED 14 - FOREIGN PENECONTEMPORANEOUS CLASTS.		
LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
B.1. Gastropod grainstone with shelf derived conodont faunas.	Lithoclastic peloidal grainstone with abundant macluritid gastropods. Conodonts correlate with upper Aguathuna Fm..	Lime sand deposited in shallow water behind shelf margin buildups.
B.2. Calcirudite.	Coarse calcirudites with cm-sized lithoclasts in a calcite spar or grainstone matrix. Lithoclasts are shallow water derived and not soft deformed.	From talus around buildups and intraformational breccia.
B.3. Massive packstones to wackestones.	Muddy, poorly washed peloidal skeletal grainstone to denser packstone to spiculitic wackestone. All are dominantly composed of algal debris.	Accumulated in quiet protected intermound areas and on upper slope.
B.4. Grainstones to rudstones.	Massive and bedded grainstones and rudstones composed of algal and skeletal debris of variable composition.	Fine- to coarse grained talus and interreef sediments. Shallow water deposits.
B.5. Boundstone	Buildup facies dominantly composed of Girvanella and Epiphyton accompanied by other algae, enigmatic tubular organisms and sponges.	Reef-like buildups which grew along the shelf edge.
B.6. Lumpy mudstone	Soft deformed rafts of bedded to rubbly mudstone with thin dolomitic argillaceous siltstone partings and occasional grainstone to rudstone lenses.	Peri-platform ooze with intercalated gravity flow deposits.

TABLE 9-3 CLAST LITHOLOGIES OF BED 14 - OLDER CLASTS.

LITHOLOGY	LITHOLOGICAL CHARACTERISTICS	INTERPRETATION
C.1. Shelf derived older clasts:		
C 1 1 Oolite	Two types of oolite: I. Oolite composed of up to 90% of normal ooids; II. Oolite composed of superficial ooids.	Type I.: High energy oolitic sand Type II.: Low energy oolitic sand Both types reworked from Cambrian deposits.
C 1.2 Lumpy Nuia-rich wackestone	Soft deformed clast of wackestone rich in skeletal debris of echinoderms, trilobites brachiopods and Nuia-grains.	Contain conodonts of Midcontinent Fauna C. Deposit of quiet subtidal environment.
C.1.3 Dolomitic wackestone/ grainstone with wellrounded quartz grains.	Massive grainstone interbedded with dolomite-rich bedded wackestone and calcirudite. Nuia-grains and well rounded quartz grains are abundant components.	Contains conodonts of Midcontinent Fauna C. Shallow water high energy deposit.
C.1.4. Echinoderm rich lumpy wackestone to grainstone.	Fossilliferous lumpy wackestone with partings of dolomite rich argillaceous siltstone Skeletal components are derived from echinoderms, brachiopods and nautiloids	Age equivalent to Catoche Fm., Quiet subtidal deposit.
C.1 5 Bedded lithoclastic grainstone to rudstone	Bedded grainstone to rudstone with abundant trilobites and nautiloids.	Age equivalent to Catoche Fm. Shallow subtidal skeletal sand.
C 2. Old foreign clasts from the shelf margin.		
C.2.1 Massive wackestone reworked from Bed 10	Mottled mudstone to wackestone, similar to lithology described from Bed 10.	Upper slope mud accretion.
C 2 2. Lumpy wackestone reworked from Bed 12	Lumpy wackestone with dolomite-rich partings similar in composition and age to lithologies described from Bed 12.	Upper slope deposit.
C.2.3 Calcirudite reworked from Bed 12	Calcirudite with up to 6cm long flat mudstone pebbles in calcarenite matrix.	Intraformational or foreslope breccia.
C 2 4 Massive wackestone/ grainstone reworked from Bed 12.	Lithology similar to lithofacies described from Bed 12 (B.1.)	Upper slope/shelfedge deposit.
C.2 5 Bedded grainstone/ mudstone reworked from Bed 12	Soft deformed clast of interbedded grainstone, rudstone and mudstone layers separated by thin shale partings	Upper slope deposit.
C.3 Old slope derived clasts		
C 3 1 Thick bedded parted limestone reworked from Bed 10	Light grey parted lime-mudstone	Hemipelagic sediment or deposit from fine grained turbidity flows.
C 3 2 Parted limestone reworked from Bed 10	Blue grey lime mudstone with dolomite-rich argillaceous siltstone partings	Hemipelagite or deposit of fine grained turbidity flows.
C 3 3 Older clasts of parted limestone	Sequence of parted limestone with interbedded chip conglomerate containing trilobites of early Tremadoc age	Hemipelagites or deposits of fine grained turbidity flows with intercalated debris flow deposits

clusters (boudinaged breccias of Schlager & Schlager, 1978). Clasts are either completely soft deformed (siltstone together with limestone) or limestone beds are brittly fractured (Pl. 9.1, fig. 1). In some clasts the limestone layers are completely fragmented into flat pebbles with rounded corners and mixed with the parting material. Much of the green argillaceous siltstone matrix in proximal sections of Bed 14 is probably derived from this lithology. Samples of ribbon limestone are always barren of conodonts, but soft deformation and first occurrence of this lithology in Bed 14 suggests age-equivalence to Bed 13.

A.1.2 Parted limestone

Description: Another type of parted limestone in Bed 14 is composed of 5-10cm thick, gray-yellow weathering mudstone layers with 1cm-5cm thick dark brown, dolomite-rich, argillaceous siltstone partings. Lime mud contains quartz silt, dolomite crystals and dispersed pyrite crystals. A mm thick layer of quartz-rich grainstone with silt sized peloids and erosional base is locally intercalated with the muddy sediment. Siltstone layers contain 30%-50% dolomite with zones or cores composed of ferroan dolomite. Dikes of parting material cut through limestone layers and connect siltstone beds. Clasts are slightly soft deformed (i.e. bent). Conodont samples from this lithology are commonly barren, the single conodont retrieved from a parted limestone indicates Bed 13 or upper Bed 11 age. Similar distinctly zoned dolomites have not been previously observed in the older conglomerates and clasts may therefore be of Bed 13-age.

Interpretation: Parted and ribbon limestones are hemipelagites or fine grained turbidites (Coniglio, 1985).

A.2. Calcarenite

Description: Clasts of calcarenite are ubiquitous in Bed 14 and conodont samples indicate that they are dominantly reworked from beds 9 (10) and 11 (12). Bed 13 calcarenites are difficult to distinguish from those from upper Bed 11 based on conodont samples. Lithological characteristics of calcarenites are:

a) Clasts of Bed 9 calcarenites are typically thick bedded and interbedded with shale and mudstone. They are composed of fine grained, well sorted peloidal sands with abundant sponge spicules, *Girvanella* rafts and single filaments (Pl. 9.1, fig. 2). Clasts illustrate both, crosslamination and parallel lamination..

b) Clasts of Bed 11 calcarenites are usually dark brown or gray and plates or fragments of sequences intercalated with mudstone and chert. They are commonly rich in mud and contain *Halisis* chains which do not occuf in Bed 10. Algae and shell debris are generally more abundant. *Girvanella* rafts and tubes are somewhat less frequent, instead spheres surrounded by *Girvanella* are common. Radiolarians typically occur in muddy portions of the sediment. Sedimentary structures (cross stratification etc.) are rarely observed. Calcarenites from Bed 9 (or 10) appear to be more abudant than than those derived from Bed 11 (or 12).

c) Calcarenites from Bed 13 appear to be rare. Typically they are coarser than older calcarenites, less well sorted and contain the highest percentage of shallow water derived bioclasts.

Clasts of fine grained unfossiliferous calcarenite occur in all three conglomerates and cannot be distinguished based on lithological characteristics.

Interpretation. These calcarenites are deposits of turbidity currents and grain flows (Coniglio, 1985).

A.3. Conglomerates

Clasts of reworked conglomerates are ubiquitous in Bed 14 and many are dolomitized and/or silicified to varying degrees which makes their age assignment difficult, because fossil data are scarce. They are therefore summarized together as conglomerates although some of them are older than Bed 13. Most of the conglomerates were probably deposited by debris flows. This can be inferred by similarity to debris flow deposits of the underlying bedded sequence. The different types of conglomerates are summarized in Figure 9-1.

A.3.1 Penecontemporaneous conglomerate with argillaceous siltstone matrix

Description: The conglomerate is composed of square subangular to subrounded flat mudstone pebbles to cobbles. The matrix is aggraded microspar interspersed with patches rich in dolomite rhombs and quartz silt which appear as greenish areas on the clast surface. A few smaller lithoclasts of peloidal wackestone and *Girvanella* intraclasts are also present. The conglomerate appears to be dominantly formed by a previously bedded mudstone with light brown, brown and gray beds which broke up into clasts.

Interpretation: The only conglomerate that can be identified as being a debris flow deposit and based on conodonts penecontemporaneous to Bed 13, 12 or upper 11.

A.3.2 Dolomitized conglomerate

Description: Clasts of this type are all completely or partly dolomitized, with some pervasively silicified (Pl. 9.1, fig. 3). They were probably derived from different sources and dolomitized after deposition. Several modes of dolomitization occur: 1. Only lithoclasts are partly or completely dolomitized while the matrix remains unaltered. 2. Only matrix is dolomitized, clasts are still limestone. 3. Conglomerate is completely dolomitized with a) sharp clast/matrix boundaries and coarser dolomite in lithoclasts (Pl. 9.1, fig. 4) or b) boundaries are diffuse and matrix and clast dolomite are of similar size. Dolomite in all instances is ferroan.

Interpretation: A dolomitized debris flow deposit which occurs in large numbers only in Bed 14, rarely in Bed 12

A.3.3 Conglomerate with silicified lithoclasts

Description: A conglomerate dominantly composed of shallow water derived lithoclasts up to 2cm long. Clasts are irregular in shape, subangular to subrounded

Figure 9-1: Conglomeratic clast lithologies in Bed 14. Ms.=mudstone, ws.=wackestone, gs.=grainstone.

CONGLOMERATE CLAST LITHOLOGIES IN BED 14

A 3 1 Penecontemporaneous conglomerate with ms silt matrix



Lithoclasts: ms - pebbles, peloidal ws, Girvanella intraclasts

Matrix: microspar patches rich in ferroan dolomite and quartz silt

Interpretation: debrisflow deposit penecontemporaneous to Bed 13 or upper Bed 11.

A 3 2 Dolomitized conglomerate



Lithoclasts: subrounded peloidal gs, ms, ws partly or completely dolomitized by coarse dolomite rhombs, sometimes ferroan dolomite

Matrix: dolomite, sometimes partly silicified

Interpretation: dolomitized debrisflow deposit, penecontemporaneous to Bed 13

A 3 3 Conglomerate with siliceous intraclasts

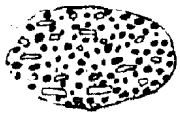


Lithoclasts: irregular subangular - subrounded peloidal gs and os, algal intraclasts, ws, ms - clasts

Matrix: dolomite with angular and round chert grains

Interpretation: debrisflow deposit reworked from Bed 11

A 3 4 Conglomerate with phosphate clasts



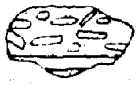
Lithoclasts: phosphate granules and pebbles, rounded, chert, flat ms pebbles

Matrix: medium calcarenite

Interpretation: debrisflow deposit reworked from lower Bed 11

A 3 5 Conglomerate with flat ms pebbles in calcarenite matrix

a) Graded stratified conglomerate



b) Chaotic fabric

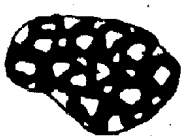


Lithoclasts: flat ms pebbles, gs, quartz grains

Matrix: calcarenite with well rounded quartz grains

Interpretation: a) turbidite incorporated from Bed 6,
b) debrisflow deposit incorporated from Bed 8

A 3 6 Chip conglomerate



Lithoclasts: ms and gs, subangular - subrounded pebble to cobble size

Matrix: calcarenite commonly silicified

Interpretation: debrisflow deposit incorporated from Bed 9

(Pl. 9.1, fig. 5) and are peloidal grainstone and packstone, algal intraclasts with *Girvanella* and *Epiphyton*, peloidal skeletal wackestone and rarely mudstone. Some lithoclasts are partly or completely silicified. Large skeletal fragments of echinoderms and gastropods are present. The matrix is dolomitic with abundant angular and round chert grains. Conodont faunas indicate a Bed 11 age.

Interpretation: Debris flow deposit reworked from Bed 11.

A.3.4 Conglomerate with phosphate granules and pebbles

Description: These conglomerates are characterized by blue weathering granule to pebble sized lithoclasts of calcium phosphate (Pl. 9.1, fig. 6). They are rounded and commonly surrounded by a rim of chalcedony (Coniglio, 1985). Where the rim is absent the surface appears to be corroded; sporadically only the collapsed rim is preserved (Pl. 9.1, fig. 7). Relict structures preserved in some of the phosphate pebbles suggest that the phosphate replaced previous limestone clasts. Other lithoclasts are up to 10% yellow weathering chert granules and a few scattered mudstone clasts. Matrix is a medium calcarenite with abundant rounded *Girvanella* intraclasts, spheres coated with algal micrite or -threads, and shell fragments. Matrix to clast ratio is about 30:70. Conodont faunas obtained indicate Bed 11 age for boulders of this lithology. Bed 11 at Lower Head contains a conglomerate very similar in composition. Conglomerates with small phosphate grains also occur in clasts reworked from Bed 10.

Interpretation: Reworked from lower Bed 11. Phosphatic sediment is probably related to starved sedimentation on slope during this period and possibly upwelling of cold water.

A.3.5 Oligomict conglomerate with flat mudstone pebbles in calcarenite matrix

Description: a) Conglomerates of this type are found associated with bedded sediments and grainstone. Typically the conglomerates resemble turbidites of Bed

8, however, they commonly show a diagenetic overprint of dolomitization and/or silicification. Unaltered clasts consist of 90% flat mudstone pebbles with rounded corners, which are slightly soft-deformed (bent) with pitted surfaces. They are 5-15cm long and 0.5-4cm thick. Mudstone clasts weather white or remain grey, some are laminated bedded peloidal packstones. A few lithoclasts of burrowed mudstone and grainstone with well rounded grains comprise up to 10% of the lithoclasts. Sporadic lithoclasts are preferentially silicified or the entire clast is pervasively silicified. The matrix is calcarenite or dolomite rich argillaceous mudstone. Commonly both matrix types are mixed. Components in calcarenites are dominantly rounded to well rounded medium sand sized lithoclasts of mudstone and peloidal grainstone accompanied by the conspicuous well rounded quartz grains which are typical in Bed 8-clasts. Bioclasts are *Nuia* grains and shell debris of brachiopods and trilobites. Grains are cemented by calcite spar or by dolomite with clay between the rhombs. Flat mudstone pebbles are usually oriented with their long axis parallel to bedding (Pl. 9.1, fig. 8). The matrix:clast ratio is between 20:80 to 80:20. Clasts are sporadically found associated with bedded dolomite.

b) Conglomerates with chaotic fabric are of similar composition and occur abundantly in Bed 14 at Lower Head (Pl. 9.7, fig. 4).

Interpretation: a) Bedded conglomerates with calcarenite matrix correspond to graded stratified conglomerates of Hiscott & James (1985) typically found in Bed 8. The facies is interpreted as a turbidite.

b) Conglomerates of similar composition with chaotic lithoclasts are probably related to Facies type B of Hiscott & James (1985). Limestone plate conglomerates are debris flow deposits. Both types of conglomerates are typically found in upper Cambrian and lower Tremadocian part of CHG.

A.3.6 Chip conglomerate

PLATE 9.1

All photographs are from clasts and thin section samples from Bed 14 at Lower Head East.

Figure 1. Soft deformed clast of ribbon limestone (A.1.1.). Hammer blade for scale is 2.5cm thick.

Figure 2. Clast of calcarenite (A.2.). Hammer blade is 10cm long.

Figure 3. Clast of laminated dolostone (d) overlain by dolomitized flat pebble conglomerate (db) (A.3.2.). Hammer blade is 19cm long.

Figure 4. Thin section photomicrograph of dolomitized conglomerate (A.3.2.). Note different styles of dolomitization of conglomerate clasts replaced by coarse dolomite crystals and matrix replaced by fine grained dolomite. Scale bar is 0.5mm long.

Figure 5. Clast of silicified conglomerate (A.5.). Arrow points out silicified conglomeratic part of clast. Hand lense is 3cm long.

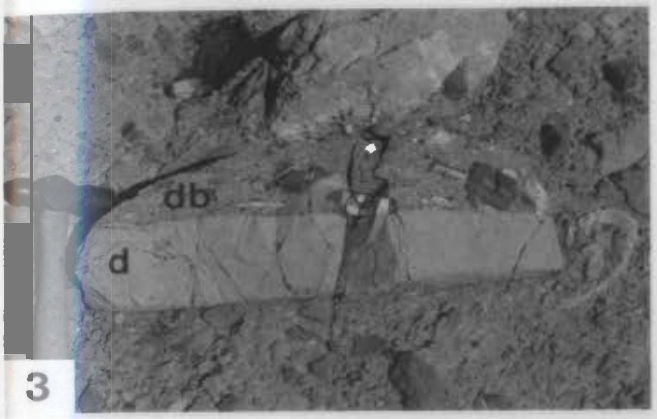
Figure 6. Clast of conglomerate with phosphate pebbles (arrow) (A.3.4.) is reworked from lower Bed 11. Scale is in cm.

Figure 7. Photomicrograph of clast with phosphate pebbles in Figure 6 Some of the phosphate pebbles are corroded (c) while others are rimmed with chalcedony (r). Scale bar is 0.5mm long.

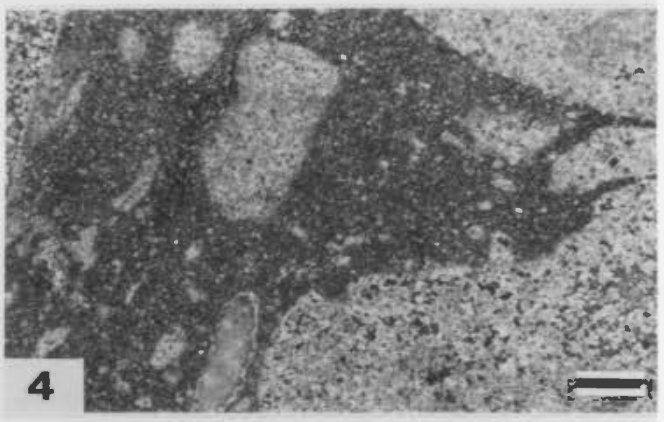
Figure 8. Clast of conglomerate with flat mudstone pebbles in calcarenite matrix (A.3.5.a). Flat pebbles are oriented parallel to bedding. Clast is of Tremadoc or upper Cambrian age. Hammer is 30cm long.


1

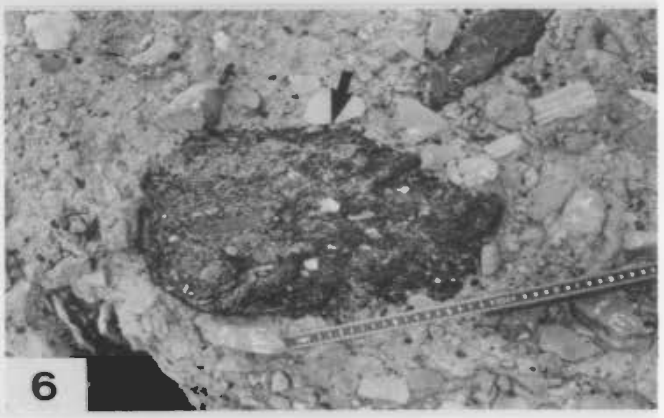

2

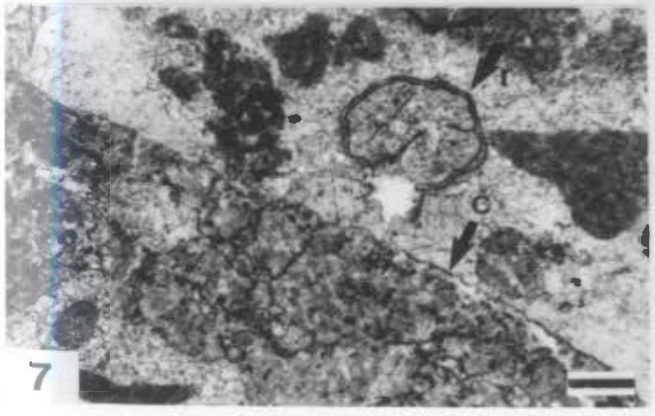


3


4


5


6



7


8

Description: Chip conglomerates occur interbedded with limestone and shale in a boulder preserving a bedded sequence of lower Tremadoc age (see C.1). Pebble to cobble sized mudstone and grainstone lithoclasts are surrounded by calcarenite matrix. Matrix is commonly pervasively silicified.

Interpretation: Limestone chip conglomerates (Facies type C of Hiscott & James, 1985) are also debris flow deposits.

A.4. Dolostone

Description: Three different types of dolostone can be recognized in Bed 14: 1. Pervasively dolomitized conglomerates and breccias, described under section A.3.2. 2. Mottled dolostones are dolomitized lumpy wackestones which are addressed in section B.3. 3. Laminated dolostones are similar to those described from Bed 12. Staining shows that all of these lithologies are ferroan.

Interpretation: Laminated dolostones are slope deposits which were dolomitized on the sea floor. Similar style of dolomitization in the other two lithologies suggests they have been altered under similar conditions.

A.5 Chert

Description: Chert in Bed 14 occurs commonly as layers or nodules associated with bedded mudstone, wackestone, grainstone and shale incorporated from beds 11 or 12. Chert is dark brown or black in colour, the latter with a bituminous smell. Chert layers may grade laterally into limestone. Pervasive silicification affects many different lithologies such as clasts of conglomerate (see A.3.3), lumpy wackestone and grainstone. As in the case of the dolostone no foreign lithologies seem to be affected apart from the lumpy wackestone. Grainstones are only silicified at the surface, probably after deposition in the conglomerate or are deep water grainstone such as the calcarenites found capping Bed 12 on Cow Head Peninsula. This evidence suggests that silicification typically ocurred in deeper,

water, affecting partly lithified lower slope lithologies. Some of these clasts were deformed while soft indicating that the chert layers formed early and before transport occurred.

Interpretation: Chert replaced limestone in marine environment.

9.3. B. Foreign penecontemporaneous lithologies

B.1 Gastropod grainstone with shelf derived conodont faunas

Description: A single small boulder (30cm^2) at Lower Head yielded a conodont fauna which is also found in the upper Aguathuna Fm. and base of the Table Head Formation. The clast is a dark brown grainstone with local patches of wackestone and abundant macluritid gastropods. The limestone is composed of rounded to subrounded micritic lithoclasts and peloids. Most prominent is algal debris comprising *Girvanella* lumps, small *Nuia* grains, *Halisis* chains and *Renalcis* fragments. Shell fragments which were probably aragonitic were replaced by calcite, after a stage of dissolution indicated by peloidal sediment filling the mold (Pl. 9.2, fig. 1). Large gastropod shells (more than 5cm across) are overgrown with *Girvanella*. Gastropod cavities are filled geopetally with grainstone of similar composition, but usually finer grained. In one sample a chamber is half filled with grainstone while the remainder of the cavity is filled with microspar containing scattered algal peloids and dolomite rhombs with cloudy cores. Large neomorphic spar crystals grow into the secondary fill which probably filtered into the open porespace during or shortly after transport (Pl. 9.2, fig. 2).

Interpretation: Lithological and faunal composition of clasts suggest derivation from the shelf interior. Probably lime sand deposited in shallow water behind a reef barrier.

B.2 Calcirudite

Description: Coarse grained calcirudites with cm sized lithoclasts embedded in a spar or grainstone matrix are conspicuous lithologies of Bed 14 (Pl. 9.2, fig. 3). These calcirudites are associated with "normal" facies such as packstones or bedded wackestones and grainstones.

Clasts are pebble to gravel sized or smaller. They are round to irregular in shape and never soft deformed. Most abundant are lithoclasts of skeletal peloidal packstone to grainstone accompanied by spiculitic wackestone, dolomitic (1-10% dolomite) packstone to wackestone and *Girvanella* intraclasts. The sandy matrix is grainstone to packstone composed of algal peloids and skeletal grains derived from echinoderms, brachiopods, trilobites and, rarely, ostracodes. Skeletal grains are subangular to subrounded. Well preserved fragile algal debris derived from *Girvanella, Epiphyton, Halysis* and other enigmatic forms is abundant. Transport of components was obviously gentle or over short distances. All components (including coarse lithoclasts) are shallow water derived. No deep water lithoclasts are present (Pl. 9.2, fig. 4). Calcirudites with neomorphic calcite spar are found associated with types yielding grainstone matrix. This configuration suggests partial replacement of finegrained particles by neomorphic spar which is similarly found in calcirudites of Bed 10.

Interpretation: Abundance of algal debris and nature of lithoclasts indicates source of components from shelf edge and shallow upper slope probably from talus around buildups. Similar deposits occur around most elevated areas of the seafloor which are, by nature, sensitive to gravity. While calcirudites of Bed 10 with their soft deformed clasts appear to be the result of instability of muddy sediment, most lithoclasts of Bed 14 calcirudites were obviously not soft when mobilized.

B.3 Massive packstone to wackestone

Description: Massive packstones to wackestones occur as isolated clasts or associated with the organic buildup facies in the large boulders at Lower Head and in Bed 14 at Cow Head. They are also found intercalated with bedded

grainstone and rudstone. The sediment shows a variety of different compositional and textural characteristics ranging from muddy, poorly washed peloidal skeletal grainstone overlying denser packstone to spiculitic wackestone. All these facies may be present within one thin section or clast. All samples of this lithology are dominated by algal debris with *Girvanella*-peloids, -rafts and spar cored *Girvanella*-grains, floating *Halysis* chains, and *Pulchrilamina* debris. Skeletal debris comprises sand-sized subrounded to subangular fragments of gastropods, trilobites, brachiopods and echinoderms. Echinoderm and gastropod fragments are commonly bored and aragonitic gastropod shells are replaced by calcite spar except for the micritic rims. In Bed 14 the massive packstone to wackestone facies are dominated by the peloidal skeletal packstone. In beds 10 and 12 in contrast finegrained wackestone is more abundant.

Interpretation: Association of the packstones and wackestones with the boundstone facies indicates that the lithology formed part of the buildup facies which probably accumulated in quiet protected intermound areas or below wave base in deeper water intercalated with reefal debris (i.e. grainstones and rudstones).

B.4 Grainstones and rudstones

Description: Massive grainstones composed of algal intraclasts and lumps comprise inter-reef sediments in boulders at Lower Head. They are rich in skeletal debris of the mound and intermound organisms the most abundant of which are gastropods, trilobites, brachiopods and echinoderms (Pl. 9.2. fig. 7). Accessory debris is derived from bryozoans, *Pulchrilamina* and algae.

A single boulder (omega-boulder) (see Fig. 2-2 for location) is entirely composed of interbedded layers of coarse rudstone and fine-grained grainstone indicating that both facies are related. The neighbouring gamma-boulder shows lateral intergradation with fine-grained wackestone and grainstone. The grainstone part of this clast illustrates a peculiar pattern of fracturing with gradation from

PLATE 9.2.

Scale bar is 0.8mm unless otherwise indicated. All clasts and thin section samples were found in Bed 14 at Lower Head East.

Figure 1. Thin section photomicrograph of shelf derived grainstone (B.1.) with gastropod mold partly filled with peloidal sand and partly with calcite spar.

Figure 2. Thin section photomicrograph of gastropod shell. Inside of shell (s) is rimmed by coarse neomorphic calcite spar (ns) and filled with crystal debris composed of ferroan calcite; outside of shell is overgrown with *Girvanella* and bored (b). Scale bar is 0.3mm.

Figure 3. Clast of calcirudite (B.2.) with lithoclasts surrounded by white crystalline calcite. Clastic facies is associated with massive wackestone in the same clast. Book end for scale is 25cm long.

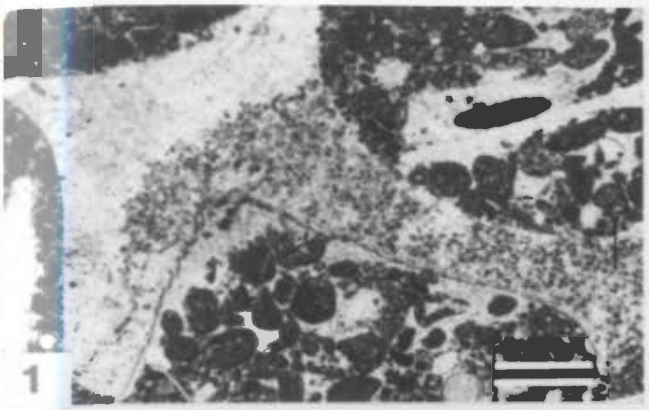
Figure 4. Negative print of calcirudite with lithoclasts composed of skeletal wackestone, packstone and grainstone rimmed with coarse calcite. Scale bar is 1cm.

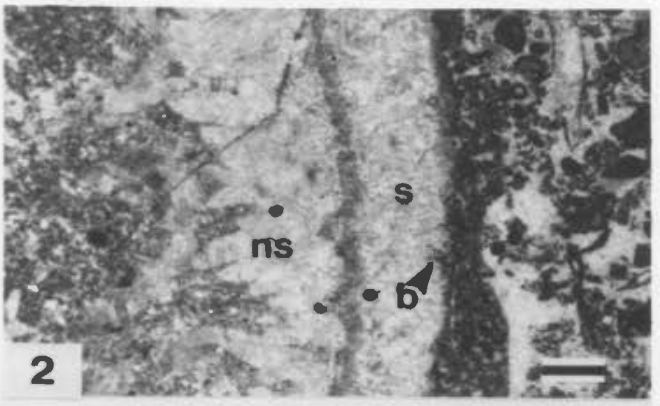
Figure 5. Thin section photomicrograph of para breccia of peloidal packstone. Fractures retain fitted fabric and are filled with argillaceous dolomitic siltstone similar in composition to the surrounding matrix.

Figure 6. Thin section photomicrograph of [redacted]plexly fractured packstone (to left of picture) is bordered by siltstone of matrix composition.

Figure 7. Thin section photomicrograph of grainstone (B.4.) composed of oriented elongate intraclasts.

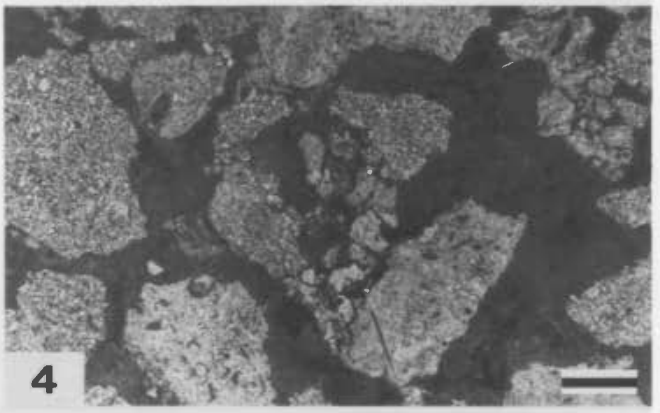
Figure 8. Thin section photomicrograph of grainstone (B.4.) with fragment of dasycladacean(?) alga.

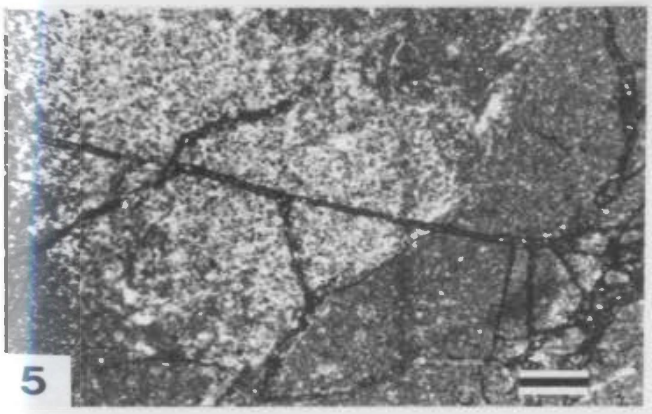

1

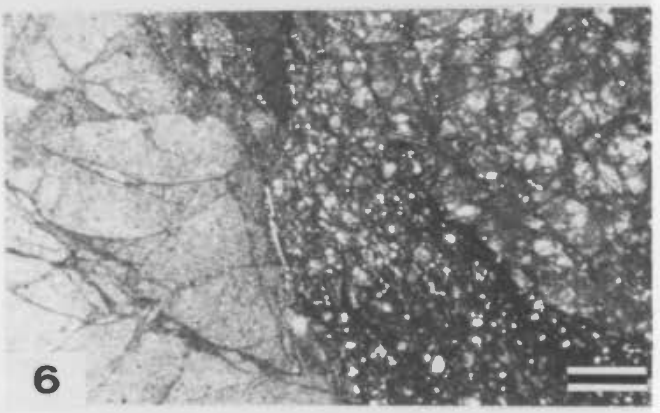


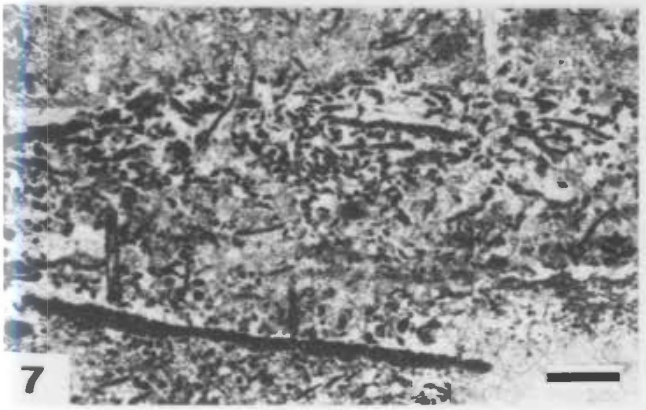
2

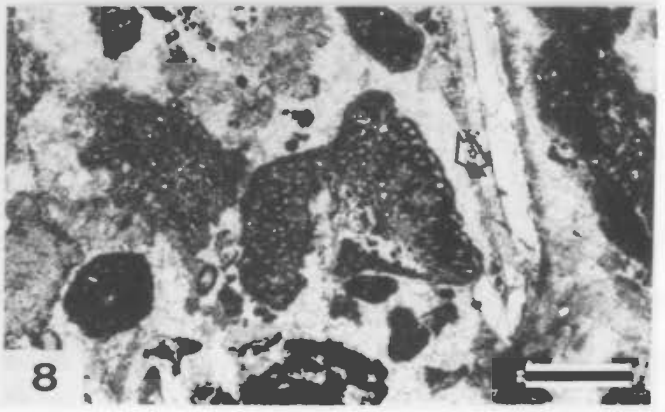

3


4


5


6


7


8

lithoclasts with fitted margins to completely disintegrated conglomerates. Spaces between lithoclasts are filled with sediment similar to the matrix of the Bed 14-conglomerate or with a mesh of crystals (Pl. 9.1, figs. 5,6). The fractures could be the result of detachment and transport from the shelf margin or they could represent some type of intraformational brecciation possibly related to faulting or earthquakes. Füchtbauer and Richter (1983) and Spaletta and Vai (1984) report on "para-breccias" or "seismites" respectively which they interpret as deposits related to earthquake shocks and which look very similar to the CH examples. Seilacher (1984) points out, however, that sedimentary structures attributed to seismic events can only be distinguished from other events through circumstantial evidence.

Bedded and massive grainstones and rudstones show variations of roundness and sorting from clast to clast and within the same clast. Composition of the grainstones and rudstones records the varying sources: e.g. some grainstones are dominated by gastropod fragments, others by algae or a *Pulchrilamina*-like organism (Pl. 9.2, fig. 7) etc.. Many skeletal remains found in this debris have not been found in the buildup facies itself such as possible dasycladaceans and *Hedstroemia*- and *Microtubus*-like forms (Pl. 9.2, fig. 8; Pl. 9.3, figs. 1,2,4). Components are cemented by clear blocky calcite spar.

Interpretation: Rudstones and grainstones are talus and inter-reef sediments which were shed from and accumulated between organic buildups. Neomorphic spar replacing lime mud is rarely observed and the lime sands were probably well washed and clean sugesting deposition in relatively shallow water above wave base.

B.5 Boundstone

Description: Large boulders measuring up to 200 x 100m in size are exposed at Lower Head East. They preserve an impressive record of shelf edge buildup facies as it existed during early Whiterock time. Examination of boulders reveals that

Girvanella in association with *Epiphyton* are the dominant sediment builders (Pl. 9.3, figs. 2,3). In addition the organic buildups were inhabited by a wealth of different algae, sponges and enigmatic organisms. *Girvanella* occurs in several growth morphologies:

1. The most abundant forms are wavy, loosely packed sheets of *Girvanella* intergrown with *Renalcis* and *Epiphyton*.

2. Regularly arranged parallel growing strands of *Girvanella* threads form small (several cm in diameter) digitate stromatolites. Algae are so densely packed that structure appears to be micritic (Pl. 9.3, figs. 5,6). Possibly similar *Girvanella* stromatolites have been described by Ahr (1971) from the Upper Cambrian Wilburns Formation in Texas.

3. "Porous" *Girvanella* aggregates in which an irregular network of threads with "pores" of up to 0.5mm diameter is formed by circular growth of a single filament. These growth forms also occur in clasts from Bed 10 (see Chapter 8, B.2). They were not found in growth position but only seen in *Girvanella* lumps. The small delicate pores may be invisible in thick layered aggregates of algae.

4. A different type of *Girvanella* with very thin filaments arranged into wavy sheets and intergrown with hemispherical organisms and showing a vague internal structure. The hemispheres are either large (0.8mm across) with thin calcitic walls with a fibrous structure or small (0.3-0.7mm in diameter) with hemispherical to irregular shape. They may be sessile foraminifers which are commonly found intergrown with algae (Pl. 9.3, fig. 7).

The different growth habits of *Girvanella* may be the expression of subtle environmental differences. Monty (1967) described recent algal mats formed by a *Rivularia* species which is capable of growing on rocks as well as on previous mats of *Schizothrix*. This flexibility is also exhibited by *Girvanella* which shows intergrowth with a variety of other algal genera. The range in diameter and wall

thickness of the calcareous tubes suggests that a number of species are present (cf. Johnson, 1966; Danielli, 1981).

Epiphyton is the other important algal genus in Bed 14 buildup facies where it occurs abundantly for the first time since its disappearance from marginal facies after deposition of Bed 7. It appears to be an inhabitant of agitated well aerated shallow waters (N.P.James, pers. com., 1986). Unlike in older facies *Epiphyton* buildups in Bed 14 are not associated with oolitic but rather with bioclastic sands. Over 80 species of *Epiphyton* are described to date, mainly in the Russian literature. The validity of this classification has been questioned by Pratt (1984), who regards *Epiphyton* (and *Renalcis*) as diagetic fossils preserving growth of different coccoid cyanobacteria. Riding and Voronova (1986) also recognize the problem of specific and even generic assignment of these algae and suggest a classification scheme based on morphologic characteristics. *Epiphyton* in Bed 14 can be distinguished from older forms because of their more robust short stemmed growth form. Edhorn and Anderson (1977) point out that growth forms of stromatolites which are similarly formed by cyanobacteria may be the expression of biological differences (i.e. different species) as well as environmental (and possibly diagenetic) control.

Another ubiquitous alga present is *Renalcis* which is found intergrown with *Epiphyton* and *Girvanella*. The form is commonly referred to cyanobacteria (cf. Pratt, 1984) but regarded by some workers as parathuraminacean foraminifer (Riding, 1975; Riding and Brasier, 1975).

Halysis is present in form of chains and pallisades depending on crossection. Guibault et al. (1976) described *Halysis* from boulders in the Mystic conglomerate and reconstructed it with a fan shaped thallus which explains the variable shapes of the alga seen in thin sections (Pl. 9.4, figs. 1,2).

Other algae present include *Solenopora*-like forms with perforated partly recrystallized walls (Pl. 9.4, fig. 3). *Solenopora* is abundant in lower Middle

PLATE 9.3.

All pictures illustrate thin section photomicrographs from samples found in Bed 14 at Lower Head. Scale bar is 0.8mm unless otherwise indicated.

Figure 1. Close-up of algal(?) packstone in Figure 4. showing clusters of spheres which remind to algae like *Vermiporella*. Scale bar is 0.3mm.

Figure 2. Massive packstone (B.3.) with divers components including *Halysis* chains (lower left) and *Epiphyton* clusters (center).

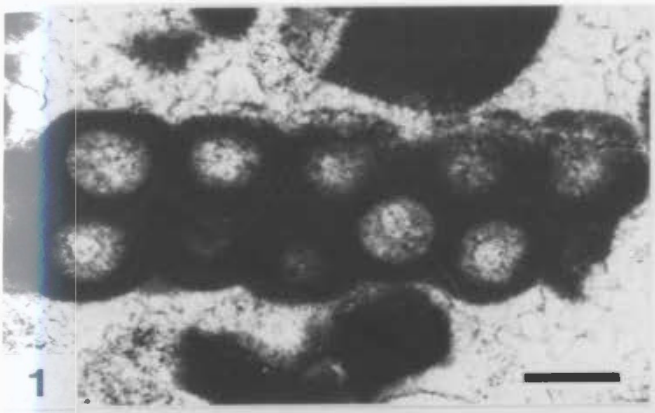
Figure 3. Wavy sheets of *Girvanella* overlain by boundstone mainly composed of poorly preserved *Renalcis*.

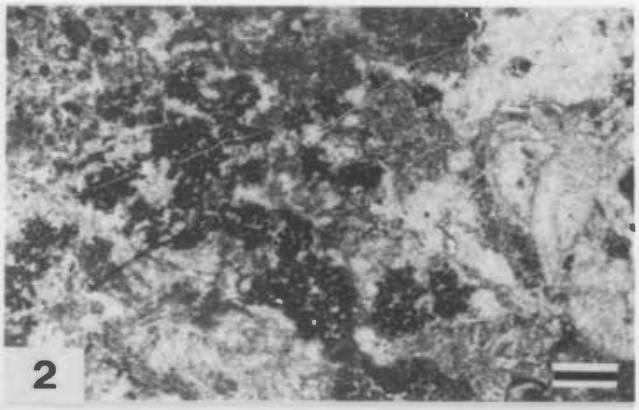
Figure 4. Algal boundstone dominantly composed of *Renalcis* (at bottom) overlain by algal(?) packstone & grainstone with fragments of *Vermiporella*-like algae(?).

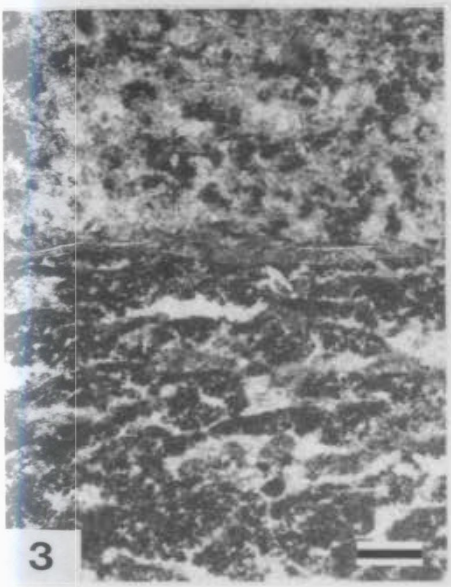
Figure 5. Fragment of a stromatolitic colony of *Girvanella* algae.

Figure 6. Close-up of *Girvanella* stromatolite illustrated in Figure 5. *Girvanella* threads form densely packed regular sheets with little remaining porespace. Scale bar is 0.3mm.

Figure 7. A type of *Girvanella* with very thin filaments intergrown with hemispherical structures, possibly foraminifers. Scale bar is 0.5mm.

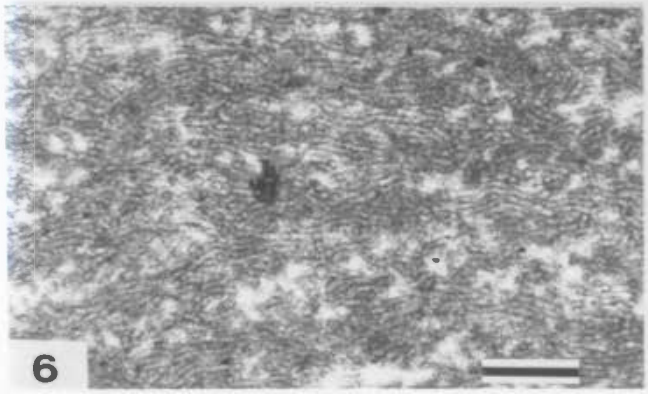

1

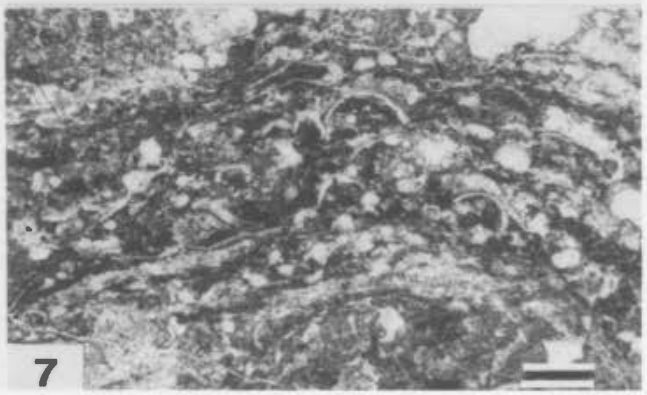

2


3


4


5


6


7

Ordovician Chazy reefs (Pitcher, 1964). Some thin sections show possible fragments of dasycladacean algae (Pl. 9.2, fig. 8; Pl. 9.3, figs. 1,4).

Apart from algae, sponges play an important role in the buildup facies. Their porous bodies are usually poorly preserved and commonly only irregular patches of spongiomorph structures can be recognized as sponge remains (Pl. 9.4, fig. 7). Small round or oval crossections with reticulate patterns report the presence of rod shaped sponges (Pl. 9.4, fig. 6). Archaeoscyphid sponges are present but different from the species found in Bed 10 (Pl. 9.4, fig. 5). Sheet-like sponges intergrown with algae are abundant but poorly preserved (Pl. 9.4, fig. 8).

Tubular organisms with intertwining networks of white-weathering calcite tubules comprise significant portions of rock in some boulders at Lower Head (boulders sigma and kappa at Lower Head East). These boulders typically show large scale (30-70cm) light and dark mottling which is the result of alternating white algal rich and dark tubule rich limestone (Pl. 9.5, figs. 1,2). Tubules measure up to 1mm in diameter and form branching networks whose extension is invisible because they curve out of the plane of the rock surface or thin section (Pl. 9.5, figs. 3,4,5). The forms possess several μm thick walls of structureless (i.e. mosaic) micrite and are filled with spar cement or with peloidal internal sediment. A few oblique cross sections show what appears to be single septae but this could be the result of overlapping (Pl. 9.5, fig. 6). Populations are usually densely crowded and remaining porespaces are filled with tangles of *Girvanella* threads. The nature of the tubular organism is enigmatic. The closest modern counterparts are buildups formed by polychaete worms or primitive coelenterates.

Reefs formed by various tubiculous polychaetes are known throughout the geologic past and from recent environments. Serpulid worms are well known for their ability to build large reef like structures and have been reported from Baffin Bay, Texas (Rusnak, 1960, Andrews, 1964) and Connemara, Ireland (Bosence, 1973).

PLATE 9.4.

All figures illustrate thin section photomicrographs except Figure 5. and all samples are from Bed 14 at Lower Head East. Scale bar is 0.8mm unless otherwise indicated.

Figure 1. Algal boundstone (B.5.) with fan shaped thallus of the alga *Halysis* (center of photograph). Scale bar is 0.5mm.

Figure 2. Close-up of *Halysis* chains. Scale bar is 0.4mm.

Figure 3. *Solenopora*-like form with perforated partly recrystallized walls.

Figure 4. *Wetheredella*-like organisms (center of photograph) similar to forms found in boundstone facies in Bed 12. Forms seem to have an encrusting growth habit.

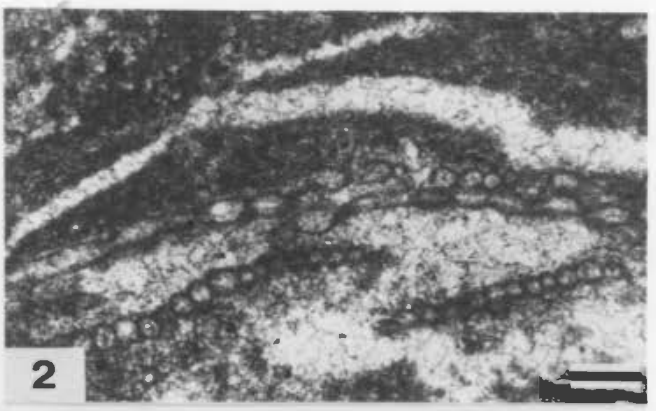
Figure 5. Clast surface illustrates crossection of large sponge. Scale bar is 2cm.

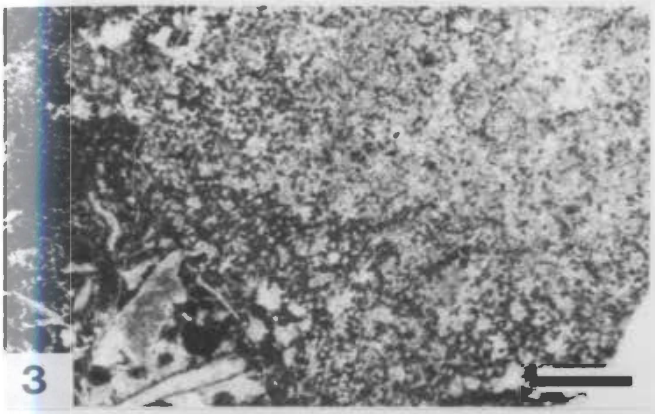
Figure 6. Crossection through rod shaped sponge with reticulate fabric.

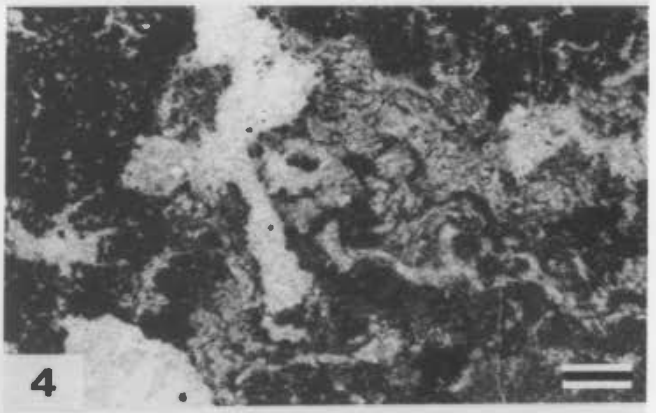
Figure 7. Peloidal grainstone at left is poorly preserved framework of a sponge surrounded by *Renalcis* colonies (to right).

Figure 8. Lattice-like walls of sponge framework. Scale bar is 1mm.

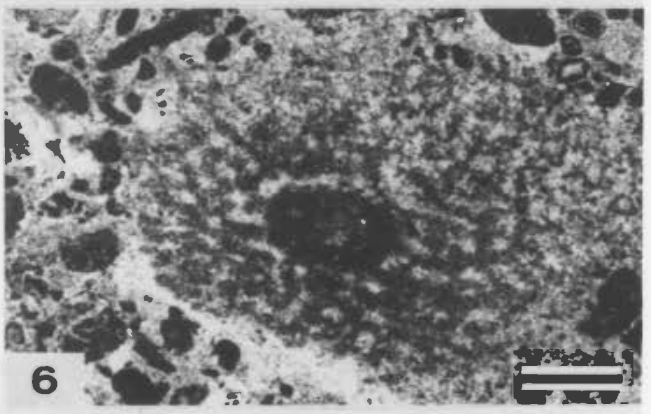

1

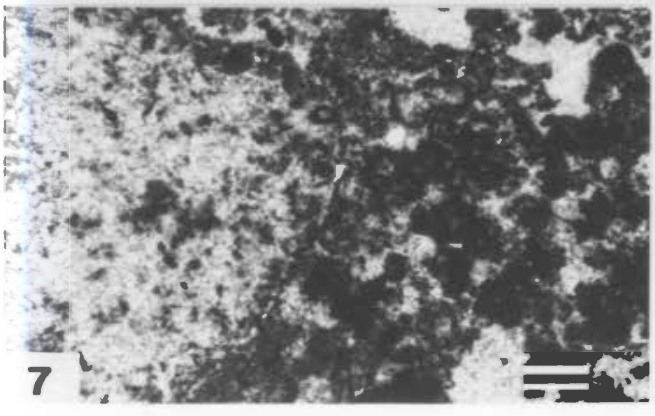

2

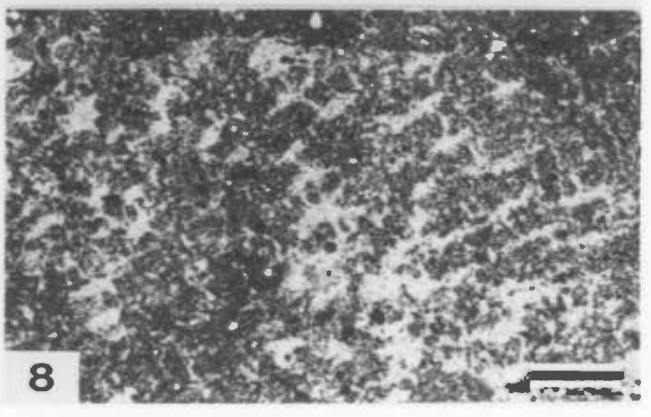

3


4


5


6


7


8

Copper (1976) reported abundant "serpulid" worms associated with *Wetheredella* buildups from the Upper Ordovician of Anticosti Island which show similarity in size (0.8-1.3mm in diameter) but have a "spiney lamellar surface" which is not present in the Cow Head-specimens. Furthermore they do not form the crowded clusters found in the Cow Head-boundstones. Leeder (1973) describes "serpulid" patch reefs, bioherms and biostromes from Tournaisian limestone (Lower Carboniferous) in Cumberland (England). The forms show the microstructure typical for serpulid worms but are septate, a feature not found in true serpulids but possibly present in the Cow Head-tubules. Associations of polychaete worms, especially serpulids, with sponges and algae are well known from Jurassic sponge-algal mounds in England and Germany (Gwinner, 1976; Parsch, 1956).

Other buildups of calcified tubes are formed by spirorbid polychaetes (which may, however, be confused with vermetid gastropods in some reports (Toomey and Cys, 1977). They are commonly found associated with stromatolites (Peryt, 1974) and other algae such as *Orthonella* and *Mitcheldeania*. Garwood (1931) reported serpulids and spirorbids with algae from Tuedian beds (Jurassic) in England. Sabellarid worms are also reported to form small reefs or heads (Richter, 1927, Remane, 1954).

In summary the tubules are most likely remains of polychaete worm tubes, but are not closely related to serpulid worms which are best known to form this type of buildup because of the differing wall structures. They differ somewhat from the much rarer tubules in Bed 12 boundstone which possess thicker walls or double walls. The tubules described from Anticosti Island appear to be the closest possible relatives; their wall structure is, however, not described.

Wetheredella-like organisms which have already been described from Bed 12 are also abundant in boundstone facies of Bed 14 and seem to have an encrusting growth habit (Pl. 9.4, fig. 4).

PLATE 9.5.

All illustrations are from samples found in Bed 14 at Lower Head.

Figure 1. K-boulder at Lower Head exhibits large scale mottling due to intercalated colonies of *Epiphyton*-rich boundstone (a) and "tubule"-rich boundstone (t). Person for scale is 170cm.

Figure 2. Close-up of algal-rich light (a) and "tubule"-rich dark (t) boundstone of boulder in Figure 1. Coin for scale is 2.5cm across.

Figure 3. Thin section photomicrograph of "tubules" intergrown with algal colonies. Scale bar is 1mm.

Figure 4. Outcrop photograph of "tubule"-rich boundstone with white weathering calcite filled tubules found in boulders at Lower Head. Coin for scale is 2cm across.

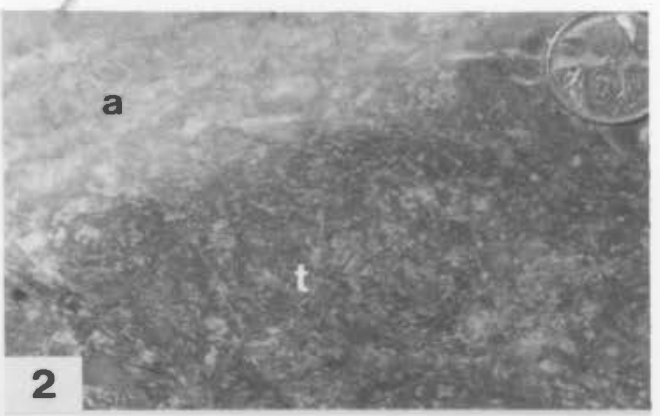
Figure 5. Thin section photomicrograph of boundstone shown in Figure 4. with densely crowded clusters of "tubules". Scale bar is 1mm.

Figure 6. Close-up of tube illustrating segmentation(?). Scale bar is 0.3mm.

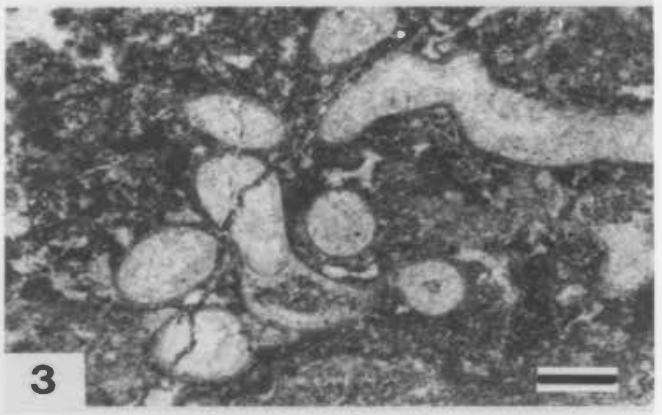
Figure 7. Lacy bryozoa. Scale bar is 1mm.



1



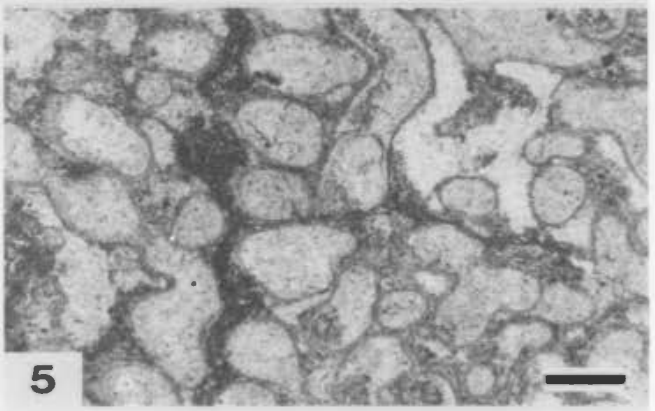
2



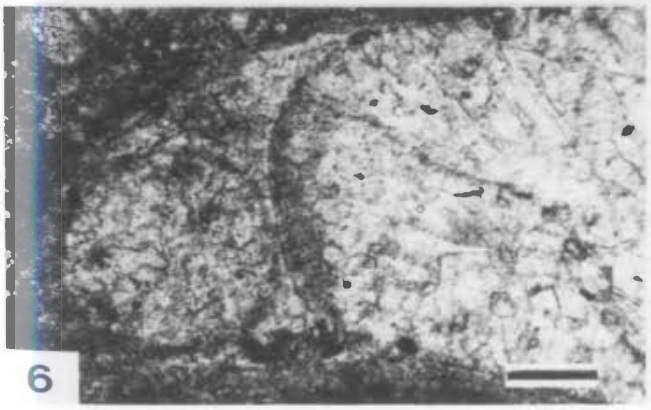
3



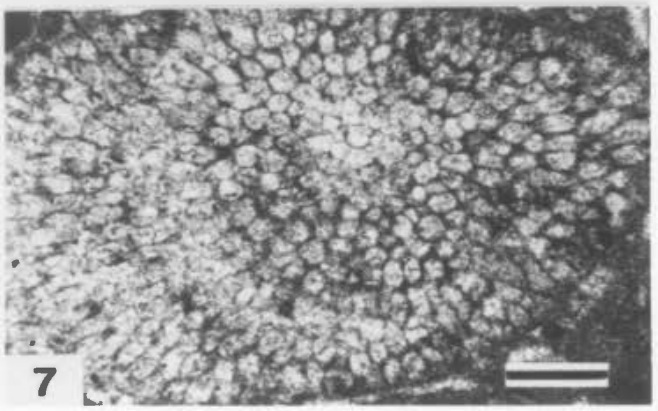
4



5



6



7

Pulchrilamina-like organisms form large (up to 50cm across) heads with lamellar structure. Lamelli are commonly outlined by yellow weathering silica. In thin section wiry pattern formed by the remains of their disintegrated walls record their abundance even in grainstones (Pl. 9.6, fig. 1,2; Pl. 9.2, fig. 7). Bryozoans are minor components of the buildups (Pl. 9.5, fig. 7).

Voids form conspicuous elements in the mound framework similar to the older Bed 10 lithologies. Cavities in Bed 11 clasts are irregularly shaped and typically measure between 20 and 40 cm in size. They are commonly lined with crusts of fibrous cement (which may also line small pore spaces between algal colonies) or have "roofs" of downward growing algae, particularly *Epiphyton*. They may be filled with bedded greenish peloidal sediment (Pl. 9.6, fig. 3) or fossils such as trilobites (alpha-boulder), nautiloids (kappa-boulder) or large macluritid gastropods (theta-boulder) which are typically found associated with *Girvanella* limestone (Banks and Johnson, 1957) (Pl. 9.6, fig. 4). Cements may also fill the larger cavities with botryoidal cement or broken cement crusts common. The nature of the cements infers that the rocks were lithified early (Pl. 9.6, fig. 5). Larger fractures lined with silica and filled with bedded coloured sediments are also abundant although they are not as large as those in shelf edge sands found in Bed 12. The buildup facies is associated with wackestones, packstones, grainstones and rudstones.

Interpretation: Most of the large boulders at Lower Head are undoubtedly the remains of complex reef-like buildups which grew along the shelf margin. The size of the boulders, the type of cementation and the amount of rudstone and calcirudite with intraclastic components around the structures suggests that the buildups reached substantial relief above the seafloor. The mounds were mainly formed by *Girvanella* and *Epiphyton*. Presence of abundant algae together with high energy grainstones indicates deposition in fairly shallow water above the wave base. The cavities and voids may record subaerial exposure of the reef as suggested by Schuchert and Dunbar (1934) or are inherited elements of the reef structure.

PLATE 9.6

Figure 1. Thin section photomicrograph of boundstone with *Pulchrilamina*-like organism found in Bed 14 at Lower Head. Scale bar is 0.8mm.

Figure 2. Close-up of thin section shown in Figure 1. with spiney vertical extensions characterizing this organism. Scale bar is 0.2mm.

Figure 3. Fracture in bedded grainstone is filled with bedded green sediment and lined with silica and fibrous calcite. Scale bar is 20cm. Clast found in Bed 14 at Lower Head.

Figure 4. Theta-boulder in Bed 14 at Lower Head contains clusters of macluritid gastropods. Pen for scale (arrow) is 18cm long.

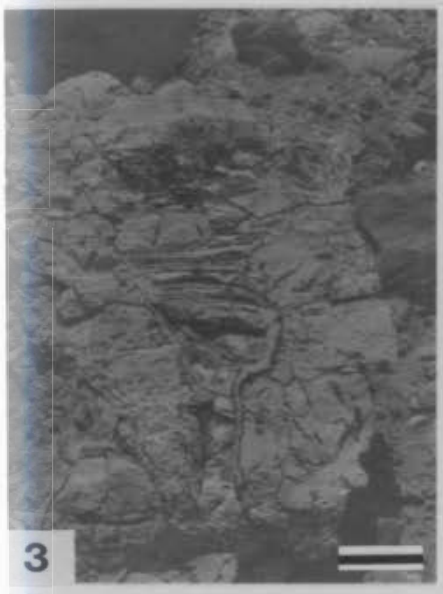
Figure 5. Skeletal and algal debris with rims of radiaxial fibrous calcite cement. Scale bar of thin section photomicrograph is 0.8mm. Sample from Bed 14 at Lower Head.

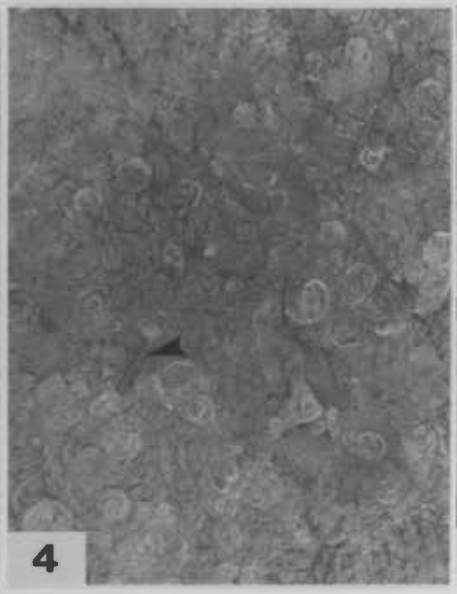
Figure 6. Clast of lumpy mudstone (B.6.) in Bed 14 on Cow Head Peninsula with lense of conglomerate (hammer). Hammer for scale is 30cm long.

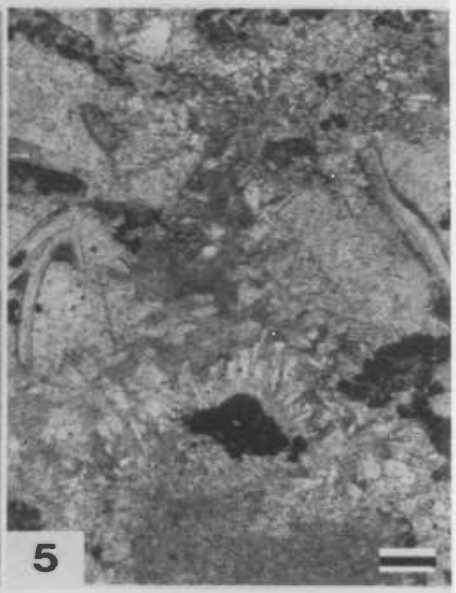
Figure 7. Close-up of clast of lumpy mudstone found in Bed 14 on Cow Head Peninsula with large silicified brachiopods. This new genus has been described by Ross and James (1987). White square on fieldbook is 9cm long.


1

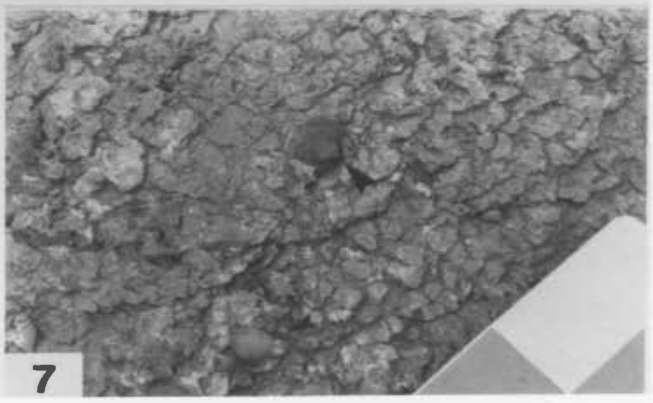

2


3


4


5


6


7

B.6 Lumpy mudstone

Description: These clasts are up to 12m wide and 5m thick soft-deformed rafts of bedded to rubbly limestone (Pl. 9.6, fig. 6). Clasts larger than 30cm in size are rare and the most common are 2-10cm large fragments. Layers of marly blue grey mudstone, 1-4cm thick are interbedded with 1mm-5cm thick dolomitic, argillaceous siltstone partings. Limestone beds are continuous or nodular and surrounded by silty sediment. Continuous beds show typically hackly weathering.

Grainstone to rudstone lenses intercalated with bedded sediments reach 20cm to 1m in lateral extension and are 1-20cm thick (Pl. 9.6, fig. 6). Lithoclasts in these lenses reach up to 10cm in size but measure commonly 1-3cm across. They are dominantly subangular grainstone, rudstone and packstone clasts with up to 10-20% white weathering flat mudstone pebbles. The matrix is medium to coarse calcarenite with subrounded to rounded lithoclasts of mudstone, *Girvanella* intraclasts and shell debris typically abundant in brachiopds, echinoderm fragments with syntaxial overgrowth and trilobites. Large (mm-sized) and small broken crystals of calcite spar, densely packed and surrounded by an argillaceous matrix compose the cement of the grainstone. Stylolites are abundant.

Mudstone layers are commonly homogenous or show traces of bioturbation. Fossils are rare and are phosphatic trilobites, brachiopods (Pl. 9.6, fig. 7) and pyrite filled burrows. Large spar filled burrows up to 1cm in diameter are locally present. Acid insolubles contain abundant pyrite, stylolite crusts, shell debris and dolomite crystals.

Interpretation: Mudstone layers are usually devoid of conodonts but grainstone lenses yield a sufficient fauna which indicates age equivalence to Bed 13. Facies represents peri-platform ooze which typically form on upper slope (Schlager & James, 1978). Grainstone lenses are probably the result of localized sediment instability.

9.4. C. Older clasts

C.1 Shelf derived older clasts

C.1.1 Oolite

Description: Two types of oolites are present. Type I consists of up to 90% normal sand sized ooids with a radial cortex. They are moderately sorted and cemented by blocky calcite spar. Broken regenerated ooids and a few superficial ooids are also present. Another oolite clast also yielded ooids with a radial cortex accompanied by ooids with tangential structure showing a bar cross under crossed nicols; also present are a few polyooids and superficial ooids together with peloids, cortoids, echinoderm and trilobite fragments. Sediment is medium to coarse calcarenite, poorly sorted and washed with dolomite and quartz silt rich mud preserved between components.

Type II contains the superficial ooids which have been described from oolites in beds 10 and 12. The rock is fractured and many ooids are broken or even crushed (Pl. 9.7, fig. 1). A rim of spar cement is present around most ooids and together with outer cortex layers is commonly broken and mixed with dolomite rhombs to form a crystal debris set in an argillaceous matrix which fills pore spaces.

Interpretation: Type I ooids were probably formed in a higher energy environment than type II (Carozzi, 1960). Presence of muddy sediment between ooids may indicate energy inversion, i.e. transport of ooids into quiet water. Fractured ooids with pore spaces filled with crystal debris may be related to transport of weakly lithified rock or tectonic events on the platform. Oolitic clasts are rare and probably Cambrian in age since oolites are found on the platform only during that time period.

C.1.2 Lumpy *Nuia*-rich wackestone

Description: A large (17x6m) softly deformed boulder at Lower Head yields

conodonts of Midcontinent fauna C indicating age equivalence to lower Boat Harbour Fm. or upper Watts Bight Fm. of the St. George Group (equivalent to about Bed 8). The boulder is a light gray wackestone with cm-sized coalescent or separate limestone lumps interbedded with or surrounded by thin greenish dolomite-rich,argillaceous parting material (Pl. 6.1, fig. 3). Bedding is developed on cm scale with foliated limestone at the base, probably the result of deformation during transport. Visible macrofossils and bioclasts are abundant small trilobites and brachiopods and echinoderm debris, the latter commonly concentrated in the grainy areas.

Muddy sediment is inhomogeneous with dense (finegrained) limestone nodules surrounded by lighter (coarse) microspar or by dolomite-rich argillaceous parting. Contacts between limestone lumps and parting material are either gradual or defined. In intraclastic portions of rock where muddy or dolomitic parting material is not present nodules are surrounded by calcite spar. Sparry cement is in places broken and hairline fractures are filled with crystal debris and argillaceous sediment. Intraclastic portions of rock yield abundant *Nuia* grains, skeletal debris of echinoderms, trilobites and brachiopods and occasional *Girvanella* intraclasts. Intraclasts are formed of mudstone, rounded, poorly sorted and of medium to coarse sand size.

Interpretation: Conodonts indicate shelf origin for this boulder, a conclusion supported by the abundance of algae (i.e. *Nuia*). Deposition in subtidal fairly quiet water is indicated by the accumulation of mud. Patches of bioclast-rich sediment may indicate relief of the seafloor or weak current action which locally removed fines. Lumpy fabrics probably resulted from preferential lithification of limestone rich zones and burrowing activity. Softly deformation preserved in a boulder of this origin and age implies that it has been reworked from an older conglomerate and was not incorporated from the shelf directly or a fault scarp during time of deposition of Bed 14 (see Chapter 6).

C.1.3 Dolomitic wackestone/grainstone with wellrounded quartz grains

Description: This is a shelf derived clast yielding conodonts of Midcontinent Zone C equivalent in age to the Watts Bight Formation of the St. George Group. The boulder shows a sequence of a) massive grainstone overlain by b) dolomite rich bedded wackestone which is interupted by c) calcirudite with lithoclasts derived from bedded sequence.

The massive grainstone is composed of well rounded micritic, dolomitic and pelsparitic lithoclasts together with well rounded quartz grains, all of medium sand-size. Accompanying peloids are round to irregularly shaped. Quartz grains may comprise from less than 5% to more than 40% of the components (Pl. 9.7, fig. 5). The sediment is moderate to well sorted. Components are cemented by clear calcite spar or set in a dolomite rich muddy matrix.

This grainstone is overlain by dolomite rich bedded wackestone with alternating microsparitic and/or dolomite richer wackestone and thin peloidal grainstone. Skeletal components are single algal filaments, trilobite, echinoderm and brachiopod fragments and *Nuia* grains. Silt sized peloids are abundant. Wackestone beds differ in amount of skeletal components. Layers with little skeletal debris show open or partly sediment filled burrows.

The bedded sequence is interupted by calcirudite with cm-sized rectangular or irregular shaped lithoclasts derived from the bedded wackestones. The matrix is a poorly washed coarse skeletal wackestone to packstone with abundant fragments of trilobites, echinoderms, brachiopods and *Nuia* grains. Some fragments are well preserved and almost complete, while others are bored and have a micritic envelope. Lithoclasts are oriented parallel or sub parallel to bedding or show almost imbricated structure. They are subrounded and some are partly disintegrated; they were obviously not completely lithified before transport occurred.

Interpretation: Grainstone with well rounded components suggests a shallow water setting with high water energy. Shallow water deposition is also indicated

by presence of abundant *Nuia* algae and conodonts. Conodont fauna suggests equivalence to lower Boat Harbour or upper Watts Bight Formation.

C.1.4 Echinoderm-rich lumpy wackestone to grainstone

Description: Most boulders which yield shelf conodont faunas are echinoderm-rich wackestone to grainstones. Boulders are highly fossiliferous. Coalescent or separate lumps of wackestone are surrounded by, or interbedded with, green dolomite-rich argillaceous siltstones. Beds show cm thick layers of mud rich sediment alternating with layers in which mud has been replaced by neomorphic calcite spar. The most common skeletal components are coarse (up to 2cm long) echinoderm fragments accompanied by partly silicified brachiopods and occasional coiled nautiloids. *Nuia* grains, trilobites, sponge fragments and occasionally *Girvanella* lumps are abundant. Skeletal debris commonly shows micrite envelops and borings. In neomorphosed portions it is apparent that the muddy sediment is composed of abundant, irregular shaped, subrounded, micritic lithoclasts and peloids which is not readily apparent in the dense fine grained mud. Dolomite contained in the parting material and interspersed with limy sediment is euhedral with a cloudy core.

Interpretation: Conodont faunas indicate age equivalence with Catoche Fm. and shelf or shallow shelf edge origin of clasts. The abundance of coarse unabraded echinoderm fragments suggest a nearby source. Algae (*Nuia*) suggest deposition in photic zone and muddy poorly washed sediment indicates quiet water, below normal wave base.

C.1.5 Bedded lithoclastic grainstone to rudstone

A highly fossiliferous bedded grainstone to rudstone clast found at Cow Head yielded a Midcontinent conodont and trilobite fauna (D. Boyce, written com., 1984) and nautiloids (B. Stait, pers. com., 1984), equivalent in age to the lower Catoche Fm. The boulder measures about 1.20 m^2 in size and shows a sequence of

grainy layers beginning with a 10cm thick layer of light grey wackestone with dark brown grains and shell debris. Trilobites and a ptilocerid nautiloid are present on a bedding plane. This is overlain by light grey to brown mudstone grading into packstone with clotted fabric. An overlying 30cm thick layer shows 1cm to 10cm large cavities rimmed with fibrous calcite cement and filled with a bioclastic grainstone. The top layer is grainstone to rudstone with rounded to subrounded grains coarsening upwards into rudstone with abundant trilobites and brachiopods.

The grainstone consists of poorly sorted angular bioclasts comprising coarse fragments of echinoderms, brachiopods, trilobites, *Nuia* grains and sponges, which are all cemented by clear calcite spar. Other grains are rounded micritic lithoclasts and peloids.

Interpretation: Poorly sorted and washed skeletal sand with abundant unabraded bioclasts, rounded lithoclasts and peloids interbedded with muddy sediment suggests deposition in a subtidal environment on the shelf platform. This interpretation is supported by the character of conodont faunas, trilobites and nautiloids.

C.2 Old foreign clasts from the shelf margin

C.2.1 Massive wackestone of Bed 10-type

Description: This lithology is a mottled mudstone to wackestone, light grey to green grey with small calcite filled burrows of mm diameter. Small cavities are rimmed with calcite but not lined with silica. The boulder is similar to the massive wackestones except for lack of silica. This assignment is supported by conodont faunas contained in the clast.

Interpretation: Upper slope mud accretion, equivalent in age to beds 9 and 10 (see Chapter 7, section B.1).

C.2.2 Lumpy dolomite rich wackestone of Bed 12-type

Description: Lumpy wackestone with dolomite-rich partings is similar in composition to lithologies described from Bed 12 (8.B.4) (Pl. 9.7, fig. 2). Conodont faunas indicate lower Bed 11 age or are indeterminable. In contrast to Bed 12 wackestones of this type, some of the Bed 14 clasts contain cm thick grainstone beds composed of medium sand sized rounded to subrounded grains. Grains are dominantly algal peloids, *Girvanella* intraclasts with moderate to poor sorting. Skeletal grains are echinoderm and brachiopod fragments, typically bored and showing micrite envelops. Components are cemented with clear calcite spar or occasionally surrounded by large patches of microspar.

Interpretation: This lithology is an upper slope deposit with preferentially lithified limestone nodules. Grainstone beds indicate instability, transport or occasional high energy conditions.

C.2.3 Calcirudite of Bed 11 (12) age

Description: This lithology comprises calcirudites with up to 6 cm long, cm thick flat mudstone pebbles in a calcarenite matrix with subangular medium to coarse sand sized grains. Conodonts indicate age equivalence to upper Bed 11. The rock is light brown to dark brown with brown or gray lithoclasts. Flat pebbles are oriented parallel or subparallel to bedding. Lithoclasts are sub angular to sub rounded and composed of homogeneous mudstone with pitted surfaces, dolomite/quartz rich mudstone and peloidal and skeletal wackestone (Pl. 9.7, fig. 3).

The calcarenitic matrix is composed of irregular shaped subangular to subrounded *Girvanella* lumps and peloids. Skeletal debris is formed by gastropods, shell fragments of brachiopods and trilobites and rare *Hulysis* chains. The depositional matrix was probably carbonate mud originally which is now aggraded to microspar and neospar. Some of the pore spaces are filled with blocky

calcite spar suggesting that the rock was originally poorly washed or that mud filtered in after deposition of coarser grains.

Interpretation: This sediment probably represents an intraformational breccia or talus near carbonate buildups. It is coarser and darker in colour than calcirudite clasts found in Bed 12.

C.2.4 Massive wackestone/grainstone age equivalent to Bed 11 (12)

Lithologies are similar in composion to lithofacies described from Bed 12 (see Chapter 8,B.2).

C.2.5 Bedded grainstone/mudstone age equivalent to Bed 12

Description: A 15x10m, soft-deformed boulder of interbedded grainstone, rudstone and mudstone is present at Lower Head. Conodont yields are low and preservation is poor but the fauna is most likely of Bed 11/12 age (Pl. 9.7, fig. 6).

The clast exhibits alternating sequences of grainstone, rudstone, wackestone and nodular mudstone separated by green shale partings. Different layers are between 5cm and 20cm thick. The grainstone beds consist of angular to subangular poorly sorted peloids, litho- and bioclasts in a poorly washed spar cement. The most common components are irregular shaped algal peloids and *Girvanella* lumps forming a medium to coarse calcarenite.

Rudstone beds contain in addition about 10% granule to pebble sized blue gray mudstone lithoclasts which are oviously derived from the underlying mudstone layers. Lithoclasts are irregular shaped with pitted surfaces and in places soft-deformed. Mudstone beds are inhomogeneous, burrowed, with irregular surfaces. Nodular horizons composed of mudstone nodules or lumps with separating green argillaceous dolomite rich siltstone are intercalated with grainstone and mudstone layers.

Interpretation: Intercalation of mudstone and grainstone is typical for upper slope deposits in Bed 12. The presence of nodular horizons, siltstone partings and thin bedding suggests deposition lower on the slope than related lithologies.

C.3 Old slope-derived clast

C.3.1 Thick bedded parted limestone of Bed 9-age

Description: A 40-20cm large soft-deformed clast found at Lower Head resembles closely thick bedded parted limestones from Bed 10. The clast is a light gray parted limestone with 4-5cm thick beds composed of homogenous lime mud. Although clasts of this type are barren of conodonts, lithological similarity suggests that this is a Bed 9 equivalent. Soft deformation suggests that clast is probably reworked from Bed 10 into which lithology was incorporated before becomming completely lithified.

C.3.2 Parted limestone of Bed 9-age.

Description: A large clast (2x1.50m) of parted limestone yields conodonts indicative of Bed 9. Blue gray limestone layers and buff weathering partings are of variable thickness ranging from 1cm-4cm. Contacts are gradational and wavy. Limestone beds are partly fractured and only slightly soft deformed. Parting material is dolomitic with cored dolomite rhombs grading into dolomite rich mudstone. No macrofossils are present.

C.3.3 Older clasts of parted limestone

Description: A sequence of dominantly parted limestone interbedded with chip conglomerate yielded *Parabolinella* sp. indicating a lower Tremadoc age (R. Ludvigsen, pers. com. to R.K. Stevens, 1983) (Pl. 9.7, fig. 7). A mm thick sequence of thin bedded laminated mudstone (1cm-5cm thick) interbedded with shale (up to 3cm thick) is followed by a chip conglomerate with pebble to cobble

PLATE 9.7.

All figured clast lithologies were found in Bed 14 at Lower Head except for those in figures 1. and 2. which where found in Bed 14 on Cow Head Peninsula.

Figure 1. Thin section photomicrograph of shelf derived oolite (C.1.1.). Rims of calcite spar commonly developed around the ooids and some of the outer cortex layers (see ooid at far right) are broken and form a debris in a argillaceous dolomitic siltstone matrix which fills pore spaces. Scale bar is 0.5mm long.

Figure 2. Clast of lumpy dolomite-rich wackestone reworked from Bed 12 (C.2.2.). Hammer for scale is 40cm long.

Figure 3. Negative print of calcirudite reworked from Bed 12 (C.2.3.) with large angular lithoclasts Scale bar is 5mm long.

Figure 4. Clast of conglomerate with flat mudstone pebbles in calcarenite matrix with well rounded quartz grains (A.3.5.b). Lithology is of upper Cambrian age. Person for scale is 170cm.

Figure 5. Thin section photomicrograph of calcarenite matrix found in clast of Figure 4. Note well rounded white quartz grains. Scale bar is 0.8mm.

Figure 6. Clast of interbedded grainstone and mudstone age equivalent to Bed 12 (C.2.5.) measures 5m across.

Figure 7. Clast of parted limestone (C.3.3.) interbedded with chip conglomerate (cc) is of Tremadoc age. Hammer for scale is 40cm long.

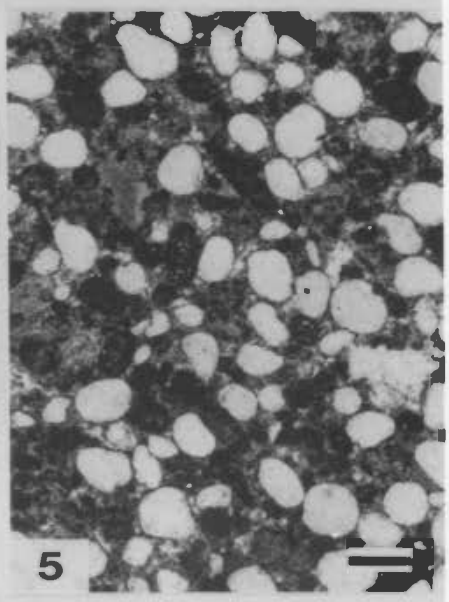

1



2


3


4


5


6



7

sized irregular lithoclasts in a medium to coarse partly silicified calcarenite matrix the pattern of intercalated fine and coarse grained facies repeats itself several times with variable thicknesses of the different sequences.

Bedded limestones are characterized by thin laminae which weather yellow. Occasional thin layers of well rounded quartz grains together with peloids and *Nuia* grains are present. Dolomite rhombs are usually dispersed throughout the mud fraction. Parting material is a dolomite rich argillaceous siltstone. Fossils are mainly trilobite fragments; traces of bioturbation are present locally.

Interpretation: The fine-grained old slope lithologies are probably all hemipelagites. They were incorporated into the debris flow from underlying beds or older conglomerates.

Chapter 10
SYNTHESIS OF LITHOFACIES

10.1. Bed 10 lithofacies

10.1.1. Introduction

Most of the Bed 10 lithologies were deposited during a high stand of sea level reflected by the subtidal sediments of the Catoche Group. Sediments from the shelf edge represented by foreign lithologies of Bed 10 are of deeper water aspect than those from beds 12 and 14.

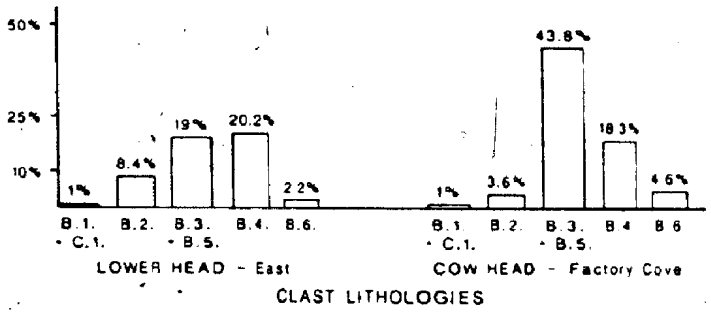
10.1.2. Lithofacies

Seven different lithofacies have been distinguished among foreign clast lithologies of Bed 10. Counts of these clasts indicate that massive wackestone (B.1) is the dominant lithology. Under this type four intergradational microfacies can be distinguished: (1) Gray *Girvanella* boundstone, (2) massive microbioclastic peloidal wackestone, (3) bedded microbioclastic peloidal wackestone and (4) spiculitic wackestone. Calcirudites are second in abundance and show somewhat different genetic origins with: (1) rare facies composed of shelf derived sands which were not found associated with other facies; (2) upper slope calcirudites associated with massive or bedded wackestone and parted limestone; (3) calcirudites containing lower and upper slope clasts associated with parted limestone. Darkbrown dolomitic *Girvanella* sponge boundstones are uncommon but this may be due to the difficulty of distinguishing this rock type in the field from the massive wackestone. Abundances of foreign lithologies in counted sections are summarized in Figure 10-1.

Figure 10-1: Abundances of foreign lithologies in counted sections

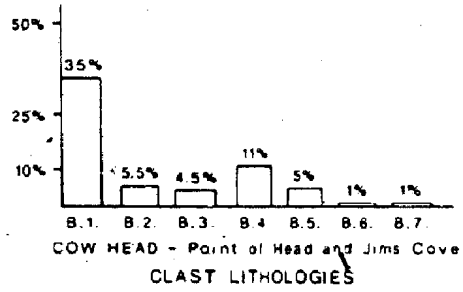
ABUNDANCES OF FOREIGN CLAST LITHOLOGIES IN CONGLOMERATES OF THE PROXIMAL FACIES

BED 14 AGE



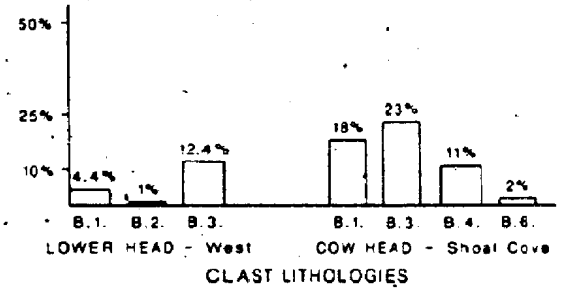
B.1 Shelf derived penecontemporaneous clasts
B.2 Calcirudite
B.3 Massive wackestone to packstone
B.4 Grainstone
B.5. Boundstone
B.6 Lumpy mudstone
C.1 Shelf derived old lithologies

BED 12 AGE



B.1. Massive wackestones / packstones
B.2. Algal-sponge boundstones
B.3. Calcirudites
B.4 Lumpy wackestone
B.5. Bedded mudstone to wackestone
B.6. Shelf derived grainstone
B.7. Lumpy mudstone

BED 10 AGE



B.1. Massive wackestones
B.2 Algal-sponge boundstones
B.3 Bedded grainstones
B.4 Calcirudites
B.6. Lumpy mudstone

10.1.3. Vertical relationships of facies

Clasts of Bed 10 correspond in age to most of underlying Bed 9 on the lower slope (i.e. *Prioniodus elegans* Zone) and the Catoche Formation on the shelf ("Fauna E").

The lower shaly intervall in Bed 9 belongs to the *Paroistodus proteus* Zone, and a similar fauna is present in clasts of lumpy wackestone (B.5). They are the oldest Bed 9 equivalent facies preserved and correlate to the lower Boat Harbour Formation below a major disconformity (Fig. 2-8). Shallow water prevailed on the shelf during this time-causing a strict faunal seggregation between shelf and slope conodont faunas. Presence of North Atlantic conodont faunas together with the presence of interbedded parted limestone suggest that the lumpy wackestone is a deeper water deposit. The single clast with a corresponding shallow water fauna ("Fauna C-D") is a coarse grainstone to rudstone, probably deposited in a fairly high energy environment.

The Boat Harbour Formation above the disconformity and Bed 9 above the *P. proteus* Zone show a short interval characterized by distinct faunal assemblages dominated by species of *Acodus* or *Diaphorodus* which have not been recognized among boulder-faunas. The *Girvanella* boundstone with the primitive prioniodid conodont species (i.e. *Prioniodus (P.) serratus* n.sp.) found in Bed 10 at Lower Head West may correlate with this interval. Scarcity of these older clasts does not allow further speculation on the nature of the shelf margin during the earliest Arenig. Composition of sandy and buildup facies, however, show that *Girvanella* already played an important role in margin sedimentation.

10.1.4. Lateral facies relationships

Except for the lithologies mentioned above, the majority of clasts in Bed 10 are of the same age and comprise five different lithofacies which probably coexisted on different areas of the slope. These are: (1) massive wackestone, (2) *Girvanella* boundstone, (3) calcirudite, (4) grainstone, (5) lumpy mudstone.

The five lithofacies types occur in the following facies relationships:

B.1 Massive wackestone - *Girvanella*-boundstone - grainstone - calcirudite.

B.2 *Girvanella*-sponge boundstone - grainstone - ?massive wackestone or *Girvanella* boundstone.

B.3 Grainstone - bedded/massive wackestone - *Girvanella*-sponge boundstone - calcirudite.

B.4 Calcirudite - bedded/massive wackestone - parted limestone.

B.6 Lumpy mudstone.

B.1 Massive wackestone grades into light gray boundstone and is interbedded with grainstone to rudstone. Wackestone with aligned stromatactoid voids usually co-occurs with massive cavity-free wackestone in the same clast. Massive as well as bedded wackestone appear to be composed of microbioclastic debris (shell fragments, algal debris, spicules) and are associated with the gray *Girvanella* boundstone with *in situ Girvanella* colonies which may have aided in sedimentation. Abundance of fine grained sediment indicates sedimentation in relatively low energy environment below the wave base. This may have been a deeply submerged shelf edge or upper slope. The presence of dilatational fractures and unstable clastic sediments (eg. calcirudites) suggests deposition on a sloping bottom. Some of the coarse rudstones are associated with massive or bedded wackestone and, hence came from the same depositional environment.

B.2 Dark brown *Girvanella* sponge boundstone with grainstone pockets seems to occur as an isolated facies but is only recognized where fresh surfaces are present and may intergrade with masssive wackestone. Their position on the slope is enigmatic: they may have been concentrated at the shelf edge in relatively shallow water or may have formed buildups intercalated with massive wackestone. Based

on the material at hand these two possibilities cannot be differentiated. *Girvanella* in growth position is, however, not known from deep water deposits and was probably dependent on light for its growth. Therefore growth of the colonies on the shallow upper slope or at the shelfbreak is favoured.

B.3 Grainstones are associated with all of the above lithologies and the calcirudites (B.4) and were obviously not restricted in their formation to specific environments across the shelfbreak and upper slope.

B.4 Rudstones or calcirudites are associated with either bedded or massive wackestone (see above) or with parted mudstones. Those found with parted limestone are probably lower slope deposits, possibly of similar origin to the intraformational breccias which Gwinner (1976) described from Jurassic algal sponge rich limestone in Germany. Both types are interpreted as forming initially by the slumping of sediments off steep flanks of algal sponge mounds; with some remaining near that environment and others being subsequently transported downslope over variable distances and showing varying degrees of mixing with lower slope lithologies.

B.6 Lumpy mudstones are always softly deformed and not found associated with other facies. They are typically intensively burrowed and contain few other bioclastic remains. They closely resemble local clasts in composition, with their fine grained unfossiliferous lime mud and dolomite rich partings and may be the bioturbated equivalents of these sediments. They were probably deposited upslope of the bedded sediments, where bottom conditions were more favourable for burrowing organisms, possibly due to more oxigenated bottom waters. A decrease of faunal activity down slope has been noted by Blake and Doyle (1983) and others and also there is little burrowing in Bed 9 sediments, which are lower slope deposits. Absence of intergradation with any of the upper slope facies as well as scarcity of organic debris suggests a position, lower on the slope below the mud mounds. Their scarcity is probably due to their soft consistency which resulted in destruction during transport.

10.1.5. Role of organisms

Algae

Girvanella in growth position and as a major source of algal debris is the dominant sediment contributor. The lime mud matrix appears to be mainly derived from disintegration of weakly lithified algal tubules or diagenetic alteration (e.g. grain aggradation) of the filaments. Similar mud has been observed further downslope (Coniglio and James, 1985) and in bioherms of the Table Head Group (Klappa and James, 1980). It is difficult to evaluate the role of *Girvanella* because of the intense reworking of the sediment by burrowing organisms which probably aided in the destruction of primary sedimentary features and desintegration of *Girvanella* tubules to mud and peloids. Boundstones where *Girvanella* apears to be preserved in growth position may thus either record lack of intense burrowing or represent the only true algal fabric present. Klappa and James (1980), who studied algal-sponge mounds of the Table Head Group suggest a combination of physical accretion and organic growth for these buildups. A similar type of accumulation may be responsible for formation of the CH mounds. A relatively large amount of sediment was transported to accumulate on the upper slope during Bed 9 time which contains large amounts of algal mud and debris suggesting that a constant source was present up-slope. These were most likely the blue-green algae which may have formed continuous or patchy mats or films binding skeletal and their own debris thus forming banks or algal mounds at or near the shelf edge which are mostly preserved as skeletal wackestone with stromatactoid voids. The abundance of *Girvanella* debris can not be explained by the relatively few boundstones alone. It is also not likely that they formed somewhere else on the shelf or at the shelfbreak, because old clasts found in Bed 14 yield "Catoche faunas" as well as "mound faunas" equivalent in age to Bed 9. The shallow water derived clasts are echinoderm wackestone and grainstones rich in sponge debris. Those with "mound faunas" are similar to the massive wackestones found in Bed 10. No intermediate facies has been found which would indicate another facies belt not recorded in the conglomerate. *Girvanella* thus

appears to have grown on the upper slope but the original fabrics are poorly preserved. Stromatactoid cavities are interpreted to represent cavities in a framework formed by algae (Pratt, 1982). In the CH mounds they are commonly found associated with preserved algal fabric.

Sponges

Preserved sponges are rare in Bed 10 but *Archaeoscyphia* sp. (identified by K.Rigby in James and Stevens, 1986) and spicules of lithistid and heteractinid sponges (K. Rigby, pers. com., 1986) are present. Abundance of sponge spicules, high silica content and the occasionally observed spongy texture of the sediment suggests, however, that they were originally more prominent than is now obvious. The reticulate pattern observed in some thin sections may have formed where algal mud filling porespaces in dead sponges remained in place (Klappa and James, 1980). Gwinner (1976) found more spicules than complete sponges in biohermal intervals in Jurassic (Tithon) cement marls and concluded that many sponges, though present, where not preserved. Townson (1975) who studied Jurassic limestones of the type Portlandian in Britain reported a direct correlation between abundance of sponge spicules and silica content of the sediment. Abundance of silica in the clasts in Bed 10 may also be an indication for an originally high content of siliceous sponges.

Siliceous sponges may have aided in trapping and baffling of sediment. Sheet like siliceous sponges have been suggested to stabilize sediment by triggering early lithification of surrounding sediments (Wiedenmayer, 1978). In recent arctic shelf environments, they form small mounds (Jackson, 1986). This evidence suggests that sponges are capable of forming or at least aiding in forming mounds. Organisms whith sheet like morphologies (such as sponges) are suspected to have been responsible for the formation of stromatactis (Klappa and James, 1980; Textoris and Carozzi, 1964) because the advent of mud mounds with stromatactis coincides with the first appearance of bioherms with abundant sponges. In summary, sponges may have aided in trapping, binding and baffling sediments in

the CH mounds but their role is difficult to evaluate because of their poor preservation.

Echinoderms

Echinoderm remains are not important among skeletal debris in either grainy or muddy facies. The fragments are generally small indicating complete disintegration, either due to transport or to the activity of burrowing animals. They are derived from stemmed echinoderms (pelmatozoans) and some can be identified as cystoids. Abundant coarse echinoderm debris occurs in shelf derived clasts in age equivalent to Catoche sediments (only found in Bed 14). This suggests that the outer shelf rather than the upper slope was the site of echinoderm growth. In other mound facies echinoderm debris is most commonly found in intermound facies and flank deposits (Troell, 1962; Klappa and James, 1980; Wilson, 1975). Scarcity of the pelmatozoans in Bed 10 foreign clasts may indicate unsuitable environmental conditions such as soft bottoms without holdfasts or turbid water. Pelmatozoans together with *Nuia* are abundant in the few examples of older (lowermost Arenig) facies.

Arthropods

Asaphid and bathyurid trilobite remains occur throughout the sediment. Bathyurid trilobites (eg. *Punka* sp., *Cromyostrom* sp.) are common in muds and mounds of the Catoche Fm. with *Cromyostrom* being more common in the mounds. The genus is also known from the Table Head Group. Other genera (eg. *Gog* sp.) also occur in upper slope sediments of Spitzbergen (D. Boyce, pers. com., 1986). Trilobites reported from clasts in Bed 10 are listed in Appendix 10.

Molluscs

Remains of orthocone and coiled nautiloids are common in the muddy facies and fill crevices in the rock. Mainly the siphuncles are preserved. Gastropods which

are conspicuous elements of the younger facies are almost completely absent. They are generally considered inhabitants of shallow water environments which may explain their absence in Bed 10 clast lithologies.

Brachiopods

Although brachiopod shells have been observed in grainstones and rudstones in clasts no collections with generic assignments were made to date.

Infauna

Next to algae infaunal organisms seem to have the strongest biogenic influence on sedimentation by a) destroying sedimentary features, b) aiding in formation of mud (probably by breaking down weakly lithified algal filaments), c) forming peloids and possibly intraclasts, d) changing the micro environment and thus affecting mineral contents (i.e. pyrite growth and glauconu formation), e) influencing organic content, f) influencing limestone diagenesis. Most of the infaunal organisms observed in recent sediments are softbodied animals, notably polychaetes and arthropods which are not likely to leave a fossil record. Their influence on sedimentation is, however, significant. Traces left by infaunal organisms are present in the wackestone facies (B.1) as well as in the lumpy mudstone (B.6) and lumpy wackestone facies (B.5).

Traces represent "primary sedimentary structures" of the substrate with which they were associated (Howard, 1978) and which they influenced in variable ways. In upper slope sediments of the CHG infaunal organisms altered sediment fabrics, colour, diagenesis and mineral content.

Sedimentary fabrics which resulted from physical accretion and algal/sponge growth appear to have been commonly destroyed and reorganized by the activity of infaunal burrowers. Bedded facies of the lower slope also show signs of bioturbation but to a much lesser extend. This implies that a larger number or highly efficient animals were present on the upper slope.

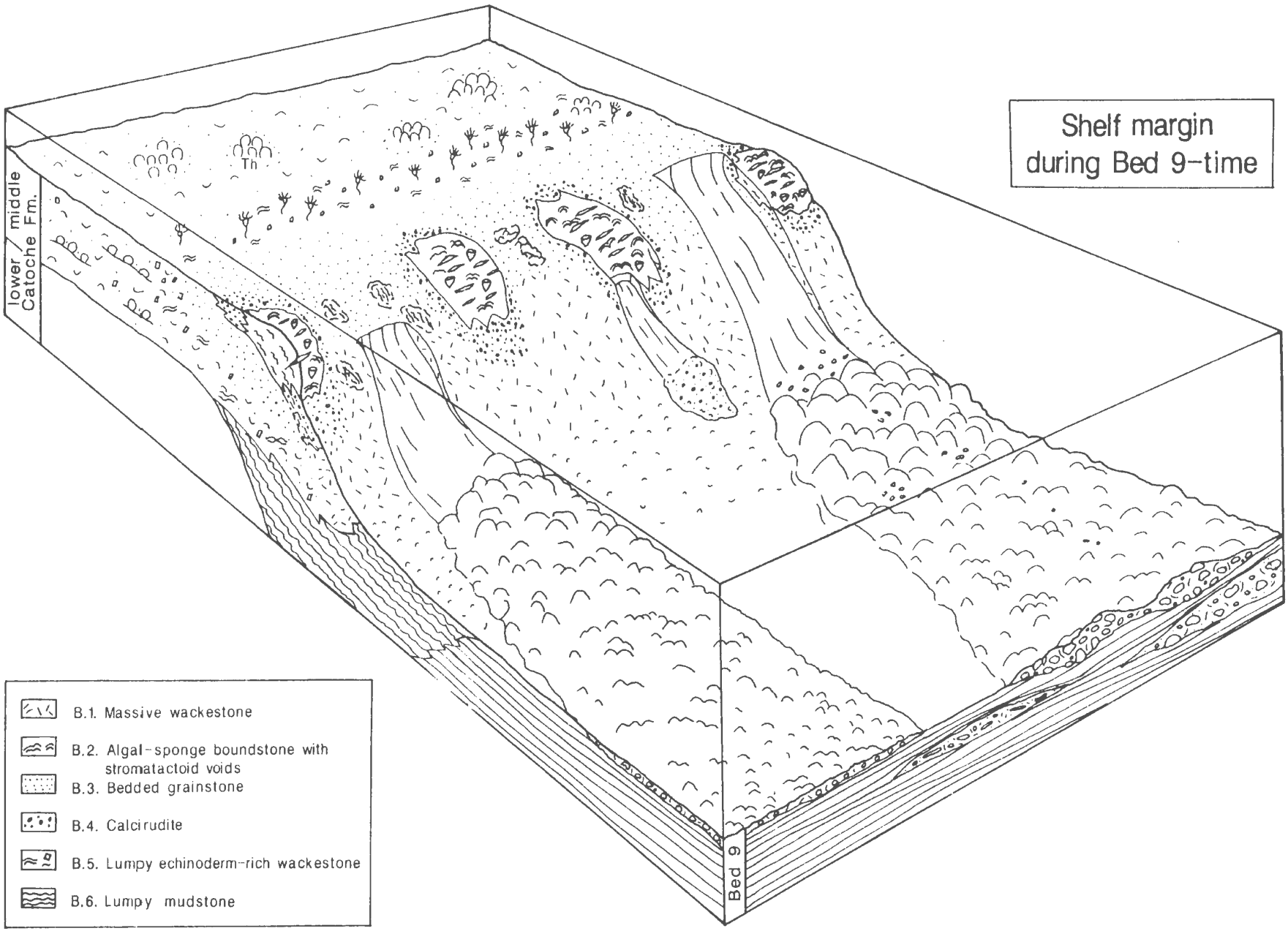
Algal mats and burrowing activity are usually mutually exclusive (Garret, 1970). Abundance of burrowers prevented the formation of mats and promoted "lumpy" growth or even terminated growth for short periods of time. It may also account for the low number of pelmatozoan animals which were attached filter feeders and may have suffered from the "water pollution" and softening of the sediment caused by infaunal burrowers (Rhoads, 1973). Complete destruction of sedimentary fabrics together with evident abundance of infauna also suggests that lithification was sufficiently delayed to allow intensive reworking (Klappa and James, 1980). This biologic activity, however, only required a few years (Tenore, 1977) and lithification after bioturbation could still be considered early and hardground formation possible after sediment reworking.

b) Activity of burrowing organisms resulted in formation of different mottled structures expressed either in colour changes (darkbrown to lightbrown, lightgreen to lightbrown) or changes in crystal size (micrite to microspar). Light/dark colour changes may be the result of different organic content, while lightgreen/brown records different mineral content (possibly due to reduction of iron). Change of crystal sizes suggests an influence of the burrowing activity on limestone diagenesis.

10.1.6. Synthesis and model

The shelf margin during deposition of Bed 9 is envisaged as an initially open platform margin with increasing buildup of algal mounds and banks over the course of Bed 9-time (Fig. 10-2). An open shelf is recorded in the high energy deposits of the Boat Harbour Fm. (Knight and James, in press) which corresponds to the lower part of Bed 9. Shelf deposition of the Boat Harbour Formation has only a scanty record in clasts of Bed 14 with clasts of echinoderm and *Nuia* rich wackestone and in Bed 10 with a coarse rudstone to grainstone clast. Time equivalent upper slope deposits are represented in echinoderm/*Nuia* wackestone with interbedded parted lime mudstone.

Figure 10-2: Reconstruction of the shelf margin during Bed 9-time


Shelf margin
during Bed 9-time
lower / middle
Catoche Fm.
Th
Bed 9
B.1. Massive wackestone
B.2. Algal-sponge boundstone with stromatactoid voids
B.3. Bedded grainstone
B.4. Calcirudite
B.5. Lumpy echinoderm-rich wackestone
B.6. Lumpy mudstone

Younger sediments, age-equivalent to upper Bed 9 are better represented and like other marginal carbonate deposits, several laterally intergrading facies are recognized which can be interpreted as the remains of algal-sponge mounds, mound talus and intermound sediments. The deep upper slope was likely composed of peri-platform ooze and intraformational breccia, while the toe of slope was probably the site of coarse clastic debris accumulation.

The building of the algal mud mounds was probably the result of physical accretion and algal/?sponge growth, the importance of micrite cementation cannot be evaluated. Fauna and flora are of low diversity and dominated by the alga *Girvanella*. Films of *Girvanella* threads which occasionally accumulated to form patchily distributed algal colonies, stabilized and added to the mud mound accretion. The activity of burrowing organisms and blankets of lime mud which spilled over the shelf edge terminated algal growth regularly but only for short periods of time. The deposits probably developed relief above the sea floor as suggested by the presence of coarse algal debris. The volumetrically important calcirudites are interpreted as flanking facies,formed by avalanche like accumulations of debris and subsequent infiltration of mud into the porespaces. The presence of this facies suggests that the mounds exhibited topographic relief above the sea floor since there is no indication of marine erosion by waves or tidal currents.

Intermound sediments were probably similar in composition to the mound sediments and are difficult to identify without continuous outcrop. In other mound facies intermound sediments are commonly bedded and richer in bioclasts, particularly echinoderms (Gwinner, 1976; Troell, 1962). Clasts of bedded wackestone with abundant bioclasts may represent this facies.

Small algal sponge bioherms or biostromes were scattered throughout the area, probably more abundant near or at the shelf edge than further downslope. Sponge faunas consisted of lithistid and heteractinid forms such as *Archaeoscyphia* and *Anthaspidella*.

Downslope the mound facies decreased and finally disappeared to be replaced by lumpy mudstones (Facies B.6) and deposits of intraformational breccias represented by the calcirudite facies intercalated with parted limestones.

Large clasts of megaconglomerates came to rest at the toe-of-slope, probably eroding the bedded sediments which accumulated between debris flows thus forming welded conglomerates whose distal equivalents can be seen on Stearing Island. The remainder of the debris spread out further down slope taking with it the clasts which were eroded at the toe-of-slope.

This time interval coincides with the begin of a rise in sea level which is recorded in the low energy deposits of the lower Catoche Fm.. The increasing water depth may have caused the algal mounds to grow upwards in order to keep pace with the rising sea level. The algal mounds which grew along the shelf margin reaching down on the upper slope may thus have formed a barrier which in conjunction with the deepening of the water protected the interior platform. The formation of a rimmed platform is also indicated by the pronounced faunal seggregation between conodonts from shelf and slope.

10.2. Bed 12 Lithofacies

10.2.1. Introduction

Foreign lithologies of Bed 12 show higher diversity than those of Bed 10 and conodont data enable distinction of older and younger clasts. The fragmented marginal sediments preserved in Bed 12 were deposited at the same time as the upper Catoche and the lower Aguathuna formations on the shelf and with Bed 11 on the lower slope. An older *Prioniodus (O.) evae*-dominated fauna in the lower part of Bed 11 and a younger *Periodon aculeatus*-dominated fauna can also be distinguished in the clast faunas. A faunal change on the shelf is probably present but data are too scarce for confident correlations.

10.2.2. Vertical facies relationships

Based on faunal and lithological criteria older and younger lithologies can be determined for some facies types, while others persist throughout the column or cannot be assigned an age because of lack of distinguishing characteristics. Among the six different foreign lithologies which have been recognized in Bed 12 only clasts of lumpy wackestone (B.4) always yield old (i.e. lower Bed 11 equivalent) conodont faunas. The calcirudites (B.3) and massive wackestone to packstone clasts (B.1) contain both, old and young faunas. Brown *Girvanella*-sponge boundstones (B.2) whose composition resembles that of boulders in Bed 14 are probably young, but yield few conodonts; the light gray algal boundstones (B.2) in contrast are more fossiliferous and yield old and young conodonts. Bedded mudstones to wackestones (B.5) exclusively yield young (i.e. upper Bed 11 equivalent) conodonts and the lumpy burrowed mudstones (B.7) finally are barren and cannot be assigned to any age group. Abundances of foreign lithologies in counted sections are shown in Figure 10-1.

10.2.3. Comparison of Bed 10 and Bed 12 lithofacies

Following deposition of Bed 10 a marked change in shelf edge and upper slope sedimentation took place. The *Girvanella* boundstones with stromatactoid voids disappeared and were replaced by more diverse algal sponge boundstone, still dominated by *Girvanella* but accompanied by *Renalcis* and *Epiphyton*. Over the course of Bed 11 deposition, diversity in the algal sponge boundstone increased and the facies became almost indistinguishable from boundstones of Bed 14. The fine grained, burrow mottled fossiliferous wackestones were replaced by coarser grained wackestones to packstones which are commonly intercalated with grainstones. The lumpy dolomitic wackestone of Bed 12 resembles the oldest facies found in Bed 10, but lacks the abundant echinoderm and *Nuia* fragments. Pelleted bedded mudstone to wackestones, sometimes with fenestral fabrics occur near the top of the marginal sequence and are not known from Bed 10. Lumpy mudstones of Bed 12 differ from their counterparts in Bed 10 in possessing large burrows of cm-diameter and by being more bedded than lumpy.

Lower slope derived clasts are less abundant in Bed 12 than they are in Bed 10 (Fig. 6-19). Regardless, as in Bed 10, parted and ribbon limestones dominate the lower slope clast lithologies. Dolostone clasts are next in abundance, different from Bed 10, where calcarenites are more common. Also conglomerate- and chert clasts are more ubiquitous in Bed 12 than in Bed 10. Shale fragments are rare and present for the first time in distal facies of Bed 12. The pattern of clast distribution reflects the different sedimentological regimes of Bed 11, a starved slope sequence and Bed 9 with more monotonous normal accretion.

10.2.4. Lateral facies relationships

Older coexisting facies of shelf edge and upper slope clasts in Bed 12 include: Massive wackestone/ grainstone - algal sponge boundstone - lumpy wackestone - lumpy mudstone. Peloidal massive wackestone is found intergrading with burrowed grainstone/packstone which in turn are found together with spongiostrome laminites and bedded equivalents of the massive facies. Lumpy wackestones and mudstones are isolated facies which differ in the amount of large *Zoophycos* like traces present. In addition lumpy wackestones shows variable degrees of dolomitization which may change within a single boulder. Shelf derived clasts (B.6) are rare and typically grainstones sometimes intercalated with coloured (red and green) lime mud.

Muddy to clean sands with complex burrow traces and fractures or voids (B.1) were deposited either in an environment where energy conditions varied, such as a moderately deep shelf or where mixed sediment input occurs, such as the foreslope, where mud and sand are transported downslope. The record of physical accretion is obscured by the activity of burrowing organisms and algae which accreted and stabilized mud between grains and aggrading neomorphism which led to the replacement of micrite by larger crystals. Several lines of evidence suggest that these muddy sands accumulated at or near the shelf edge: (1) association of algal boundstone with grainstone, (2) fractures filled with coloured sediment typical for shelf derived lithologies, (3) possible solution cavities in some

grainstone boulders. The interpretation of the muddy sands as true shallow water shelf edge deposits is not favoured because: (1) No true high energy grainstones were found apart from the shelf derived clasts, (2) no shallow water conodont faunas are associated with the highly fractured rocks, (3) many voids are filled with marine shells, (4) muddy grainstone facies persists throughout the sequence in similar abundance although trend on shelf is shallowing upwards. It is possible, however, that the muddy lime sands were deposited and lithified at the shelf edge and subsequently exposed. Subaerial exposure of the shelf edge as a result of shallowing of the water would explain the extensive silicification and cavernous nature of some these lithologies. High energy sediments may have been eroded over the course of the regression and were therefore not preserved.

Patches of burrowed wackestone and algal boundstone are associated with bedded and massive muddy sands suggesting that the associated organisms were involved in mud accretion either by binding, baffling or accreting fine grained sediment. The light gray algal boundstone (B.2) also occurs in isolated blocks not associated with other sediments. The presence of shallow water algae (eg. *Epiphyton*) and other organisms (eg. *Renalcis*) commonly found in shallow water buildups indicates the rock formed within the photic zone. The relatively low number of boundstone clasts suggests a patchy distribution of small algal buildups among burrowed bioclastic lime mud and sand deposits. Encrustation of the sediment by algal mats was common.

Calcirudites (B.4) decreased in abundance and are more variable in their composition than their older counterparts. This is probably the result of greater facies diversity on the upper slope. More commonly than in Bed 10 the calcirudites grade into calcarenite, or are very coarse. Like their predecessors in Bed 10 the calcirudites are probably polygenetic and interpreted as coarse rubble deposited adjacent to steep flanks of algal sponge buildups or as intraformational breccias in the case of calcirudite with lower slope derived lithoclasts.

Lumpy dolomitic wackestone (B.4) is usually not associated with other

lithofacies types except in a few clasts of Bed 12-age found in Bed 14 which are intercalated with muddy grainstones. The lumpy wackestones most likeley record a separate facies belt which only existed during lower Bed 11 time. The sediment is rich in organisms such as brachiopods and trilobites and remains of infaunal activity (i.e. burrows) and differs in this respect from the lumpy mudstone facies. The fabric resembles shelf derived lumpy wackestones of equivalent age found in Bed 14 but lacks *Nuia*, abundant echinoderm debris and shallow water conodont faunas all of which are typical for the shelf lithology. The nature of conodont faunas, lack of algae and similarity to lumpy mudstone suggests an upper slope rather than shelf origin for this lithology which is commonly reported from this sedimentary environment (Wilson, 1975, McCrossan, 1958). Downslope the wackestones probably graded into less fossiliferous lumpy and finally bedded mudstone; upslope intercalation with grainstone was more common.

With shallowing of the water on the shelf the lumpy wackestone facies disappeared and two new facies were introduced: the bedded peloidal wackestone/mudstones (B.5) and a high diversity algal sponge boundstone (B.2). The bedded peloidal wackestone/mudstone illustrates irregular thin laminae, spongiostrome texture and occasionally fenestral fabric. The lithology is interpretated to be algal-bound sediment deposited on marine shoals. The greenish and reddish sediment colours and the nature of the conodont faunas support this interpretation. No lateral relationships to other facies are observed.

Boundstones developed from a simple algal sponge-facies to more complex organic buildups with *Pulchrilamina*-like heads and enigmatic tubular and wetheredellid organisms in addition to sheet-like sponges, *Girvanella, Renalcis* and *Epiphyton*. The boundstones are associated with patches of more or less clean sands and grade laterally and/or vertically into massive to flasery burrowed wackestone and packstone. The facies is very similar to boundstone facies in Bed 14 and heralds the development of true reef buildups in the Middle Ordovician.

Shelf facies found in Bed 12 all contain conodonts of Midcontinent Fauna E and

are difficult to assign to a stratigraphic position in the shelf sequence. They correlate to the Catoche and possibly to the lower Aguathuna formation. They are high energy grainstones (B.6) sometimes associated with the coloured muddy sediment typical of the shallow water deposits.

10.2.5. Role of organisms

Algae.

Like in Bed 10 *Girvanella* is the dominant element in the boundstone facies. In Bed 12 several additional forms are present: *Renalcis*, *Epiphyton* and *Halysis*. Algae are the main functional entities in 3 types of facies:

(1) *Girvanella* together with *Renalcis*, *Epiphyton*, *Halysis* and other accessory organisms formed patchily distributed biostromes (algal-sponge boundstone). The occurrence of new algae suggests that the boundstones formed in shallower water than the *Girvanella* boundstones in Bed 10.

(2) In some of the bedded muddy grainstones blue green algae acted as sediment binders, probably by forming mats which stabilized the sand.

(3) Blue green algae form spongiostrome mats preserved in the bedded peloidal wackestone/mustone-facies (B.5).

Types of algae, their activity and abundance suggests a shallowing upward trend from Bed 10 through Bed 12.

Sponges

Sheet-like sponges are more ubiquitous in Bed 12 than they were in older buildup facies. They probably acted as sediment stabilizers and upon death and decay they added significant amounts of peloids to the sand fraction of the sediment. Discoid (*Psarodyctyum* sp.), funnel- (*Anthaspidella* sp.) and vase-

shaped (*Archaeoscypha* sp.) sponges are listed from clasts in Bed 12 (Appendix 10).

Burrowing organisms

The burrowing organisms left 2 basic types of traces: (1) Feeding burrows (Fodinichnia of Seilacher, 1964) preserved as cloudy patches of bioturbated sediment or as irregularly outlined holes commonly filled actively with meniscus sediment. (2) Burrows with stabilized walls which were probably a combination of feeding and dwelling burrows (Domichnia of Seilacher, 1964).

(1) Most of the muds and muddy sands were thoroughly reworked. The high degree of bioturbation suggests that sedimentation was slow enough so that the rate of infaunal reworking kept pace with, or even exceeded deposition (Howard, 1978). As a result primary depositional structures and relationships were destroyed.

(2) Many of the burrow traces were formed by organisms capable of building tubes with stable walls, either by secreting mucus or by compacting surrounding sediment. Other possible organic cements such as chitin or horn which are used by recent polychaetes may not be preserved. Preservation of mud around burrows in sandy sediment suggests that tube dwellers helped to baffle or bind sediment (Frey, 1973; Frankel and Meade, 1973). An influence of infauna on diagenesis is indicated by the different colours and crystal sizes of bioturbated sediment.

Echinoderms

Pelmatozoan debris constitutes minor skeletal components present in most of the foreign lithologies. Most abundant in the grainstones and lumpy wackestones.

Pulchrilamina-like organism

A poorly preserved specimen occurs for the first time in Bed 12. The enigmatic

organism is a rare component of the darkbrown boundstone facies. Pratt (1979) reported *Pulchrilamina*-like forms from shallow water deposits of the upper Boat Harbour Formation. Its occurrence in Bed 12 suggests that favourable conditions for its growth (i.e. shallow water) in a shelf edge environment occurred during deposition of upper Bed 11.

Arthropods

Trilobites occur in almost all facies, but are best preserved and most abundant in lumpy wackestones. This is probably a function of slow deposition which resulted in accumulation of many fossils in a relatively thin sediment pile. Trilobites are indicative of zones H, I and J of the Ross-Hintze zonal scheme. Species and genera reported from Cow Head Peninsula (Appendix 10) are illaenid-cheirurid assemblages (e.g. *Telephina* sp., *Kawina* cf. *vulcanus*, *Spaerocoryphe* sp.) typically found in platform edge environments. The also abundant nileids are characteristic for upper slope settings (Fortey, 1975). Many of the trilobites listed are also known from the Catoche Fm. (e.g. *Catochia* sp., *Carolinites genacinata*, *Niobe ornata* and others) and from Spitzbergen (*Sycophantia* sp., *Nileus* sp.) (D. Boyce, pers. com., 1986; James and Stevens, 1986). Small thin shelled fossils forming coquinas in the large grainstone/packstone boulder on CH Peninsula may be the remains of ostracods. Poor preservation makes identification difficult and the shells may also be remains of small bivalves.

Molluscs. Macluritid and other gastropods occur for the first time in grainstones and packstones of Bed 12.

Coiled and orthocone nautiloids are ubiquitous components of boundstone, grainstone and packstone facies. They are found in large numbers in crevices of the grainstone/packstone lithologies.

Brachiopods

Genera occurring in clasts of Bed 12 (e.g. *Orthidium*, *Pleurorthis*, *Camerella*, *Idiostrophia*) (Appendix 10) are also present in the mound facies at Meijklejohn Peak in Nevada (Ross, 1972) and have been considered to belong to the older *Orthidiella* Zone of the Whiterock Stage (Ross and James, 1987; James and Stevens, 1986).

Enigmatic organisms

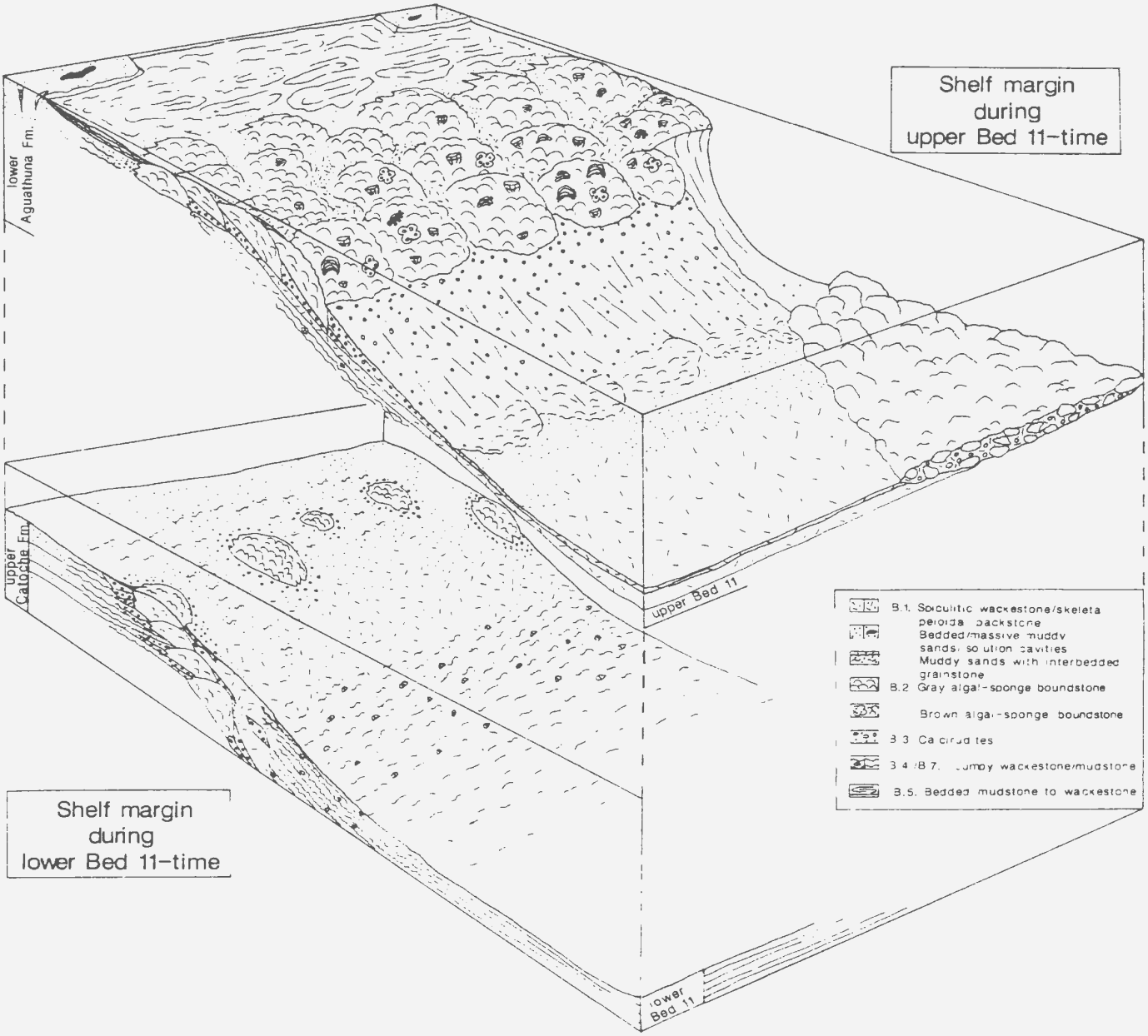
The youngest, dark brown boundstones contain two types of enigmatic organisms: *Serpula*-like tubes and *Wetheredella*-like tubules. The role of these organisms is speculative. The *Serpula*-like tubes are found in small groups together and because of their rareness their growth habit is difficult to evaluate. They may have formed intergrown colonies at or near the sediment surface. The *Wetheredella*-like organisms seem to have an encrusting habit and are found overgrowing algal buildups. They, too are rare and volumetrically played no important role in the buildup community.

10.2.6. Synthesis and model

Clasts of foreign lithologies in Bed 12 display a variety of different lithofacies which are by and large contemporaneous to Bed 11. The faunal change near the top of Bed 11 can be recognized in clast faunas of Bed 12. The change-over probably coincides with the Lower/Middle Ordovician boundary (Ross and James, 1987, Johnston, 1987). Conodonts and clast lithologies record a shallowing upward trend during deposition of Bed 11 and margin development during this time interval is recorded in 2 stages (Fig. 10-3):

Stage I is contemporaneous with lower Bed 11-time which corresponds to highest relative sea level stand during the Arenig (Vail et al. 1977; James and Stevens, 1986). The shelf edge was probably deeply submerged and poorly washed peloidal/skeletal sands were deposited intergrown and stabilized to varying degrees by blue-green algae. Alternating periods of low and high energy are

Figure 10-3: Development of the shelf margin from lower to upper Bed 11-time


Shelf margin
during
upper Bed 11–time
lower
Aguathuna Fm.
upper
Cathedral Fm.
upper Bed 11
lower
Bed 11
Shelf margin
during
lower Bed 11–time
B.1. Spiculitic wackestone/skeleta
peloida packstone
Bedded/massive muddy
sands, solution cavities
Muddy sands with interbedded
grainstone
B.2 Gray algal-sponge boundstone
Brown algal-sponge boundstone
B.3 Calcirudites
B.4/B.7. Lumpy wackestone/mudstone
B.5. Bedded mudstone to wackestone

displayed in interbedded mudstones and grainstones. This type of sedimentation commonly occurs under conditions of intermittent deposition alternating with periods of significant erosion such as storm- and non-storm conditions in an environment at or just below wave base (Howard, 1978). Downslope, the sands were increasingly intercalated with burrowed mudstones or wackestones. The abundance of this facies in clast counts suggests that it was a dominant lithology in the path of the flow. Small organic buildups formed by algae and sponges are intercalated with the muddy sediment and probably ranged in depth down to the limit of sufficient light penetration on the upper slope. Talus of grainstone and rudstone formed around these organic buildups. Catastrophic events such as debris flows or turbidity currents generated at or near the shelfedge (for example by storms) involved these and other deposits and transported them downslope where lower slope sediments were incorporated in the flows forming the mixed clast-calcirudites. Lumpy dolomite-rich wackestone formed on the upper slope during lower Bed 11-time. This facies typically formed where temporary drowning of the platform occurred (Read, 1982). It likely is the expression of the high sea level stand during this interval which led to deposition of muddy sands at the shelf edge and decline and/or shelfward retreat of the buildup facies associated with upslope encroachment of lumpy wackestone. Abundance of burrows and organisms in this sediment indicates aerated bottom conditions and slow sedimentation. Further downslope oxygen content may have declined and lumpy mudstones formed which only accomodated a few specialized burrowers. On the lower slope siliceous and phosphatic sediments and presence of omission surfaces (top of Bed 10) suggests reduced sedimentation.

Stage II of the margin development is characterized by the first appearance of Bed 14-buildup facies, development of bedded shallow water mudstone/bindstone, the occurrence of coarse calcirudites and disappearance of the lumpy dolomitic wackestone facies. Seen in this context the combination of events can be related to a relative relative slowing of sea level rise which is also recorded in the shallowing upward cycles of the Aguathuna Formation. This may have resulted

in exposure of the shelf edge which was, during stage I, the site of muddy sands and thin algal mat deposition. Grainstone/packstone clasts in Bed 12 show complicated patterns of voids which may be solution cavities formed during subaerial exposure. Formation of a shallow barrier would have resulted. Bed 14-type marginal buildup facies developed in the shallow well aerated water in front of the barrier from where it gradually build out seaward and caused steepening of the slope which resulted in formation of a coarse peri-platform talus observed in calcirudite clasts of Bed 14. The sheltered environment between a barrier formed by the relict shelf edge (lower Bed 11 time) and a reefal belt at the new shelf edge allowed deposition of spongiostrome algal bindstone and bedded mudstone (B.5) in the protected backreef area. The steeper slope in front of the buildups prevented lumpy wackestones from forming on the upper slope which was now bypassed by sediment or allowed only short term deposition followed by "flushing". The observed facies changes thus seem to record transition from a more depositional margin to a bypass margin.

10.3. Bed 14 Lithofacies

10.3.1. Introduction

Bed 14 is the megaconglomerate with the largest clasts and the highest amount of older clasts. This relationship implies that the horizon records failure of an entire segment of the margin possibly in response to seismicity. The exact stratigraphic position of Bed 14 with respect to the platform is difficult to evaluate because fossil data are sparse. The information present suggests that implacement of Bed 14 was time equivalent to the uppermost Aguathuna Formation.

Five different lithofacies have been distinguished among foreign contemporaneous clasts from Bed 14. Clast counts (Fig. 10-1) indicate that massive wackestones and boundstones represent the most abundant lithologies followed by grainstones, rudstones and lumpy mudstones in descending order.

Vertical facies relationships within the time range of Bed 13 cannot be distinguished in Bed 14 based on conodont data or lithologies. Lithologies as old as Tremadoc or even upper Cambrian have been found among the older foreign clasts.

10.3.2. Lateral facies relationships

All of the foreign contemporaneous lithologies show intergradational relationships except for the rare lumpy mudstones, which were derived from a facies belt of their own. The calcirudites occasionally co-occur interbedded with massive wackestones and grainstones. The remaining three lithologies (wackestones, boundstones and grainstones) can be found together within the same boulder.

10.3.3. Role of organisms

Algae

The abundance and variety of algae in the clasts indicates that they represent an important component of the shelf margin facies where they obviously found favourable growth conditions during Bed 13-time. The dominant genera are *Girvanella*, *Epiphyton*, *Renalcis* and *Halysis*. The large boundstone clasts where they occur in growth position were lithified before transport occured. The algae were apparently capable with help of early cementation (indicated by nature of some cements) to form large buildups.

Sponges

Abundant sponges occur in some of the boundstones preserved in life position. Some are similar in shape to the archaeoscyphid sponges found in Bed 10 but represent a different species. A variety of morphologies occurs (i.e. cup-shaped, rod-shaped and sheet-like sponges) which aided in formation of the buildups.

Tubular organisms

In some of the large boulders at Lower Head these enigmatic organisms form intertwining networks intercalated with algal dominated sectors. They comprise 30-40% of the framework builders in these rocks and were quite important as constituents of the buildups. No sign of compaction of their tubes is visible and they probably possessed calcified stable walls capable of withstanding pressure and probably forming small "reefs".

Pulchrilamina-like organism

These large heads with lamellar layered walls are numerically not important components of the buildup facies.

Arthropods

Trilobites are abundant inhabitants of the algal mounds. Like conodonts from the large boulders at Lower Head trilobites are similar to taxa found in the deep subtidal deposits of the Middle Table Head Formation. Trilobite assemblages are typical for platform edge and deeper water environments (Appendix 10).

Brachiopods

Like species and genera from clasts in Bed 12 the brachiopods in Bed 14 are indicative of the *Orthidiella* Zone and typical of the deep subtidal environment.

Molluscs

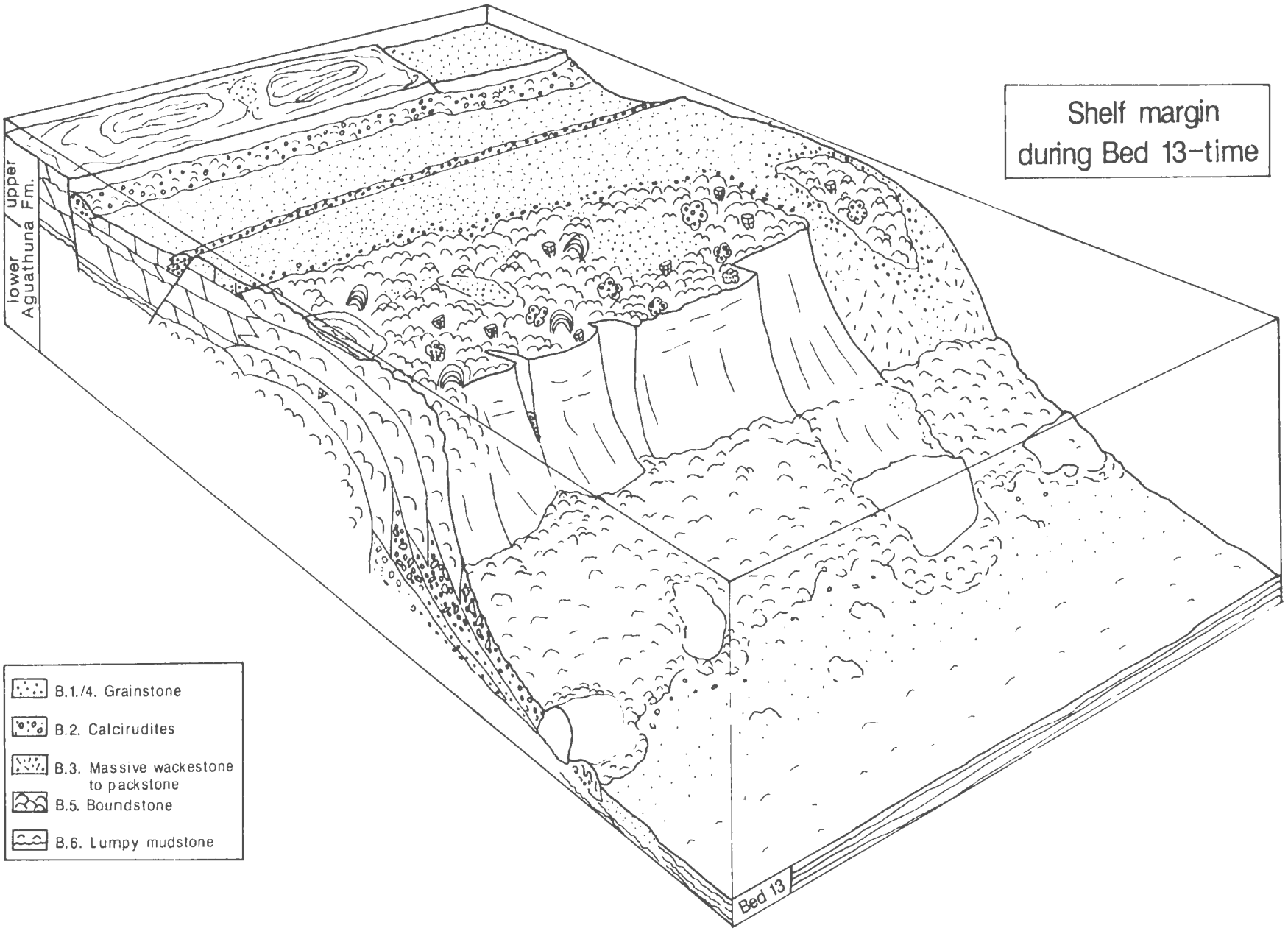
Macluritid gastropods are abundant components of the boundstones in Bed 14. Coiled and orthocone nautiloids are also ubiquitous.

10.3.4. Synthesis and model

The relative lowering of sea level that began in upper Bed 11-time (equivalent to lower Aguathuna Fm.) continued during deposition of Bed 13 and is expressed in the peritidal cycles of the Aguathuna Formation on the shelf.

The shelf edge built out seawards continuing a trend begun in upper Bed 11-time in response to the relative sea level fall (Fig. 10-4). Large boulders of boundstone exposed in Bed 14 at Lower Head illustrate the remains of an shelf edge at least tens of meters in height. The shelf edge was constructed of early lithified algal-sponge-"tubule" reefs (B.3), shelf-edge sands (B.5) and skeletal muds (B.2). Greatest abundance of the reef facies at Lower Head suggests that boulders here are derived from the largest buildups which declined in size and volume further south (i.e. Cow Head Peninsula). Slope sediments found in the Lobster Cove allochthonous terraine are interpreted as lateral equivalents of the Cow Head Group and show no major conglomerates with clasts of reefal facies or other evidence of large upslope buildups suggesting, that the reefs, indeed, represent a local facies possibly restricted to a promontory (James et al., in press). At the toe of the escarpment peri-platform talus accumulated, preserved in clasts of coarse calcirudite (B.4). Further down slope peri-platform oozes with occasional conglomerate lenses accumulated (B.6). The lower slope (Bed 13) is composed in the lower part dominantly of calcarenite, in the upper part of parted and ribbon limestone. The abundance of lime sands and mega conglomerates on the lower slope is typical for bypass slopes (Read, 1982). Scarcity of coarse debris on the upper slope supports the interpretation that the margin was a bypass rather than an accretionary slope. The limestone dominated facies is distally replaced by red and green shales.

Figure 10-4: Reconstruction of the shelf margin during Bed 13-time


Shelf margin
during Bed 13-time
upper
lower
Aguathuna Fm.
B.1./4. Grainstone
B.2. Calcirudites
B.3. Massive wackestone
to packstone
B.5. Boundstone
B.6. Lumpy mudstone
Bed 13

Chapter 11
SUMMARY AND CONCLUSIONS

11.1. Summary

11.1.1. Introduction and geological setting

Rocks of the CHG represent a fragment of the continental slope of the Cambro-Ordovician Iapetus Ocean. This allochthonous sequence has been transported westwards some 200km to lie directly on equivalent autochthonous carbonate platform strata. The bedded slope sequence of dominantly limestone and shale is punctuated by three megaconglomerate horizons (beds 10, 12, 14) in the Arenig part of the succession. The clasts and boulders found in these conglomerates are derived from different sources but mostly from the shelfbreak and upper slope which is not preserved elsewhere. The megaconglomerates are found in the limestone dominated section of the CHG and were investigated at Lower Head, Cow Head Peninsula and on Stearing Island. These deposits are regarded as proximal slope sediments in contrast to the shale dominated sections to the south-east (St. Pauls Inlet, Martin Point, Western Brook Pond, Green Point) which are regarded as their distal equivalents (James and Stevens, 1986).

11.1.2. Conodont taxonomy

Over 12000 conodonts were recovered from 256 samples taken from clasts and matrix of the three megaconglomerate horizons. Taxonomic study of selected species which were found to provide new information to Lower Ordovician conodont paleontology was employed. One new genus (*Texania*) was defined as a replacement for the older name *Microzarkodina?*. Several new species were

recognized (e.g. *Texania heligma*) and a few were redefined (e.g. *Oistodus elongatus* Lindström). Taxonomic treatment proceeded all other conodont studies and enabled a clearer recognition of the distribution of the species found as well as correlation to other localities.

11.1.3. Conodont biostratigraphy

The conodonts recovered from shelfedge derived lithologies enabled correlation with faunas from the shelf and lower slope. Lower slope successions have been investigated in terms of graptolites (Williams and Stevens, in press), conodonts (Johnston, 1987) and trilobites (Kindle and Whittington, 1958). Shelf strata of the St George Group were studied by Knight and James (in press), Stouge, (1982; conodonts), Stouge and Boyce (1983; conodonts and trilobites) and Williams et al. (1987, graptolites and trilobites) among others. Comparison of all data suggest that the lower part of Bed 9 with *Paroistodus proteus* correlates to the upper Boat Harbour Formation (below the pebble bed), a short interval near the middle of Bed 9 with *Acodus deltatus* to the uppermost Boat Harbour Formation and the rest of Bed 9 and Bed 10 bearing *Prioniodus (Prioniodus) elegans* to the lower and middle Catoche Formation (Fauna E). Lower Bed 11 belongs to the Baltoscandian *Oepikodus evae* Zone and probably correlates to the upper middle and upper Catoche Formation (Fauna E). The upper part of Bed 11, Bed 12 and lower Bed 13 are difficult to correlate to Baltoscandia because of the lack of North Atlantic zone fossils. The fauna is instead dominated by *Periodon aculeatus* The interval probably includes the *Baltoniodus navis - Paroistodus originalis* zones and is equivalent to the upper Catoche and lower Aguathuna formations on the shelf. The middle and upper part of Bed 13 and Bed 14 are still dominated by *P. aculeatus* but the presence of other taxa suggests correlation with the *Microzarkodina flabellum* and possibly the lower *Eoplacognathus? variabilis* zone in Baltoscandia.

11.1.4. Conodont paleoecology

Four different conodont biofacies can be recognized from clasts in the three megaconglomerates. Rare old clasts in Bed 10 yield *Paroistodus numarcuatus* and *Drepanoistodus inconstans* and are assigned to a *Drepanoistodus - Paroistodus* Biofacies. Most of the remaining clasts yield a fauna dominated by *Prioniodus (P.) marginalis* n.sp. together with the distincive form *Texania* sp. aff. *T. adentata* (McTavish) and is named the *Prioniodus - Texania* Biofacies. Bed 12 also yields an older and a younger biofacies: The fauna in the older clasts is dominated by *Prioniodus (Oepikodus) evae* and *Periodon flabellum* (*Prioniodus - Periodon* Biofacies); the younger fauna yields abundant *P. aculeatus* accompanied by *Texania heligma* n.sp. (*Periodon - Texania* Biofacies). Clasts in Bed 14 comprise the *Periodon - Parapanderodus* Biofacies after the dominant species *P. aculeatus* and the characteristic form *P. arcuatus* Stouge.

Comparison of the shelfedge/upper slope faunas to those found on the lower slope showed that both environments are similar with respect to the dominating species but differ in accessory faunal elements. An exception is the *Prioniodus - Texania* Biofacies of Bed 10 which is highly endemic. Shelf faunas are very distinct from slope faunas with regard to the dominating species but share some of the accessory elements. Migrations of faunas from slope to shelf and vice versa are probably related to sealevel changes on the shelf. This can be demonstrated by the amount of Midcontinent (=shelf-) species versus North Atlantic (=slope-) species in the shelfedge derived clasts. Regressions are reflected in a higher proportion of Midcontinent species at the shelfbreak (*Prioniodus - Texania* and *Periodon - Parapanderodus* Biofacies); transgressions result in a larger component of North Atlantic species (*Prioniodus - Periodon* Biofacies).

11.1.5. Conglomerate sedimentology

The carbonate clasts in the megaconglomerates were studied by visual examination and description of the various lithologies and by pointcounting the different types recognized using a 10cm spaced grid. About 500 thin section samples were taken and studied petrographically with a microscope. The clasts and boulders in the conglomerates were subdivided according to their origin and age into (A) local lithologies, (B) foreign lithologies and (C) older clasts. Local lithologies are interpreted as being derived from within or close to the depositional environment of the bedded lower slope sediments of the CHG and are penecontemporaneous to the immediately underlying bed; foreign lithologies are also penecontemporaneous to the underlying bed, but come from outside of the depositional environment, mostly from the upper slope and shelfbreak, rarely from the shelf; older clasts comprise local as well as foreign lithologies, but are older than the immediately underlying bedded strata. Study of the clasts in distal as well as proximal Arenig conglomerates shows that both contain similar types of clasts but different ratios of foreign and local clasts and matrix. Foreign clasts are concentrated in proximal conglomerates, local clasts in distal conglomerates. The lateral change in clast composition suggests that either the debris flows are different or the same flow changed its composition on its way downslope. The presence of similar old foreign lithologies in proximal as well as distal conglomerates suggests, however, that both drew from the same source and are deposits of the same flow (except for Bed 10 which appears to be the result of a series of smaller events). Old softly deformed clasts found in Bed 14 suggest that older megaconglomerates were incorporated into this younger debris flow. Vertically the megaconglomerate horizons increase in thickness and size of clasts.

11.1.6. Clast lithofacies

In the oldest of the three Arenig megaconglomerates, Bed 10, five different types of local clasts can be distinguished. These are: parted and ribbon limestone, calcarenite, conglomerate, dolostone and chert. These are similar in composition to sediment of the underlying Bed 9. Foreign penecontemporaneous clasts are subdivided into six different lithologies: massive (unbedded) wackestone, algal sponge boundstone, bedded grainstone, calcirudite, lumpy wackestone and mudstone. The lumpy wackestone lithologies are rare and represent the oldest facies as indicated by conodont data. Clasts of massive wackestone are most abundant. They are composed of muds and peloids derived from the alga *Girvanella* together with other microbioclastic debris (e.g. sponge spicules, shell fragments of trilobites, brachiopods, cephalopods and minor echinoderms). Clasts are intersected by sediment-filled fractures and silica-lined, fibrous calcite-filled voids. The sediments are interpreted as upper slope and shelfedge mud deposits or mounds stabilized by algal growth. Organic buildup facies is represented by boundstones formed by *Girvanella*-stromatolites and clusters together with archaeocyphid and other lithistid and hexactinellid sponges. Calcirudites represent mound talus sediments. The rare bedded grainstones are interpreted as intermound and mound flank sediment. Lumpy mudstones finally represent a peri-platform ooze deposited on the deep upper slope. Old clasts are rare in Bed 10 and are represented by *Epiphyton* boundstone, oolite and calcarenite clasts.

Local clasts in Bed 12 are similar in composition to those in Bed 10. Foreign penecontemporaneous clasts were subdivided into seven different lithologies: B.1 Massive wackestone intercalated with massive to bedded muddy grainstone. This facies is usually intensively reworked and shows discontinuity surfaces. It is interpreted as representing shelfedge sands and upper slope muds. Among the boundstones (B.2) two different types are distinguished: an older light grey boundstone dominated by the algae *Renalcis*, *Epiphyton* and *Girvanella*, and a younger brown boundstone with a similar algal flora, but in addition, sponges and enigmatic organisms which are similar to those in boundstones of Bed 14.

Calcirudites (B.3) are rarer in Bed 12 than they are in Bed 10, but calcirudites of Bed 12-age are a distinctive lithology and are common in Bed 14. They are also interpreted as talus sediments and/or foreslope breccias. Lumpy dolomitic wackestones (B.4) are equivalent in age to lower Bed 11 and are composed of skeletal mud intercalated with dolomitic argillaceous parting material. This facies is interpreted as an upper slope deposit. In contrast bedded mudstones to wackestones (B.5) correlate to upper Bed 11. They are rubbly to bedded mudstones, packstones, and wackestones with locally preserved fenestrae, anastomosing tubes and spongiomorph fabric. They are interpreted as shallow water deposits. Clasts with shelf-derived conodont faunas are rare in Bed 12 and are grainstones (B.6). Lumpy mudstones are similar to those in Bed 10 and are interpreted as peri-platform ooze. Old clasts are similar to those found in Bed 10 but with the addition of clasts of Bed 9-age the latter being a wackestone with discontinuity surfaces (C.1) and a calcirudite (C.4).

Bed 14 differs from the older megaconglomerates in yielding more old clasts which are sometimes difficult to distinuish from the penecontemporaneous lithologies. Lower slope lithologies include soft deformed clasts of ribbon limestone (A.1), calcarenite (A.2), conglomerate (A.3), dolomite (A.4) and Chert (A.5). Foreign clasts are dominantly boundstone composed of *Epiphyton* and *Girvanella* accompanied by other algae, enigmatic tubular organisms and sponges (B.5). They probably formed reef-like buildups along the shelfedge and were lithithified early. The boundstones are associated with packstone and wackestone (B.3), abundant grainstone (B.4) and coarse calcirudite (B.2) with angular early lithified lithoclasts. Rare are shelf-derived grainstones with a conodont fauna correlative to the upper Aguathuna Formation (B.1) and rafts of peri-platform ooze (B.6). Old clast are common in Bed 14 and they comprise foreign and local lithologies as old as upper Cambrian in age. Shelf derived old clasts are more common in Bed 14 than in the older megaconglomerates.

11.2. Conclusions

Conclusions on evolution of the shelf margin can be drawn from the combining condont biofacies and carbonate lithofacies data.

11.2.1. Bed 10

The shelf margin as it existed during Bed 9-time is interpreted to have been rimmed by mud mounds formed by accumulations of the alga *Girvanella* and lithistid sponges. The mounds were situated in moderately deep water within the photic zone (indicated by algal growth) but not significantly influenced by wave action (indicated by lack of energy indicators such as grainstones) (Fig. 11-1) Lithification of the mounds was sufficienlty delayed to allow intensive bioturbation and formation of flanking calcirudites with soft-deformed lithoclasts but was early enough to allow transport of large undeformed angular clasts with calcite-filled stromatactoid voids in the Bed 10 debris flows. The mounds attained some relief above the sea floor as indicated by the presence of abundant coarse talus sediments (calcirudites). The mounds at the shelfedge are inhabited by a conodont fauna that is quiet distinct from those of the lower slope and the shelf with respect to the dominating species. It is termed the *Prioniodus - Texania* Biofacies and is characterized by endemic species (*Prioniodus marginalis* and *Texania* sp. aff. *T. adentata*) together with North Atlantic forms and a relatively large number of Midcontinent species.

Downslope the mound facies graded into peri-platform ooze which is commonly devoid of conodonts. Clasts of this facies are rare, but their usually soft deformed nature suggests that they disintegrated during transport. Local clasts reworked from the lower slope are relatively abundant in proximal facies of Bed 10 (compared to later megaconglomerates). Sedimentation on the lower slope (Bed 9) was characterized by sediment derived from the marginal buildups. This is indicated by the abundance of algal-derived sedimentary particles such as algal peloids, lumps, rafts, filaments and muds (Coniglio and James, 1985). Slope

instability is indicated by the presence of welded conglomerates on Stearing Island and abundant minor conglomerates near the top of Bed 9. These closely spaced debris flows are referred to as the Bed 10 complex (James and Stevens, 1986). Old clasts are rare in these conglomerates suggesting that no deep erosion occurred, (observed down-cutting is minor) nor were major fault scarps present.

The adjacent penecontemporaneous shelf succession is represented by the lower-middle Catoche Formation, a sequence of dominantly subtidal carbonates. The abundance of muddy sediments in the middle Catoche Formation suggests that low energy conditions prevailed on the shelf, either because of relatively deep water or because a rimmed shelf margin developed during this time which protected the shelf interior from wave action. The lack of exchange between open ocean conodont faunas and those of the shelf platform indicates, however, that the water was not deep or cold enough to allow for migrations of North Atlantic elements onto the platform. Furthermore the number of Midcontinent species at the shelf edge is fairly high (compared to later times) suggesting that conditions were favourable for these shallow water elements. The presence of a rimmed platform as suggested by James et al. (in press) is indicated by the faunal evidence with sharp distinction of shelf-, mound- and lower slope faunas. The nature of the mud mounds, however, suggests that they were deposited in fairly deep water and that they did not have a wave resistant indurated surface. Sediments indicating wave action such as grainstones which are found in younger shelfedge facies are scarce in Bed 10. It is therefore questionable wether or not the mounds were capable of forming a significant rim at the shelfedge. Probably a combination of deep shelfmargin buildups and deep water on the shelf accounts for the low energy conditions on the shelf.

11.2.2. Bed 12

The lithological and faunal composition of shelfedge and upper slope derived clasts changes drastically with the onset of Bed 11 deposition. Slow and condensed deposition beginning already during upper Bed 9-time is indicated by the presence of old clasts with discontinuity surfaces yielding *Prioniodus (P.) elegans* in Bed 12. This trend is also visible in the silicification of the surfaces of Bed 10 and deposition of black shale and phophorite in lower Bed 11. The slowed deposition may be the result of termination of the buildup facies at the shelf margin which contributed large amounts of sediment to the lower slope. It is probably the response to deepening of the water at the shelfedge which led to drowning of the algal mounds and their retreat shelfwards (Fig. 11-1). The now open margin became the site of deposition of muddy shelf edge sands interbedded with burrowed muds recording fluctuating energy conditions. Muddy grainstones grade into grainstones interbedded with lumpy wackestone and finally into lumpy wackestone and mudstone downslope. The *Prioniodus - Texania* Biofacies of Bed 10 is replaced by a fauna clearly dominated by North Atlantic species, notably *Prioniodus (Oepikodus) evae*. This period of time probably correlates to the upper Catoche Formation on the shelf, an interval of sedimentation that records the change from deepest submergence to gradual shallowing towards the top of the formation.

The clast lithologies and conodont faunas indicate that the formation of mud mounds at the shelfedge had almost completely ceased and lumpy wackestones then characterized much of the upper slope. Buildup facies on a minor scale exist and contain a larger variety of different algae (i.e. *Renalcis, Epiphyton*) in addition to those from Bed 10 (*Girvanella*); the stromatactoid fabrics characteristic of the Bed 10 mud mounds decrease greatly in abundance.

Over the course of Bed 11 deposition the *Prioniodus - Periodon* Biofacies is replaced by a younger *Periodon - Texania* Biofacies, probably the expression of shallowing recorded in the lower Aguathuna Formation. This fauna is dominated

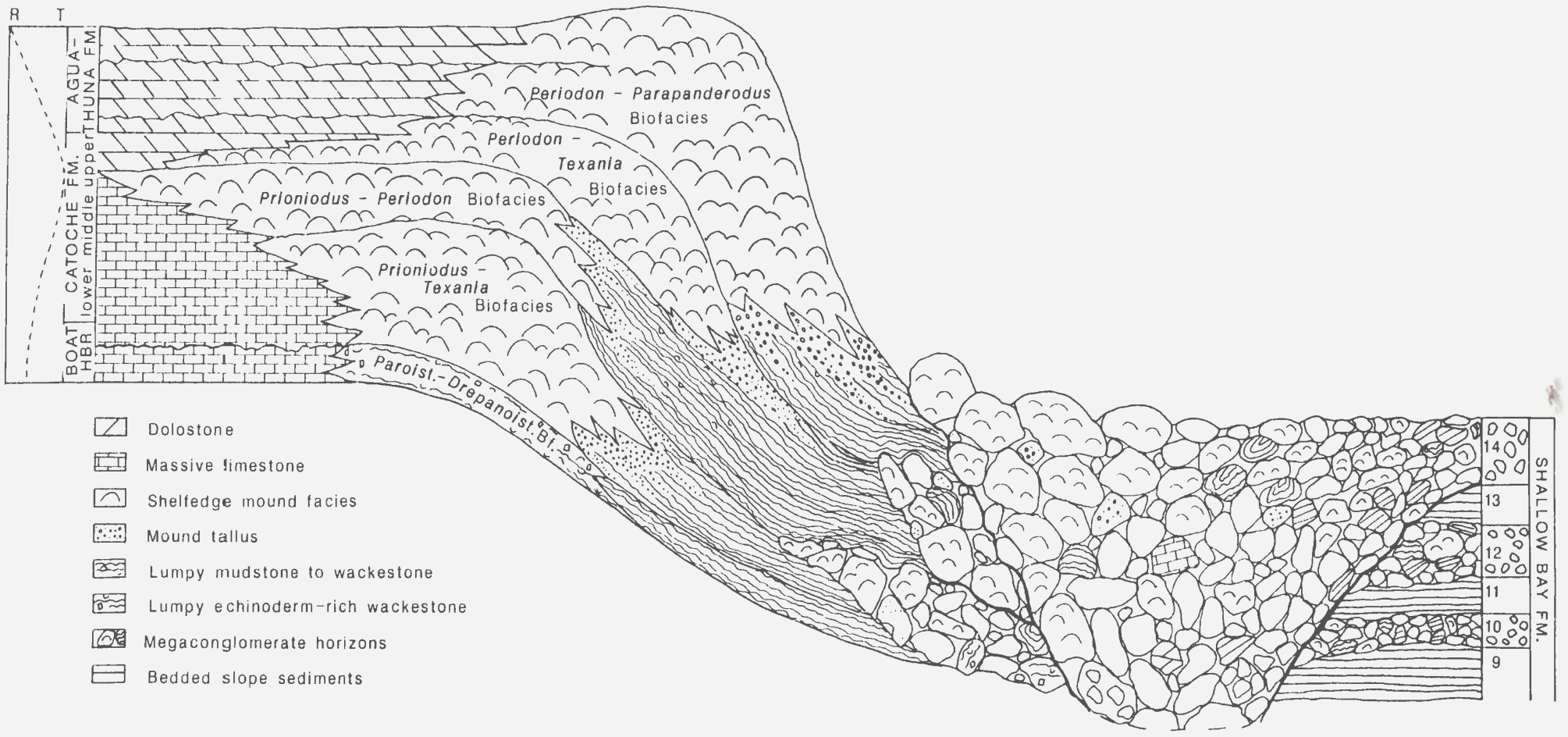
by *Periodon aculeatus* but contains a relatively large number of Midcontinent faunal elements which probably moved toward the shelfedge indicating a biofacies shift occurring with the regression. Shallowing is also expressed in the re-establishment of shelfedge buildups during upper Bed 11-time recorded in boundstone clasts of Bed 12. This younger buildup facies has similarities to that of Bed 14 with a high diversity of different algae, sponges and enigmatic organisms such as *Pulchrilamina*-like heads and serpulid tubules.

The Bed 12 debris-flow is a major event that may be the result of progradation of the platform edge during upper Bed 11-time following the backstepping of the margin during lower Bed 11-time. The number of old clasts is not significantly increased in this flow and tectonic activity such as faulting as a trigger for the event is not indicated. Bed 12 is a widespread horizon with distinctive clast lithologies which are present in proximal as well as distal sections. It probably represents a single event rather than a series of flows as the Bed 10 complex.

11.2.3. Bed 14

Clasts of Bed 14 yield conodonts and other fossils which correlate in age to most of the Aguathuna Formation and to Bed 13. Abundance of boundstone boulders in this megaconglomerate records the establishment of large scale marginal buildups (Fig. 11-1). The large size and angularity of the clasts suggests that they were lithified early and formed wave-resistant reef-like mounds. They are composed of *Girvanella* and *Epiphyton* accompanied by other algae, various sponge genera and enigmatic tubular organisms. A new conodont biofacies, the *Periodon - Parapanderodus* Biofacies is established, a fauna dominated by *Periodon aculeatus* together with many Midcontinent species which are, however, different from those in Bed 12. They resemble in many respects younger faunas found in the middle Table Head Group, an interval of deepening on the shelf. This similarity demonstrates the response of conodont faunas to environmental changes, particularly water depth and emphasizes the necessity to evaluate other parameters (e.g. sedimentology, waterdepth, paleogeographical situation) in

Figure 11-1: Diagram illustrating the evolution of the shelf margin and the succession of biofacies. The curve at left shows the response of Midcontinent and North Atlantic species to shallowing (r) and deepening (t) of the water at the shelfedge


R
T
AGUA FM.
THUNA FM.
upper
middle
lower
CATOCHE FM.
BOAT HBR
Periodon - Parapanderodus Biofacies
Periodon - Texania Biofacies
Prioniodus - Periodon Biofacies
Prioniodus - Texania Biofacies
Paroist.-Drepanoist. Bf.
Dolostone
Massive limestone
Shelfedge mound facies
Mound tallus
Lumpy mudstone to wackestone
Lumpy echinoderm-rich wackestone
Megaconglomerate horizons
Bedded slope sediments
14
13
12
11
10
9
SHALLOW BAY FM.

addition to species composition for correlative purposes. A single clast found in Bed 14 yields a contemporaneous conodont fauna from the upper Aguathuna Formation with hyaline species which have not been found in the shelfedge buildups. Their presence provides an lower age-limit for Bed 14: it must be at least as old as the upper Aguathuna Formation in order to incorporate these clasts.

Bed 14 is distinguished by a large number of older clasts (as old as upper Cambrian) and of huge boulders. This suggests that the event records failure of an entire segment of the margin possibly in response to faulting on the platform recorded in the upper Aguathuna Formation (Knight and James, in press). Bed 14 at Lower Head East is an olistostrome which was transported to its present location from further upslope (Coniglio, 1985) and supports the interpretation of Bed 14 as reflecting a tectonic event possibly related to the synsedimentary faulting recorded in the upper Aguathuna Formation. The large size of the clasts contained in this olistostrome suggests, that a conglomerate facies even more proximal than that of Cow Head and Stearing Island was present further upslope. It is apparently not preserved in the Humber Arm Allochthon.

Several conclusions emerged concerning the carbonate lithofacies and conodont biofacies of shelfedge deposits: 1. Conodont faunas inhabiting the shelfedge at this segment of the North American margin are in general of North Atlantic aspect and show closer kinship to the North Atlantic Province than to the Midcontinent Province.

2. Comparison of lower slope and shelfedge/upper slope faunas shows that different conodont biofacies exist which can be distinguished by the character of the accesssory species rather than by the dominating forms which commonly account for 70-90% of the total fauna. The composition of these biofacies corresponds to the sea level history of the area.

3. Buildup facies are generally found to be barren of conodonts or to have low

yields. An exception are the algal mounds preserved in Bed 10 which contained an abundant endemic fauna (*Prioniodus - Texania* Biofacies) while younger faunas of beds 12 and 14 generally contain a mixture of species known either from the shelf or the slope. The establishment of endemic faunas seems to require special environmental parameters which were obviously only found in the mud mounds of Bed 10 and not in the later buildups.

4. The clast lithologies of the three megaconglomerates record the existence of marginal buildups and their development from deepwater algal-sponge mounds with stromatactoid fabric in the Lower Ordovician to more complex *Girvanella - Epiphyton* mounds in the lower Middle Ordovician. Bed 12 lithologies record termination of the older algal-sponge mounds and re-establishment of the younger buildup facies found in Bed 14.

5. Shelfedge buildups of Lower and lower Middle Ordovician age are unlike other buildups described from carbonate sequences of similar age on the shelf platform.

6. Combined evidence from conodont and sedimentary data derived from this study and comparison with other related studies of the area reported in the literature suggests that changes of shelfedge carbonate lithofacies and conodont biofacies represent a response of the environment to sea level changes on the shelf platform and the resulting consequences.

Several aspects and questions remain unresolved and should be addressed in further studies. These include:

1. Was the shelfedge subaerially exposed? Several boulders in Bed 12 and 14 show structures which may be the result of subaerial exposure and study of their diagenesis supported by isotope data might provide an answer.

2. The correlation of the shelf and slope is still insecure mainly because of lack

of data from the shelf sequence. Study of conodonts from the St. George Group by Z. Ji is currently under way and will allow better understanding of the faunal dynamics.

3. The graptolite data from the shelf do not entirely support the sedimentological evidence. This may be result of lack of understanding of the precise range of the graptolite zones involved. In St. Pauls Inlet the occurrence of the *Tetragraptus akzharensis* Zone above a conglomerate horizon (Bed 10?) containing *Prioniodus (P.) elegans* coincides with the co-occurrence of *P. elegans* and *P. (O.) evae*. This, together with the indication of slowed or condensed sedimentation in lower Bed 11 raises the question whether or not this graptolite zone ranged up into the lower Bed 11 and was subsequently eroded (together with the bevelled clasts found at the silicified top of Bed 10 on Cow Head Peninsula). For correlative purposes the ranges of graptolite zones in shelf and slope sequences and their possible migrational patterns should be addressed.

4. The unique carbonate buildups deserve further study, particularly the enigmatic tubules and the algal flora in Bed 14. No similar rocks are described to date in the literature with the exception of a few clasts of the Mystic conglomerate (Guibault et al., 1976).

REFERENCES

Aalto, K.R., 1972: Flysch pebble conglomerate of the Cap-des-Rosier Formation (Ordovician), Gaspe Peninsula, Quebec: Journal of Sedimentary Petrology, **42**, 922-926.

Ahr, W.M., 1971: Paleoenvironment, algal structures and fossil algae in the Upper Cambrian of Central Texas. Journal of Sedimentary Petrology, **41**, 205-216.

An, T., Zhang, F., Xiang, W., Zhang, Y., et al., 1983: The conodonts of North China and of the adjacent regions. (Chinese with English Abstract), Beijing. 233 pp.

Ando, C.J., Cook, F.A., Oliver, J.E., Brown, L.D., and Kaufman, S., 1983: Crustal geometry of the Appalachian Orogen from seismic reflection studies. In: R.D. Hatcher Jr., H. Williams, and I. Zietz, (eds.): Contributions to the tectonics and geophysics of mountain chains. Geological Society of America, Memoir **158**, 83-101.

Andrews, P.B., 1964: Serpulid reefs, Baffin Bay, southeast Texas. In: A.J. Scott (ed.). Depositional environments south central Texas coast, Gulf Coast Assoc. Geol. Soc., Field trip guidebook for annual meeting, **101**.

Austin, R., 1987: Conodonts: Investigative Techniques and Applications. British Micropalaeontological Society Series, Ellis Horwood Limited, Chichester, England, 422 pp.

Bagnoli, G., Barnes, C.R., and Stevens, R.K., 1987: Lower Ordovician (Tremadocian) conodonts from Broom Point and Green Point. western Newfoundland. Bolletino della Societa Paleontologica Italiana, **25**, 145-158.

Bagnoli, G. and Stouge, S.S., 1985: Species of *Prioniodus* Pander, 1856 from Bed 9, (Lower Ordovician), Cow Head Group, Western Newfoundland. In: R.J.

Aldridge, A.L. Austin and M.P. Smith (eds.), Fourth European Conodont Symposium (ECOS IV), Abstracts, Private Publication, University of Southampton, p. 3-4.

Baird, D.M., 1960: Observations on the nature and origin of the Cow Head breccias of Newfoundland. Geological Survey of Canada, Paper 60-3, 26pp.

Baldis, B.A., 1978: Lineas de control estructural en las cuencas Ordovicias Argentinas. Acta Geol. Lill., **14**, 11-14.

Ball, M.M., 1967: Carbonate sand bodies of Florida and the Bahamas. Journal of Sedimentary Petrology, **37**, 556-591.

Banks, M.R. and Johnson, J.H., 1957: *Maclurites* and *Girvanella* in the Gordon River Limestone (Ordovician) of Tasmania. Journal of Paleontology, **31**, 632-640.

Barnes, C.R., 1984: Early Ordovician eustatic events in Canada. In: Aspects of the Ordovician System. D.L. Bruton (ed.), Paleontological Contributions from the University of Oslo. Universitetsforlaget, **295**, 51-64.

Barnes, C. R., and Fahraeus, L. E., 1975: Provinces, communities, and the proposed nektobenthic habit of Ordovician conodontophorids. Lethaia, **8**, 133-149.

Barnes, C.R., Jackson, D.E., and Norford, B.S., 1976: Correlation between Canadian Ordovician zonations based on graptolites, conodonts and benthic macrofossils from key successions. In: M.G. Basset (ed.). The Ordovician System: Proceedings of a Paleontological Association Symposium, Birmingham, September 1974, 209-226. Cardiff.

Barnes, C.R., Kennedy, D.J., McCracken, A.D., Nowlan, G.S., and Tarrant, G.A., 1979: The structure and evolution of Ordovician conodont apparatusses. Lethaia **12**, 125-151.

Barnes, C.R., and Poplawski, M.L.S., 1973: Lower and Middle Ordovician conodonts from the Mystic Formation, Quebec, Canada, Journal of Paleontology. **47**, 760-790.

Barnes, C.R., Rexroad, C.B., and Miller, J.F., 1973: Lower Paleozoic conodont provincialism. In: Rhodes, F.H.T., (ed.). Conodont paleozoology. Geological Society of America Special Paper, **141**, 156-190.

Barnes, C.R., and Tuke, M.F., 1970: Conodonts from the St. George Formation (Ordovician), northern Newfoundland. In: Contributions to Canadian Paleontology. Geological Survey of Canada Bulletin **187**, 79-97.

Bathurst, R.C.G., 1959: The cavernous structure of some Mississippian *Stromatactis* reefs in Lancashire, England. Journal of Geology, **67**, 506-521.

Bathurst, R.G.C., 1980: *Stromatactis* - origin related to submarine-cemented crusts in Paleozoic mud mounds. Geology, **8**, 131-134.

Bathurst, R.G.C., 1982: Genesis of stromatactis cavities between submarine crusts in Paleozoic carbonate mud buildups. Geological Society of London, Journal, **139**, 165-181.

Behr, K. and Behr, H.-J., 1976: Cyanophyten aus oberjurassischen Algen-Schwamm Riffen. Lethaia, **9**, 283-292.

Bergström, S.M., 1961: Conodonts from the Ludibundus Limestone (Middle Ordovician) of the Tvären area (S.E. Sweden). Arkiv for Mineralogi och Geologi **3**, 1-61.

Bergström, S.M., 1971: Conodont biostratigraphy of the Middle and Upper Ordovician of Europe and eastern North America, p. 83-161. In: W.C. Sweet and S.M. Bergström (eds.), Symposium on Conodont Biostratigraphy. Geological Society of America, Memoir **127**.

Bergström, S.M., 1971a: Correlation of North Atlantic Middle and Upper Ordovician conodont zonation with the graptolite succession, p. 177-187. In: Colloque Ordovician-Silurian, Brest. Bureau de Recherches Geologiques et Minieres, Memoir, Mineraux, France, **73**.

Bergström, S.M., 1973: Biostratigraphy and facies relations in the lower Middle Ordovician of easternmost Tennessee. American Journal of Science, **273-A**, 261-293.

Bergström, S.M., 1977: Early Paleozoic biostratigraphy in the Atlantic borderlands. In: F.M. Swain (ed.). Stratigraphic micropaleontology of Atlantic basin and borderlands, p. 85-100, Amsterdam.

Bergström, S.M., 1979: Whiterockian (Ordovician) conodonts from the Holanda Limestone of the Trondheim region, Norwegian Caledonides: Norsk Geologisk Tidsskrift, **59**, 295-307.

Bergström, S.M., and Carnes, J.B., 1976: Conodont biostratigraphy and paleoecology of the Holston Formation (Middle Ordovician) and associated strata in eastern Tennessee. Geological Association of Canada Special Paper, **15**, 27-57.

Bergström, S.M., Epstein, A.G., and Epstein, J.B., 1972: Early Ordovician Atlantic Province conodonts in eastern Pennsylvania. U.S. Geological Survey Professional Papers **800-D**, D37-D44.

Bergström, S.M., Riva, J. and Kay, M., 1974: Significance of conodonts, graptolites, and shelly faunas from the Ordovician of western and north-central Newfoundland. Canadian Journal of Earth Sciences, 11, 1625-1660.

Berry, W.B.N., 1968: British and North American Lower Ordovician correlation. Geological Society of America Bulletin, **79**, 1265-1272.

Billings, E., 1865: Paleozoic Fossils, v.1. Geological Survey of Canada, 326 pp.

Blake, N.J., and Doyle, L.J., 1983: Infaunal-sediment relationships at the shelf-slope break. In: D.J. Stanley and G.T. Moore (eds.). The shelfbreak: critical interface on continental margins. SEPM Special Publication **33**, 381-390.

Bleifnik, D.M., Robertson, A.H.F., and Sheridan, A.E., 1983: Deposition and provenance of Miocene intraclastic chalks, Blake - Bahama Basin, western North Atlantic. In: Initial Reports of the Deep Sea Drilling Project, **44**, 727-748.

Boirie, J.-M. et Souquet, P., 1982: Les poudingues de Mendibelza: depots de cones sous-marins du rift Albien des Pyrenees. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, **6**, 405-435.

Bosence, D.W.J., 1973: Recent Serpulid Reefs, Connemara, Eire. Nature, **242**, 10-11.

Bouma, A.H., 1962: Sedimentology of some flysch deposits. Amsterdam, Elsevier, 168 pp.

Bourque, P.A., and Gignac, H., 1983: Sponge-constructed stromatactis mud mounds, Silurian of Gaspe, Quebec. Journal of Sedimentary Petrology, **53**, 521-532.

Boyce, W.D., 1979: Further developments in western Newfoundland Cambro-Ordovician biostratigraphy. In: R.U. Gibbons (ed.). Report of Activities for 1978. Newfoundland Department of Mines and Energy, Mineral Development Division, Report **79-1**, 7-10.

Boyce, W.D., 1983: Early Ordovician trilobite faunas of the Boat Harbour and Catoche formations (St. George Group) in the Boat Harbour - Cape Norman area, Great Northern Peninsula, western Newfoundland. M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 272 pp.

Boyce, W.D., 1985: Cambrian-Ordovician biostratigraphic investigations, Great

Northern Peninsula, western Newfoundland. In: K. Brewer, D. Walsh and R.V. Gibbons (eds.). Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report **85-1**, 60-69.

Boyce, W.D., 1986: Ordovician biostratigraphic investigations, Great Northern Peninsula. In: R.F. Blackwood, D. Walsh, and R.V. Gibbons, (eds.). Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report **86-1**, 161-168.

Bradshaw, L.E., 1969: Conodonts from the Fort Pena Formation (Middle Ordovician), Marathon Basin, Texas. Journal of Paleontology, **43**, 1137-1168.

Brand, U., and Ethington, R.L., 1981: *Oneotodus simplex* (Furnish) and the Genus *Oneotodus* (Conodonta). Journal of Paleontology, **55**, 239-247.

Branson, E.B., and Mehl, M.G., 1933-1934: Conodont studies, numbers 1 and 2: University of Missouri Studies, **8**, nos. 1, 2, pp. 1-349..

Breakey, E.C., 1974: Sedimentology of the Lower Paleozoic shelf-slope transition Levis, Quebec. Unpublished M.Sc. Thesis, McGill University, Montreal, 182 pp.

Bruton, D.L., Lindström, M., and Owen, A.W., 1985: The Ordovician of Scandinavia. In: The Caledonide Orogen - Scandinavia and related areas. D.G. Gee and B.A. Sturt (eds.), 273-282. John Wiley and Sons Ltd.

Burchette, T.P., 1981: European Devonian reefs: a review of current concepts and models. In: D.F. Toomey (ed.). European Fossil Reef Models. SEPM Special Publication, **30**, 85-142.

Burrett, C., Stait, B., Sharples, C. and Laurie, J., 1984: Middle-Upper Ordovician shalllow platform to deep basin transect, Tasmania, Australia. In: Aspects of the Ordovician System. D. C. Bruton, (ed.). Paleontological Contributions from the University of Oslo, No. 295, Universitetsforlaget, pp. 149-158.

Burrett, C., Stait, B., and Laurie, J., 1983: Trilobites and microfossils from the Middle Ordovician of Surprise Bay, southern Tasmania, Australia. Alcheringa, **1**, 171-193.

Bursnall, J.T. and De Witt, M.J., 1975: Timing and development of the orthotectonic zone in the Appalachian Orogen of Northwest Newfoundland. Canadian Journal of Earth Science, **12**, 1712-1722.

Callahan, R.K.M., 1974: Stratigraphy, sedimentation and petrology of the Cambro-Ordovician Cow Head Group at Broom Point and Martin Point, western Newfoundland. (M.Sc. thesis), Memorial University of Newfoundland, St, John's, Newfoundland, 119 pp.

Carozzi, A.V., 1960: Microscopic sedimentary petrography. 485 pp., Wiley, New York - London.

Chow, N., 1986: Sedimentology and diagenesis of Middle and Upper Cambrian platform carbonates and siliciclastics, Port au Port Peninsula, western Newfoundland. Unpublished Ph.D thesis, Memorial University of Newfoundland, St, John's, Newfoundland, 458pp.

Church, W.R., 1987: Comment on "Deep seismic reflection profile across the northern Appalachians". Geology, **15**, 182.

Church, W.R. ,and Stevens, R.K., 1971: Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. Journal of Geophysical Research, **76**, 1460-1466.

Conaghan, P.J., et al. 1976: Nubrigyn algal reefs (Devonian), eastern Australia; allochthonous blocks and mega-breccias. Geological Society of America Bulletin, **87**, 515-530.

Coniglio, M., 1984: Algal origin of peloids, peloidal intraclasts, and structure

grumeleuse in Paleozoic limestones: evidence from Cow Head Group, western Newfoundland. (Abstract), AAPG Bulletin, **68**, 464-465.

Coniglio, M., 1985: Origin and diagenesis of fine-grained slope sediments: Cow Head Group (Cambro-Ordovician), western Newfoundland. (Ph.D. thesis) Memorial University of Newfoundland, St. John's, Newfoundland, 684 pp..

Coniglio, M. and James, N.P., 1985: Calcified algae as sediment contributors to early Paleozoic limestones: Evidence from deep water sediments of the Cow Head Group, western Newfoundland. Journal of Sedimentary Petrology, **55**, 746-754.

Coniglio, M. , *in press*: Submarine slope failure and the origin of intrafolial deformation in deep-water slope carbonates, Cow Head Group, western Newfoundland. Canadian Journal of Earth Sciences.

Cook, H.E., 1965: Geology of the southern part of the Hot Creek Range, Nevada. Unpublished PhD thesis, University of California, Berkeley, 116 pp.

Cook, H.E., McDaniels, P.M., Mountjoy, E.W., Pray, L.C., 1972: Allochthonous carbonate debris flows at Devonian bank ("reef") margins, Alberta, Canada. Bulletin of Canadian Petroleum Geology, **20**, 439-497.

Cook, H.E. and Mullins, H.T., 1983: Basin margin environment. In: P.A. Scholle, D.G. Bebout and C.H. Moore (eds.). Carbonate Depositional Environments. AAPG Memoir **33**, 540-617.

Cook, H.E. and Taylor, M.E., 1975: Early Paleozoic continental margin sedimentation, Trilobite biofacies, and the thermocline, western U.S. Geology, **3**, p. 559-562.

Cook, H.E. and Taylor, M.E., 1977: Comparison of continental slope and shelf environments in the upper Cambrian and lowest Ordovician of Nevada. *In*: H.E. Cook and P. Enos (eds.). Deep Water Carbonate Environments. SEPM Special Publication **25**, 51-81.

Cook, H.E., Hine, A.C., and Mullins, H.T. (eds.), 1983: Platform Margin and Deep Water Carbonate Environments. SEPM Short Course No. 12, 516 pp..

Cooper, B.J., 1981: Early Ordovician conodonts from the Horn Valley Siltstone, central Australia. Paleontology, **24**, 147-183.

Cooper, G.A., 1956: Chazyan and related brachiopods. Smithonian Miscellaneous Collections, **127**,

Cooper, G.A., 1976: Early Middle Ordovician of the United States. In: M.G. Basset (ed.). The Ordovician System, Proceedings of a Paleontological Association Symposium, Birmingham, September, 1974, p. 171-194.

Copper, P., 1976: The cyanophyte *Wetheredella* in Ordovician reefs and off-reef sediments. Lethaia, **9**, 273-281.

Crevello, P.D. and Schlager, W., 1980: Carbonate debris sheets and turbidites, Exuma Sound, Bahamas. Journal of Sedimentary Petrology, **50**, 1121-1147.

Crowell, J.C., 1957: Origin of pebbly mudstones. Geological Society of America Bulletin, **68**, 993-1009.

Danielli, H.M.C., 1981: The fossil alga *Girvanella* Nicholson and Etheridge. Bulletin of the British Museum (Natural History) Geology Series **35**, 79-107.

Davies, G.R., 1970: Carbonate bank sedimentation, eastern Shark Bay, western Australia. AAPG Memoir **13**, 85-168.

Davies, G.R., 1977; Turbidites, debris sheets, truncation structures in Upper Paleozoic deep-water carbonates of the Sverdrup Basin, Arctic Archipelago. In: Deep Water Carbonate Environments, H.E. Cook and P. Enos (eds.). SEPM Special Publication **25**, 221-247.

Davies, I.C. and Walker, R.G., 1974: Transport and deposition of resedimented conglomerates: the Cap Enrage Formation, Cambro-Ordovician, Gaspe; Quebec. Journal of Sedimentary Petrology, **44**, 1200-1216.

Debrois, E.J., Lagier, Y. et Souquet, P., 1983: Turbidites calcaires exceptionelles dans le flysch turono-conacien du versant nord des Pyrénees occidentales. Bulletin Societe geol. France, **25**, 911-919.

Dickson, J.A., 1966: Carbonate identification and genesis as revealed by staining. Journal of Sedimentary Petrology, **36**, 491-505.

Druce, E.C., 1973: Upper Paleozoic and Triassic conodont distribution and the recognition of biofacies. In: F.H.T. Rhodes (ed.). Conodont paleozoology. Geological Society of America Special Paper **141**, 191-237.

Dunham, R.J., 1962: Classification of carbonate rocks according to depositional texture. AAPG Memoir **1**, 108-121.

Dzik, J., 1976: Remarks on the evolution of Ordovician conodonts. Acta Palaeontologica Polonica, **21**, 395-455.

Dzik, J., 1978: Conodont biostratigraphy and paleogeographical relations of the Ordovician Mojcza Limestone (Holy Cross Mountains, Poland). Acta Palaeontologica Polonica, **23**, 51-72.

Dupont, E., 1892: Les Iles coralliennes de Roly et de Philippeville. Museum Royale d'Histoire Naturelles, Bulletin, **1**, 89-160.

Edhorn, A.-St. and Anderson, M.M., 1977: Algal remains in the Lower Cambrian Bonavista Formation, Conception Bay, SE Newfoundland. In: E. Flügel (ed.) Fossil Algae, p. 113.

Ekdale, A.A., Bromley, R.G. and Pemberton, S.G., 1984: Ichnology: trace fossils in sedimentology and stratigraphy. SEPM, Short Course **15**, 317 pp.

Embry, A.F. and Klovan, J.E., 1972: Absolute water depth limits of late Devonian paleecological zones. Geologische Rundschau, **61**, 672-686.

Enos, P., 1977: Tamabra Limestone of the Poza Rica Trench, Cretaceous, Mexico. In: H.E. Cook and P. Enos (eds.). Deepwater carbonate environments: SEPM Special Publication **25**, 273-314.

Epstein, J.B., Epstein, A.G., and Bergström, S.M., 1972: Significance of Lower Ordovician exotic blocks in the Hamburg Klippe, eastern Pennsylvania. U. S. Geological Survey Professional Paper **800-D**, D29-D36. Washington.

Epstein, A.G., Epstein, J.B., and Harris, L., 1977: Conodont color alteration - an index to organic metamorphism. U.S. Geological Survey Professional Paper **995**, 1-27.

Erdtmann, B.-D., 1971: Ordovician graptolite zones of western Newfoundland in relation to paleogeography of the North Atlantic; Geological Society of America Bulletin, **82**, 1509-1528.

Ethington, R.L., 1972: Lower Ordovician (Arenigian) conodonts from the Pogonip Group, Central Nevada. In: Lindström, M. and Ziegler, W. (eds.): Symposium on Conodont Taxonomy. Geologica et Palaeontologica **SB-1**, 17-27. Marksburg.

Ethington, R.L., and Clark, D.L., 1964: Conodonts from the El Paso Formation (Ordovician) of Texas and Arizona. Journal of Paleontology, **38**, 685-704.

Ethington, R.L., and Clark, D.L., 1971: Lower Ordovician conodonts in North America. Geological Society of America, Memoir **127**, 63-82.

Ethington, R.L. and Clark, D.L., 1981: Lower and Middle Ordovician Conodonts from the Ibex Area Western Millard County, Utah. In: Brigham Young University Geology Studies, **28**, part 2, 159 pp.

Ethington, R.L., and Repetski, J.E., 1984: Paleobiogeographic distribution of Early Ordovician conodonts in central and western United States. In: D.L. Clark (ed.), Conodont Biofacies and Provincialism. Geological Society of America, Special Paper, p.89-102.

Fahraeus, L. E., 1970: Conodont-based correlations of Lower and Middle Ordovician strata in western Newfoundland. Geological Society of America, Bull. **81**, 2061-2076. Boulder.

Fahraeus, L.E., 1976: Conodontophorid ecology and evolution related to global tectonics. In: C.R. Barnes (ed.). Paleoecology. Geological Association of Canada, Special Paper, **15**, 12-26.

Fahraeus, L.E., 1977: Isocommunities and correlation of the North American *Didymograptus bifidus* Zone (Ordovician). Newslet. Stratigr. **6**, 85-96.

Fahraeus, L. and Nowlan, G.S, 1978: Franconian (Late Cambrian) to Early Champlainian (Middle Ordovician) conodonts from the Cow Head Group, western Newfoundland. Journal of Paleontology, **52**, 444-471.

Fahraeus, L.E., Slatt, R.M. and Nowlan, G.S., 1974: Origin of carbonate pseudopellets; Journal of Sedimentary Petrology, **44**, 27-29.

Fleming, J.M., 1970: Petroleum exploration in Newfoundland and Labrador Newfoundland Department of Mines, Agriculture and Resources, Mineral Resources Report No. 13, 118 pp.

Flügel, E., 1978: Mikrofazielle Untersuchungsmethoden von Kalken. Springer Verlag, Berlin, Heidelberg.

Flügel, E. and Steiger, T., 1981: An Upper Jurassic sponge-algal buildup from the Northern Frankenalb, West Germany. In: D.F. Toomey (ed.). European fossil reef models. SEPM Special Publication, **30**, 371-397.

Folk, R.L., 1962: Spectral subdivision of limestone types. AAPG Memoir **1**, 62-84.

Folk, R.L., 1974: Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas, 182 pp.

Fortey, R.A., 1975: Early Ordovician trilobite communities; Fossils and Strata, **4**, 339-360.

Fortey , R.A., 1979: Early Ordovician trilobites from the Catoche Formation (St. George Group), western Newfoundland. Geological Survey of Canada, **321**, 61-114.

Fortey, R.A., Landing, D., and Skevington, D., 1982: Cambrian - Ordovician boundary sections in the Cow Head Group. In: M.G. Basset and W.T. Dean (eds.). The Cambrian - Ordovician boundary: sections, fossil distributions, and correlations. National Museum of Wales, Geological Series, **3**, 95-129.

Fortey, R.A., and Barnes, C.R., 1977: Early Ordovician conodont and trilobite communities of Spitsbergen: Influence on biogeography. Alcheringa, **1**, 297-340.

Fortey, R.A. and Skevington, D., 1980: Correlation of Cambrian - Ordovician boundary between Europe and North America: new data from western Newfoundland. Canadian Journal of Earth Scinces, **17**, 382-388.

Fraenkel, L. and Meade, D.J., 1973: Mucilaginous matrix of some estuarine sands of Connecticut. Journal of Sedimentary Petrology, **43**, 1090-1095.

Freeman-Lynde, R.P., 1979: Defacement of the Bahama Escarpment: EOS, **60**, 286.

Frey, R.W., 1973: Concepts in the study of biogenic structures. Journal of Sedimentary Petrology, **43**, 6-19.

Fuchtbauer, H. and Richter, D.K., 1983: Carbonate internal breccias: a source of mass flows at early geosynclinal platform margins in Greece. SEPM Special Publication, **33**, 207-215.

Furnish, W.M., 1938: Conodonts from the Prairie du Chien beds of the Upper Mississippi Valley. Journal of Paleontology, **12**, 318-340.

Gaetani, M., Fois, E., Jadqoul, F., and Nicora, A., 1981: Nature and evolution of Middle Triassic carbonate buildups in the dolomites (Italy). In: M.B. Cita and W.B.F. Ryan (eds.). Carbonate Platforms of the Passive-Type Continental Margins, Present and Past. Marine Geology, **44**, 25-57.

Garret, P., 1970: Phanerozoic stromatolites, non-competitive ecologic restriction by grazing and burrowing animals. Science, **169**, 171-173.

Garwood, E.J., 1931: The Tuedian beds of northern Cumberland and Roxburgshire east of the Liddel water. Geological Society of London, Quarterly Journal, **87**, 97-159.

Ginsburg, R.N. and Lowenstam, H.A., 1958: The influence of marine bottom communities on the depositional environment of sediments. Journal of Geology, **66**, 310-318.

Gohn, G.S., 1976: Sedimentology, Stratigraphy and Paleogeography of lower Paleozoic Carbonate Rocks, Conestoga Valley, Southeastern Pennsylvania: Unpubl. PhD thesis, The University of Delaware, Newark Delaware, 315pp.

Graves, R. W., and Ellison, S. P., Jr., 1941: Ordovician conodonts of the Marathon Basin, Texas: University of Missouri School of Mines and Metallurgy, Bulletin, Technical Series, **14**, 1-16.

Guibault, J.P., Hubert, C. and Mamet, B., 1976: *Nuia* and *Halisis*, deux algues Ordoviciennes enigmatiques des Basses-Terres du Saint-Laurent. Naturaliste canadien. **103**, 119-132.

Gwinner, M.P., 1976: Origin of the Upper Jurassic limestones of the Swabian Alb (Southwest-Germany). Contributions to Sedimentology, 5, 1-75.

Hadding, A.R., 1913: Undre dicellograptusskiffern i Skane jämte nagra därmed ekvivalenta bildningar. Lunds Univ. Arsskr. N.F. Avd. 2, 9:15, 1-90.

Halley, R.B., Harris, P.M., and Hine, A.C., 1983: Bank Margin. In: Scholle, P.A., Bebout, D.G., and Moore, C.H., (eds.). Carbonate Depositional Environments., AAPG Memoir, p. 463.

Hampton, M.A., 1972: Transport of oceanic sediments by debris flow [abs.]. AAPG Bulletin **56**, 622.

Harland, W.B. and Gayer, R.A., 1972: The Arctic Caledonides and earlier oceans. Geological Magazine, **109**, 289-314.

Harris, R.W., 1962: New conodonts from the Joins (Ordovician) Formation of Oklahoma: Oklahoma Geology Notes, **22**, 199-211.

Harris, A.G., Bergström, S.M., Ethington, R.L., and Ross, R.J., Jr., 1979: Aspects of Middle and Upper Ordovician conodont biostratigraphy of carbonate facies in Nevada and Southeast California and comparison with some Appalachian successions. In: C.A. Sandberg and D.L. Clark (eds.): Conodont biostratigraphy of the Great Basin and Rocky Mountains. Brigham Young University Geology Studies **26**, 7-43.

Harris, A.G. and Repetski, J.E., 1982; Conodonts across the Lower - Middle Ordovician boundary - U.S. Appalachian Basin: Maryland to New York. In: L. Jeppson and A. Löfgren (eds.). Third European Conodont Symposium (ECOS III) Abstracts: Institutes of Mineralogy, Paleontology and Quaternary Geology, University of Lund, Sweden, Publication **238**, p. 13.

Hawley, D., 1957: Ordovician shales and submarine slide breccias of northern Champlain Valley in Vermont. Geological Society of America Bulletin **68**, 55-94.

Haywick, D.W, 1985: Dolomite within the St. George Group (Lower Ordovician), western Newfoundland. M.Sc. thesis, Memorial Univerity of Newfoundland, St. John's, Newfoundland.

Haywick and James, in press: Multiple dolomitization and epigenetic overprinting: St George Group (Early Ordovician), western Newfoundland, Canada. Journal of Sedimentary Petrology.

Hein, J.H. and Walker, R.G., 1982: The Cambro-Ordovician Cap Enrage Formation, Quebec, Canada: conglomeratic deposits of a braided submarine channel with terraces. Sedimentology **29**, 309-329.

Helwig, J., 1975: Tectonic evolution of the southern continental margin of North America from a Paleozoic perspective. In: A.E. Nairn and Stehli, F.G. (eds.). The ocean basins and margins, pp. 243-255.

Hendry, H.E., 1973: Sedimentation of deep water conglomerates in Lower Ordovician of Quebec - composite bedding produced by progressive liquefaction of sediment. Journal of Sedimentary Petrology, **43**, 125-136.

Hendry, H.E., 1976: The orientation of discoidal clasts in resedimented conglomerates, Cambro-Ordovician, Gaspe, eastern Quebec. Journal of Sedimentary Petrology, **46**, 48-55.

Hendry, H.E., 1979: Grosses Roches - Early Ordovician mid-fan conglomerates and sandstones. In: G.V. Middleton et al., (eds.). Cambro-Ordovician submarine Channels and Fans, L'Islet to Sainte-Anne-de-Monts, Quebec. Geological Association of Canada, Fieldtrip Guidebook **A-6**, Quebec City.

Hill, P.R., Aksu, A.E., and Piper, J.W., 1982: The deposition of thin bedded subaqueous debris flow deposits. In: S. Saxov and J.K. Nieuwenhuis (eds.). Marine slides and other mass movements, pp.273-287.

Hjne, A.C., Wilber, R.J. and Neumann, A.C., 1981: Carbonate sand bodies along contrasting shallow-bank margins facing open seaways; northern Bahamas. AAPG Bulletin, **65**, 261-290.

Hintze, L.F., 1951: Lower Ordovician detailed stratigraphic sections from western Utah. Utah Geological and Mineralogical Survey, Bulletin **39**, 99 pp.

Hintze, L.F., 1952: Lower Ordovician trilobites from western Utah and eastern Nevada. Utah Geological and Mineralogical Survey, Bulletin **48**, 249pp.

Hiscott, R. and James, N.P., 1985: Carbonate debris flows, Cow Head Group, western Newfoundland. Journal of Sedimentary Petrology, **55**, 735-745.

Hoffmann, P.F., 1968: Stratigraphy of the Lower Proterozoic (Aphebian), Great Slave Supergroup, East Arm of Great Slave Lake, District of MacKenzie, Geological Survey of Canada, Paper **68**, 42.

Hopkins, J.C., 1977: Production of foreslope breccia by differential submarine cementation and downslope displacement of carbonate sands, Miette and Ancient Wall buildups, Devonian, Canada. SEPM Special Publication **25**, 155-170.

Howard, J.D., 1978: Sedimentology and Trace Fossils. SEPM Short Course No. 5, 11-42.

Hubert, C., Lajoie, J. and Leonard, M.A., 1970: Deep sea sediments in the lower Paleozoic Quebec Supergroup. In: J. Lajoie (ed.), Flysch sedimentology in North America. Geological Association of Canada, Special Paper, **7**, 103-125.

Hubert, J.F., Suchecki, R.K. and Callahan, R.K.M., 1977: The Cow Head Breccia: Sedimentology of the Cambro-Ordovician continental margin. SEPM Special Publication **25**, 125-154.

Hunter, D.R., 1978: Conodonts from the Cobbs Arm Formation (Middle

Ordovician) north-central Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's Newfoundland, 180 pp.

Jaanusson, V., 1976: Faunal dynamics in the Middle Ordovician of Balto-Scandia. In: M.G. Basset (ed.). The Ordovician System, Proceedings of a Paleontological Association Symposium, Birmingham, September, 1974, p. 301-326.

Jaanusson, V., 1978: Ordovician Meiklejohn carbonate mound, Nevada. Geological Magazine, **115**, 467-468.

Jaanusson, V., 1979: Ordovician. In: R.A. Robinson and C. Teichert (eds.). Treatise on invertebrate paleontology, Part A, Introduction, Geological Society of America (and University of Kansas Press), p. 136-166.

Jackson, A., 1986: Ice Island lab shows petroleum potential. Geos, **2**, 1-4.

James, N.P., 1981: Megablocks of calcified algae in the Cow Head Breccia, western Newfoundland: Vestiges of a Cambro-Ordovician platform margin. Geological Society of America Bulletin, **92**, 799-811.

James, N.P. and Stevens, R.K., 1982: Excursion 2B: Anatomy and evolution of a Lower Paleozoic continental margin, western Newfoundland. Field Excursion Guidebook, 11th International Congress on Sedimentology, Hamilton, Ontario, 75 pp.

James, N.P. and Stevens, R.K., 1986: Stratigraphy and correlation of the Cambro-Ordovician Cow Head Group, western Newfoundland. Geological Survey of Canada Bulletin **366**, 143 pp..

James, N.P., Stevens, R.K., and Fortey, R.A., 1979: Correlation and timing of platform margin megabreccia deposition, Cow Head and related groups, western Newfoundland. AAPG Bulletin, **63**, 508.

James, N.P., Botsford, J.W., and Williams, S.H., in press: Allochthonous slope sequence at Lobster Cove Head: evidence for a complex Middle Ordovician platform margin in western Newfoundland. Canadian Journal of Earth Science.

James, N.P., Stevens, R.K., Barnes, C.R., and Knight, I., in press: Evolution of a Lower Paleozoic continental margin carbonate platform, Northern Canadian Appalachians. In: P.D. Crevello et al. (eds.). Controls on Carbonate Platform and Basin Development. SEPM Special Publication.

Jansa, L.F., 1974: Trace fossils from the Cambro-Ordovician Cow Head Group, Newfoundland, and their paleobathymetric implications; Paleogeography, Paleoclimatology, Paleoecology, **15**, 233-244.

Jindrich, V., 1969: Recent carbonate sedimentation by tidal channels in the Lower Florida Keys. Journal of Sedimentary Petrology, **39**, 5-53.

Johnson, A.M., 1970: Physical processes in Geology. San Francisco. Freeman, 577 pp.

Johnson, H., 1941: Paleozoic lowlands of northwestern Newfoundland; The New York Academy of Sciences, Transactions, Series II, **3**, 141-145.

Johnson, J.H., 1966: The late Cambrian algal genus *Nuia* from Brewster County, Texas. Journal of Paleontology, **40**, 433-434.

Johnson, B.A. and Walker, R.G., 1979: Paleocurrents and depositional environments of the deep water conglomerates in the Cambr-Ordovician Cap Enrage Formation, Quebec Appalachians. Canadian Journal of Earth Sciences, **16**, 1375-1387.

Johnston, D.I., 1987: Early Ordovician (Arenig) conodonts from St. Pauls Inlet and Martin Point, Cow Head Group, western Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's Newfoundland, 226 pp.

Joysey, K.A., 1959: Probable cirripede, phoronid and echiuroid burrows within a Cretateous echinoid test. Paleontology, **1**, 397-400.

Keen, C.E., et al., 1986: Deep seismic reflection profile across the northern Appalachians. Geology, **14**, 141-145.

Keen, C.E., et al., 1987: Reply on "Deep seismic reflection profile across the northern Appalachians". Geology **15**, 182-183.

Keith, B.D. and Friedman, 1977: Slope-fan-basin model, Taconic sequence Journal of Sedimentary Petrology, **47**, 1220-1241.

Kenna, K., 1986: Upper Canadian to Whiterock conodonts of the upper St. George Group, western Newfoundland. Canadian Paleontology and Biostratigraphy Seminar. Paleontology Division, Geological Association of Canada, Quebec City. Program with Abstracts, p. 11.

Kennedy, D.J., 1980: A restudy of conodonts described by Branson and Mehl, 1933, from the Jefferson City Formation, Lower Ordovician, Missouri. Geologica et Palaeontologica, **14**, 45-76.

Kindle, C.H., 1982: The C.H. Kindle Collection: Middle Cambrian to Lower Ordovician trilobites from the Cow Head Group, western Newfoundland. In Current Research, Part C, Geological Survey of Canada, Paper 82-1C, p. 1-17.

Kindle, C.H., and Whittington, H.B., 1958: Stratigraphy of the Cow Head region, western Newfoundland. Geological Society of America, Bulletin, **69**, 315-342.

Kindle, C.H., and Whittington, H.B., 1959: Some stratigraphic problems of the Cow Head area in western Newfoundland. The New York Academy of Sciences, Transactions, **22**, 7-18.

King, P.B., 1937: Geology of the Marathon Region: U.S. Geological Survey, Professional Paper **187**, 148pp.

King, P.B., 1975: The Ouachita and Appalachian Orogenic belts. In: A.E. Nairn and Stehli, F.G. (eds.), The ocean basins and margins, pp. 201-241.

Klappa, C.F., and James, N.P., 1980: Small lithistid sponge bioherms, early Middle Ordovician Table Head Group, western Newfoundland. Bulletin of Canadian Petroleum Geology, **28**, 425-451.

Klapper, G., et al., 1977: Catalogue of Conodonts, Volume III. W. Ziegler, (ed.), E. Schweitzerbart'sche Verlagsbuchhandlung. Stuttgart.

Klapper, G., et al., 1981: Catalogue of Conodonts, Volume IV. W. Ziegler, (ed.), E. Schweitzerbart'sche Verlagsbuchhandlung. Stuttgart.

Klement, K.W. and Toomey, D.F., 1967: Role of the blue-green alga *Girvanella* in skeletal grain destruction and lime-mud formation in the Lower Ordovician of West Texas. Journal of Sedimentary Petrology, **37**, 1045-1051.

Knight, I., 1977: The Cambrian - Ordovician platformal rocks of the Northern Peninsula, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report **77-8**, 27 pp.

Knight, I., 1978: Platformal sediments on the Great Northern Peninsula. Stratigraphic studies and geological mapping of the North St. Barbe District. In: Report of activities for 1977. V. Gibbons (ed.). Newfoundland Department of Mines and Energy, Mineral Development Division, Report **78-1**, 140-150.

Knight, I. and James, N.P., in press: Stratigraphy of the St. George Group (Lower-Middle Ordovician), western Newfoundland. Canadian Journal of Earth Sciences.

Krause, F. F., and Oldershaw, A. E., 1979: Submarine carbonate breccia beds - a depositional model for two-layer, sediment gravity flows from the Sekwi Formation (Lower Cambrian), Mackenzie Mountains, Northwest Territories, Canada: Canadian Journal of Earth Sciences, **16**, 189-199.

Lajoie, J., Heroux, Y., and Mathey, B., 1971: The Precambrian Shield and lower Paleozoic shelf: The unstable provenance of the lower Paleozoic flysch sandstones and conglomerates of the Appalachians between Beaumont and Bic, Quebec. Canadian Journal of Earth Science, **11**, 951-963.

Landing, E., 1976: Early Ordovician (Arenigian) conodont and graptolite biostratigraphy of the Taconic allochthon, eastern New York. Journal of Paleontology, **50**, 614-646.

Landing, E., 1986: Depositional tectonics and biostratigraphy of the western portion of the Taconic Allochthon, Eastern New York State. In: Preprint of the Canadian Paleontology and Biostratigraphy Seminar, Albany, New York, p. 181-209.

Landing, E. and Benus, A.P., 1985: The Lévis Formation: Passive margin slope processes and dynamic stratigraphy in the "western area". Canadian Paleontology and Biostratigraphy Seminar, Field excursions guidebook, J.F. Riva (ed.), Ste-Foy, Quebec, Canada, p.19.

Lash, G.G. and Drake, A.A. Jr., 1984: The Richmond and Greenwich Slices of the Hamburg Klippe in eastern Pennsylvania, stratigraphy, sedimentology and plate tectonic implications. U.S. Geological Survey Professional Paper **1312**.

Lee, Ha-Young, 1970: Conodonten aus der Choson Gruppe (Unteres Ordovizium) von Korea. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **136**, 303-344.

Leeder, M.R., 1973: Lower Carboniferous Serpulid Patch Reefs, Bioherms and Biostroms. Nature, **242**, 41.

Lees, A., 1964: The structure and origin of the Waulsortian (Lower Carboniferous) "reefs" of west-central Eire. Philosophical Transactions of the Royal Society of London, Series B, **247**, 483-531.

Lindström, M., 1955: Conodonts from the lowermost Ordovician strata of south central Sweden: Geologiska Föreningens i Stockholm Förhandlingar **76**, 517-604.

Lindström, M., 1964: Conodonts. Elsevier, New York, 196 pp.

Lindström, M., 1970: Faunal provinces in the Ordovician of the North Atlantic areas. Nature **225**, 1158-1159.

Lindström, M., 1971: Lower Ordovician conodonts of Europe: Geological Society of America, Memoir, **127**, 21-61.

Lindström, M., 1976: Conodont Provincialism and paleoecology - a few concepts. In: C.R. Barnes (ed.). Paleoecology. Geological Association of Canada Special Paper **15**, p.3-9.

Lindström, M., 1976a: Conodont paleogeography of the Ordovician. In: M.G. Basset (ed.). The Ordovician System: Proccedings of a Paleontological Association Symposium, Birmingham, September 1974, p. 501-522, Cardiff.

Lindström, M., 1977: see under Klapper, 1977.

Lock, B.E., 1972: Lower Paleozoic history of a critical area; eastern margin of the St. Lawrence Platform in White Bay, Newfoundland, Canada. 24th IGG - Section 6, 310-324.

Löfgren, A., 1978: Arenigian and Llanvirnian conodonts from Jämtland, northern Sweden. Fossils and Strata, **13**, 129 pp.

Löfgren, A., 1985: Early Ordovician conodont biozonation at Finngrundet, south Bothnian Bay, Sweden. Bulletin of the Geological Institutions of the University of Uppsala, N.S., **10**, 115-128.

Logan, W. E., 1863: Geology of Canada. Geological Survey of Canada, Report of its progress from its commencement to 1863, Montreal.

McCrossan, R.G., 1958: Sedimentary boudinage structures in the Upper Devonian Ireton Formation of Alberta. Journal of Sedimentary Petrology, **28**, 316-320.

McDaniel, P.N., and Pray, L.C., 1967: Bank to basin transition in Permian (Leonardian) carbonates, Guadalupe Mountains, Texas. In: G.M. Friedman (ed.), Depositional environments in carbonate rocks. SEPM Special Publication, **14**, 79.

McIlreath, I.A. and James, N.P., 1984: Carbonate slopes. In: Facies Models, R.G. Walker (ed.), Geoscience Canada, Reprint Series 1, 245-257.

McTavish, R. A., 1973: Prioniodontacean conodonts from the Emanuel Formation (Lower Ordovician) of Western Australia. Geologica et Palaeontologica **7**, 27-58.

McTavish, R.A. and Legg, D.P., 1976: The Ordovician of the Canning Basin, western Australia. In: D.A. Basset (ed.). The Ordovician System: Proceedings of a Paleontological Association Symposium, Birmingham, September 1974, p. 447-478, Cardiff.

Merrill, G.K., 1966: Pennsylvanian platform-type conodonts from the Appalachian Conemaugh [abs.]. Geological Society of America Special Paper **115**, 147-148.

Middleton, G.V. and Hampton, M.A., 1976: Subaqueous sediment transport and deposition by sediment gravity flows. In: D.J. Stanley and D.J.P. Swift (eds.):

Marine sediment transport and Environmental Management, p. 197-218, New York, Wiley.

Monty, Cl., 1967: Distribution and structure of recent stromatolitic algal mats. Eastern Andros Island, Bahamas. Annales. Societe Geologique de Belgique. Memoires, **90**, 55-100.

Moskalenko, T.A., 1973: Conodonts of the Middle and Upper Ordovician of the Siberian Platform: Akademiya Nauk SSSR, Sibirskoie Otdelenie, Instituta Geologii i Geofiziki Trudy, vyp. 137, 143 pp.

Mountjoy, E.W. and Playford, P.E., 1972: Submarine megabreccia debris flows and slumped blocks of Devonian of Australia and Alberta: a comparison [abs.]. AAPG Bulletin, **56**, 641.

Mountjoy, E.W., Cook, H.E., Pray, L.C., and McDaniel, P.N., 1972: Allochthonous carbonate debris flows - worldwide indicators of reef complexes, banks or shelf margins; 24th International Geological Congress, Section 6, 172-189.

Müller, K.J., 1962: Zur systematischen Einteilung der Conodontophorida. Paläontologische Zeitschrift, **36**, 109-117.

Müller, K. J., 1964: Conodonten aus dem unteren Ordovizium von Südkorea. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, **119**, p. 93-102.

Müller, K.J., 1973: Late Cambrian and Early Ordovician conodonts from northern Iran. Geological Survey of Iran, Report **30**, 77 pp.

Mullins H.F., Neumann, A.C., Wilber, R.J., and Boardman, M.R., 1980: Nodular carbonate sediment on Bahaman slopes: possible precursors to nodular limestones. Journal of Sedimentary Petrology, **50**, 117-131.

Mullins, H.F., Gradulski, A.F., and Hine, A.C., 1986: Catastrophic collapse of the west Florida carbonate platform margin. Geology, **14**, 167-170.

Mullins, H.F., Heath, K.C., Van Buren, M., and Newton, C.R., 1986: Anatomy of a modern open-ocean carbonate slope: northern Little Bahama Bank. Sedimentology, **31**, 141-168.

Mutti, E., Ricci-Lucchi, F., Seguret, M., and Zanzucchi, G., 1984: Seismoturbidites: A new group of resedimented deposits. Marine Geology, **55**, 103-116.

Nelson, S.J., 1955: Geology of Portland Creek, Port Saunders area, west coast. Geological Survey of Newfoundland, Report 7, 58 pp.

Neumann, A.C., Gebelein, C.D., and Scoffin, T.P., 1970: The composition, structure and erodability of subtidal mats, Abaco, Bahamas. Journal of Sedimentary Petrology, **40**, 274-297.

Neumann, A.C., Keller, G.H., and Kofoed, J.W., 1972: "Lithoherms" in the Straights of Florida. Geological Society of America, Abstract Programs, **6**, 611.

Neuman, R.B., 1984: Geology and paleobiology of islands in the Ordovician Iapetus Ocean: Review and implications. Geological Society of America, Bulletin **95**, 1188-1201.

Newell, N.D., Purdy, E.G. and Imbrie, J., 1960: Bahamian oolithic sand. Journal of Geology, **68**, 481-497.

Nicholson, H.A. and Etheridge, R., 1878: A Monograph of the Silurian Fossils of the Girvan District in Ayrshire. Edinburgh, London: Blackwood. 135 pp.

Nitecki, M.H., 1969: Algal nature of calathids. 11th International Botanical Congress, Abstracts, p.159.

Nowlan, G.S., 1974: Conodonts from the Cow Head Group, western Newfoundland. M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 78 pp.

Nowlan, G.S., 1976: Late Cambrian to Late Ordovician conodont evolution and biostratigraphy of the Franklinian Miogeosyncline, eastern Canadian Arctic Islands. Unpublished Ph.D. thesis, University of Waterloo, Waterloo, Ontario, 590 pp.

Nowlan, G.S. and Barnes, C.R., 1987: Thermal maturation of Paleozoic strata in eastern Canada from conodont alteration index (CAI) with implications for burial history, tectonic evolution, hotspot tracks and mineral and hydrocarbon exploration. Geological Survey of Canada, Bulletin, **367**, 47 pp.

Oxley, P., 1953: Geology of the Parsons Pond-St. Pauls area, west coast, Newfoundland Geological Survey, Report No. 5, 53 pp..

Palmer, A.R., DeMis, W.D., Muehlberger, W.R., Robison, R.A., 1984: Geological implications of Middle Cambrian boulders from the Haymond Formation (Pennsylvania) in the Marathon Basin, west Texas. Geology, **12**, 91-94.

Pander, C.H., 1856: Monographie der fossilen Fische des silurischen Systems der russisch-baltischen Gouvernements. Buchdruckerei der Kaiserlichen Akademie der Wissenschaften, St. Petersburg, 91 pp.

Paquette, J., 1986: Diagenetic history of the Levis conglomerates, Quebec. GAC, MAC, CGU-AGC, AMC, UCG Joint Annual Meeting. Program with Abstracts, p.11. Carleton University, Ottawa.

Parsch, K.O.A., 1956: Die Serpuliden-Fauna des Südwestdeutschen Jura. Palaeontographica, **7**, Part A, 211-240.

Paull, C.K. and Dillon, W.P., 1980: Erosional origin of the Blake Escarpment: An alternative hypothesis. Geology, **8**, 538-542.

Peryt, T.M., 1974: Spirorbid-algal stromatolites. Nature, **249**, 239-240.

Pfeil, R. W., and Read, J. F., 1980: Cambrian platform margin facies, Shady Dolomite, Southwestern Virginia, U.S.A., Journal of Sedimentary Petrology, **50**, 91-116.

Philcox, M.E., 1963: Banded calcite mudstone in the Lower Carboniferous "reef" knolls of the Dublin Basin, Ireland. Journal of Sedimentary Petrology, **33**, 904-913.

Pia, J., 1927: Thallophyta. In: M. Hirmer (ed.). Handbuch der Paläobotanik **1**, 31-136. München-Berlin.

Pickering, K., Stow, D., Watson, M. and Hiscott, R., 1986: Deep-water Facies, Processes and Models: A Review and Classification Scheme for Modern and Ancient Sediments. Earth-Science Reviews, **23**, 75-174.

Pitcher, M., 1964: Evolution of Chazyan (Ordovician) reefs of eastern United States and Canada. Bulletin of Canadian Petroleum Geology, 2b[12], 632-691.

Playford, P.E., 1984: Platform margin and marginal slope relationships in Devonian reef complexes of the Canning Basin. In: Purcell, P.G. (ed.). The Canning Basin, Geological Society of Australia, Proceedings/Petroleum Exploration Society of Australia Symposium, p. 189-214.

Pohler, S.L., Barnes, C.R. and James, N.P., 1987: Reconstructing a lost faunal realm: conodonts from the Ordovician Cow Head Group, western Newfoundland. In: R. Austin (ed.). Conodonts: Investigative Techniques and Applications. British Micropalaeontological Society Series, p. 341-362.

Pratt, B.P., 1979: The St. George Group (Lower Ordovician), western Newfoundland: Sedimentology, diagenesis and cryptalgal structures (M. Sc. thesis): Memorial University of Newfoundland, St. John's, Newfoundland, 214 pp.

Pratt, B.R., 1982: Stromatolitic framework of carbonate mudmounds. Journal of Sedimentary Petrology, **52**, 1203-1227.

Pratt, B.R., 1984: *Epiphyton* and *Renalcis* - Diagenetic microfossils from calcification of coccoid blue-green algae. Journal of Sedimentary Petrology, **54**, 948-971.

Pratt, B.R., and James, N.P., 1982: Cryptalgal-metazoan bioherms of early Ordovician age in the St. George Group, western Newfoundland. Sedimentology, **52**, 543-569.

Pray, L.C., Cook, H.E., Mountjoy, E.W., and McDaniel, P.N., 1967: Allochthonous carbonate debris flows at Devonian bank ("reef") margin, Alberta, Canada. [Abst.] International Symposium on the Devonian System, Alberta Society of Petroleum Geologists, Calgary.

Pray, L.C. and Stehli, F.G., 1962: Allochthonous origin, Bone Spring "Patch Reefs", West Texas. (Abst.), Geological Society of America, Special Paper **73**, 218-219.

Raymond, P.E., 1925: Some trilobites of the lower Middle Ordovician of eastern North America. Museum of Comparative Zoology, Bulletin **67**, 1-180.

Read, J.F., 1982: Geometry, facies, and development of Middle Ordovician carbonate buildups, Virginia Appalachians. AAPG Bulletin , **66**, 189-207.

Read, J.F., 1985: Carbonate platform facies models; AAPG Bulletin **69**, 1-21.

Reinhardt, J., 1974: Stratigraphy, sedimentology and Cambro-Ordovician paleogeography of the Frederick Valley, Maryland: Maryland Geological Survey, Report of Investigations, **23**, 74pp.

Remane, A., 1954: Wurm-Riffe am Tropenstrand. Natur und Folk (Frankfurt am Main), **84**, 177-183.

Repetski, J.E., 1982: Conodonts from El Paso Group (Lower Ordovician) of westernmost Texas and southern New Mexico. New Mexico Bureau of Mines and Mineral Resources Memoir **40**, 121 pp.

Repetski, J.E. and Ethington, R.L., 1977: Conodonts from graptolite facies in the Ouachita Mountains, Arkansas and Oklahoma. Arkansas Geological Commission Symposium on the Geology of the Ouachita Mountains. Volume 1. 92-106.

Repetski, J.E. and Ethington, R.L., 1983: *Rossodus manitouensis* (Conodonta), a new Early Ordovician index fossil. Journal of Paleontology, **57**, 289-301.

(R.O.C.C.) Research on Cretaceous Cycles Group, 1986: Rhythmic bedding in Upper Cretaceous pelagic carbonate sequences: Varying sedimentary response to climatic forcing. Geology, **14**, 153-156.

Rhodes, F.H.T., 1955: The conodont fauna of the Keisley Limestone. Geological Society of London Quarterly Journal, **11**, 117-142.

Richter, R., 1927: "Sandkorallen"-Riffe in der Nordsee. Natur und Museum, 49-62.

Riding, R., 1975: Problems of Affintiy of Paleozoic Calcareous Algae. In: E. Flügel (ed.), Fossil Algae, 202-211.

Riding, R., 1975a: *Girvanella* and other algae as depth indicators. Lethaia **9**, 173-179.

Riding, R. and Brasier, M.D., 1975: The earliest calcareous foraminifera. Nature, **257**, 833-8-18.

Riding, R. and Voronova, L., 1985: Morphological Groups and Series in Cambrian Calcareous Algae. In: D.F. Toomey and M.H. Nitecki (eds.). Paleoalgology.

Rigby, J.K., 1986: Sponges from the Cow Head Group and equivalent rocks in western Newfoundland. GAC, MAC, CGU-AGC, AMC, UCG Joint Annual Meeting, Program with Abstracts, p.11. Carleton University, Ottawa.

Rigby, J.K. and Toomey, D.F., 1978: A distinctive sponge spicule assemblage from organic buildups in the Lower Ordovician of southern Oklahoma. Journal of Paleontology, **52**, 501-506.

Rhoads, D.C., 1973: The influence of deposit-feeding benthos on water turbidity and nutrient recycling. American Journal of Science, **273**, 1-22.

Rodgers, J., 1968: The eastern edge of the North American continent during the Cambrian and Early Ordovician. In : Zen, E-an et al. (eds.) Studies of Appalachian Geology: Northern and Maritime. J. Wiley and Sons, p. 141-149.

Rodgers, J. and Neale, E.R.W., 1963: Possible "Taconic" klippen in western Newfoundland; American Journal of Science, **261**, 713-730.

Ross, R.J., Jr., 1951: Stratigraphy of the Garden City formation in northeastern Utah, and its trilobite faunas. Yale University, Peabody Museum, Bulletin **6**, 161 pp.

Ross, R.J., Jr., 1964: Relations of Middle Ordovician time and rock units in Basin Ranges, western United States. AAPG Bulletin **48**, 1526-1554.

Ross, R.J. Jr., 1972: Fossils from the Ordovician bioherm at Meiklejohn Peak, Nevada. U.S. Geological Survey Professional Paper, **685**, 47 pp.

Ross, J.R., Jr., 1976: Ordovician sedimentation in the western United States. In: M.G. Basset (ed.). The Ordovician System, Proceedings of a Paleontological Association Symposium, Birmingham, September, 1974, p. 73-106.

Ross, R.J., Jr., 1984: The Ordovician System, progress and problems. Annual Review of Earth and Planetary Sciences, **12**, 307-335.

Ross, R.J., Jr., Jaanusson, V., and Friedman, I., 1975: Lithology and origin of Middle Ordovician calcareous mudmound at Meiklejohn Peak, southern Nevada. U.S. Geological Survey Professional Paper **871**, 48 pp.

Ross, R.J., Jr. et al., 1982: The Ordovician System in the United States. International Union of Geological Sciences, Publication No. 12, 73 pp..

Ross, J.R., Jr. and James, N.P., 1987: Brachiopod biostratigraphy of the middle Ordovician Cow Head and Table Head groups, western Newfoundland. Canadian Journal of Earth Sciences, **24**, 70-95.

Ruedemann, R., 1947: Graptolites of North America. Geological Society of North America, Memoir **19**, 652pp.

Ruhrman, G., 1971: Riff-ferne Sedimetation unterdevonischer Krinoidenkalke im Kantabrischen Gebirge (Spanien). Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, **4**, 231-248.

Ruppel, S.C. and Walker, K.R., 1982: Sedimentology and distinction of carbonate buildups: Middle Ordovician, east Tennessee. Journal of Sedimentary Petrology, **52**, 1055-1071.

Rusnak, G.A., 1960: Sediments of Laguna Madre, Texas. In, Recent sediments, northwest Gulf of Mexico. AAPG Bulletin, Tulsa, 153-196.

Schindewolf, O.H., 1925: Einige Bemerkungen zur Entstehung der oberdevonischen Kramenzelgesteine. Zentralblatt für Mineralogie und Paläontologie B, **125**, 405-411.

Schlager, W., and James, N.P., 1978: Low magnesian calcite limestones, forming at the deep sea floor, Togue of the Ocean, Bahamas. Sedimentology, **25**, 675-702.

Schuchert, C. and Dunbar, C.O., 1934: Stratigraphy of western Newfoundland. Geological Society of America, Memoir **1**, 123 pp.

Schwarzacher, W., 1961: Petrology and structure of some Lower Carboniferous reefs in northwestern Ireland. AAPG Bulletin, **45**, 1481-1503.

Scientific Party, 1985: Ocean Drilling Program: Rise and fall of carbonate platforms in the Bahamas. Nature, **315**, 632-633.

Searle, M., and Stevens, R.K., 1984: Obduction processes in ancient, modern and future ophiolites. In: Ophiolites and Oceanic Lithosphere, I.G. Gass, S.J. Lipp, and A.W. Shelton (eds.). Geological Society of London, Special Publication **13**, 303-317.

Seddon, G. and Sweet, W. C., 1971: An ecologic model for conodonts. Journal of Paleontology **45**, 869-880. Tulsa.

Seilacher, A., 1964: Sedimentological classification and nomenclature of trace fossils. Sedimentology, **3**, 253-256.

Seilacher, A., 1984: Sedimentary structures tentatively attributed to seismic events. Marine Geology, **55**, 1-12.

Sellwood, B.W., 1978: Shallow-water Carbonate Environments. In: M.G. Reading (ed.): Sedimentary Environments and Facies. Blackwell, Oxford.

Sergeeva, S.P., 1963: Conodonts from the Lower Ordovician of the Leningrad region. Paleontologicheskii Zhurnal, **2**, 93-108.

Serpagli, E., 1974: Lower Ordovician conodonts from Precordilleran Argentina (Province of San Juan). Bolletino Societe Paleontologico Italiana, **13**, 17-93.

Shaw, A.B., 1958: Stratigraphy and structure of the St. Albans area, Northwestern Vermont. Geological Society of America, Bulletin, **69**, 519-568.

Spalletta, C. and Vai, G. B., 1984: Upper Devonian intraclast parabreccias interpreted as seismites. Marine Geology, **55**, 133-144.

Stanley, D.J., 1977: Post-Miocene depositional patterns and structural displacement in the Mediterranean. In: A.E.M. Nairn, W.H. Kanes and F.G. Stehli (eds.). The Ocean Margins and Basins, vol. 4A: The Eastern Mediterranean. New York, Plenum Press, 77-150.

Stanley, D.J., 1982: Welded slump-graded sand couplets: evidence for slide generated turbidity currents. Geo-Marine Letters, **2**, 149-155.

Stanley, D.J. and Unrug, R., 1972: Submarine Channel Deposits, Fluxoturbidites and other Indicators of Slope and Basin-of-Slope Environments in Modern and Ancient Marine Basins. In: J.K. Rigby and W.K. Hamblin. (eds.). SEPM Special Publication **16**, 287-340.

Stauffer, C.R., 1935: Conodonts of the Glenwood beds. Geological Society of America Bulletin, **46**, 125-168.

Stauffer, P.H., 1967: Grain-flow deposits and their implications, Santa Inez Mountains, California. Journal of Sedimentary Petrology **37**, 487-508.

Stevens, R.K., 1970: Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a Proto-Atlantic Ocean. In: J. Lajoie (ed.). Flysch sedimentology in North America. Geological Association of Canada, Special Paper **7**, 165-177.

Stone, C.G. and Stearling, P.G., 1962: New lithologic markers in Ordovician rocks, eastern Ouachita Mountains of Arkansas. AAPG Bulletin, **46**, 387-390.

Stouge, S.S., 1982: Preliminary conodont biostratigraphy and correlation of Lower and Middle Ordovician carbonates of the St. George Group, Great Northern Peninsula, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report **82-3**, 1-59.

Stouge, S. S., 1984: Conodonts of the Middle Ordovician Table Head Formation, western Newfoundland. Fossils and Strata, **16**, 145 pp.

Stouge, S.S., and Boyce, W.D., 1983: Fossils of northwestern Newfoundland and southeastern Labrador: conodonts and trilobites. Newfoundland Department of Mines and Energy, Mineral Development Division, Report **83-3**, 1-55.

Stricker, G.D. and Carozzi, A.V., 1973: Carbonate microfacies of Pogonip Group (Lower Ordovician) Arrow Canyon Range, Clark County, Nevada, U.S.A. Centre de Recherches de Pau, Bulletin, **7**, 499-541.

Suchecki, R.K., Perry, E.A., and Hubert, J.F., 1977: Clay petrology of Cambro-Ordovician continental margin, Cow Head Klippe, western Newfoundland. Clay and Clay Minerals, **25**, 163-170.

Surlyk, F., 1978: Submarine fan sedimentation along fault scarps on tilted fault blocks (Jurassic-Cretateous boundary, East Greenland). Gronlands Geologiske Undersogelse, **128**, 108 pp.

Sweet, W.C. and Bergström, S.M., 1962: Conodonts from the Pratt Ferry Formation (Middle Ordovician) of Alabama. Journal of Paleontology, **36**, 1211-1252.

Sweet, W.C. and Bergström, S.M., 1976: Conodont biostratigraphy of the Middle and Upper Ordovician of the United States. In: M.G. Basset (ed.), The Ordovician System, Proceedings of a Paleontological Association Symposium, Birmingham, September, 1974, p. 121-151.

Sweet, W.C. and Bergström, S.M., 1974: Provincialism exibited by Ordovician conodont faunas. In C.A. Ross (ed) Paleogeographic provinces and proviniciality. SEPM Special Publication **21**, 189-202.

Sweet, W.C., Ethington, R.L., and Barnes, C.R., 1971: North American Middle and Upper Ordovician conodont faunas. Geological Society of America, Memoir **127**, 163-193.

Sweet, W.C., Turco, C.A., Warner, Earl, and Wilkie, L.C., 1959: The American Upper Ordovician standard. I. Eden conodonts from the Cincinnati region of Ohio and Kentucky. Journal of Paleontology, **33**, 1029-1068.

Swett, Keene and Smitt, D.E., 1972: Paleogeography and depositional environments of the Cambro-Ordovician shallow marine facies of the North Atlantic. Geological Society of North America Bulletin, **83**, 3223-3248.

Swinchatt, J.P., 1965: Significance of constiuent composition, texture and skeletal breakdown in some Recent carbonate sediments. Journal of Sedimentary Petrology, **35**, 71-90.

Taylor, M.E., 1977: Late Cambrian of Western North America: trilobite biofacies, environmental significance, and biostratigraphic implications. In: E.G. Kauffman and J.E. Hazel (eds.). Concepts and Methods of Biostratigraphy. Stroudsburg, p. 397-425.

Tenore, K.R., 1977: Food chain pathways in detrital feeding benthic communities. In: B.C. Coull (ed.). Ecology of marine Benthos. University of South Carolina Press, Columbia. p. 37-55.

Textoris, D.A. and Carozzi, A.V., 1964: Petrography and evolution of Niagaran (Silurian) Reefs, Indiana. AAPG Bulletin **48**, 397-426.

Toomey, D.F., 1970: An unhurried look at a Lower Ordovician mound horizon, southern Franklin Mountains, west Texas, Journal of Sedimentary Petrology. **40**, 1318-1335.

Toomey, D.F., 1981: Organic-buildup comstructional capability in Lower Ordovician and late Paleozoic mounds. In: J. Gray et al. (eds.). Communities of the Past, p. 35-68, Hutchinson Ross Publications Co., Stroudsburg.

Toomey, D.F., and Cys, J.M., 1977: Spirorbid/algal stromatolites, a probable

marginal marine occurrence from the Lower Permian of New Mexico, U.S.A. Neues Jahrbuch für Geologie und Paläontologie, Monatshefte **6**, 331-342.

Toomey, D.F., and Nitecki, M.H., 1979: Organic buildups in the Lower Ordovician (Canadian) of Texas and Oklahoma: Fieldiana, new series, no.2, 181 pp.

Townson, W.G., 1975: Lithostratigraphy and deposition of the type Portlandian. Geological Society of London, Journal **31**, 619-638.

Troell, A.R., 1962: Lower Mississippian bioherms of southwestern missouri and northwestern Arkansas. Journal of Sedimentary Petrology, **32**, 629-644.

Tsien, H.H., 1985a: Algal-Bacterial Origin of Micrites in Mud Mounds. In: D.F. Toomey and M.H. Nitecki (eds.); Paleoalgology, p. 290-296.

Tsien, H.H., 1985b: Origin of Stromatactis - a Replacement of Colonial Microbial Accretions. In: D.F. Toomey and M.H. Nitecki (eds.); Paleoalgology, p. 274-289.

Tudhope, A.W. and Scoffin, T.P., 1984: The effects of *Callianassa* bioturbation on the preservation of carbonate grains in Davies Reef Lagoon, Great Barrier Reef, Australia. Journal of Sedimentary Petrology, **54**, 1091-1096.

Ueno, T. T. and Barnes, C. R., 1970. Conodonts from the Levis Formation (zone Ordovician), Levis, Quebec. In: Contributions to Canadian Paleontology. Geological Survey of Canada, Bulletin., **187**, 99-123.

Vail, P.R., Mitchum, R.M., and Thompson, S., III, 1977: Global cycles of relative changes of sea level. In: C.E. Payton (ed.). Seismic Stratigraphy - Applications to Hydrocarbon Exploration, AAPG Memoir, **26**, 83-92.

Van Wamel, W. A., 1974, Conodont Biostratigraphy of the Upper Cambrian

and Lower Ordovician of northwestern Oland, southeastern Sweden. Utrecht Micropalaeontological Bulletins, **10**, 1-125.

Viira, V., 1974: Ordovician conodonts of the east Baltic. Insitut Geologii Akademii Nauk Estonskoi SSR, Tallin, 142 pp.

Walker, K.R., 1974: Mud substrata. In: A.M. Ziegler et al. (eds.). Principles of Benthic Community Analysis. Sedimenta IV, Notes for a Short Course, 5.1-5.11.

Walker, K.R. and Alberstadt, L.P., 1975: Ecological succession as an aspect of structure in fossil communities. Paleobiology, **1**, 238-257.

Walker, K.R., and Diehl, W.W., 1986: The effect of synsedimentary substrate modification on the composition of paleocommunities: paleoecologic succession revisited. Palaios, **1**, 65-74.

Wallace, M.W., 1987: The role of internal erosion and sedimentation in the formation of stromatactis mudstones and associated lithologies. Journal of Sedimentary Petrology, **57**, 695-700.

Watson, A. J., 1903: Observations on the habits of the Onuphidae (Polychaete) and on the internal structures with which they fortify their homes : Liverpool Biological Society/Proceedings and Transactions, **17**, 303-318.

Webby, B.D., 1978: History of the Ordovician continental platform shelf margin of Australia. Geological Society of Australia, Journal, **25**, 41-63.

Webby, B.D., 1981 (comp. and ed.): The Ordovician System in Australia, New Zealand and Antarctica: Correlation Chart and Explanatory Notes. International Union of Geological Sciences, Publication **6**, 64 pp.

Whittington, H. B., 1963: Middle Ordovician trilobites from Lower Head, western Newfoundland. Bulletin of the Museum of Comparative Zoology, Harvard University, **132**, 277-441.

Whittington, H.B. and Kindle, C.H., 1969: Cambrian and Ordovician stratigraphy of western Newfoundland. In: M. Kay (ed.). North Atlantic Geology and Continental Drift. AAPG Memoir, **12**, 655-664.

Wiedenmayer, F., 1978: Modern sponge bioherms of the Great Bahama Bank. Eclogae Geologicae Helvetiae, **71**, 699-744.

Williams, H., 1975: Structural succession, nomenclature, and interpretation of transported rocks in western Newfoundland. Canadian Journal of Earth Sciences, **12**, 1874-1894.

Williams, H., 1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, **16**, 792-807.

Williams, H., James, N.P. and Stevens, R.K., 1985: Humber Arm Allochthon and nearby groups between Bonne Bay and Portland Creek, western Newfoundland; Current Research, Part A, Geological Survey of Canada, Paper **85-1A**, 399-409.

Williams, H., Quinn, L., Nyman, M., and Reusch, D.N., 1984: Geology of Lomond map area (12H/5), western Newfoundland. Geological Survey of Canada, Open File 1012.

Williams, H., and Stevens, R. K., 1974: The ancient continental margin of eastern North America, in Burk, C.A., and Drake, C.L., (eds.). The Geology of Continental Margins, New York, Springer-Verlag, p. 781-797.

Williams, S.H., 1986: Lower Ordovician Chronostratigraphy and Graptolite Biostratigraphy in eastern Canada. In: Preprint of the Canadian Paleontology and Biostratigraphy Seminar, Albany, New York, p. 172-179.

Williams, S.H., Boyce, W.D., and James, N.P., 1987: Graptolites from the Lower-Middle Ordovician St. George and Table Head groups, western

Newfoundland, and their correlation with trilobite, brachiopod, and conodont zones. Canadian Journal of Earth Sciences, **24**, 456-470.

Williams, S.H., and Stevens, R.K., in press: Lower Ordovician (Arenig) graptolites of the Cow Head Group, western Newfoundland. Palaeontographica Canadiana.

Wilson, J.L., 1954: Late Cambrian and early Ordovician trilobites from the Marathon uplift Texas. Journal of Paleontology, **28**, 249-285.

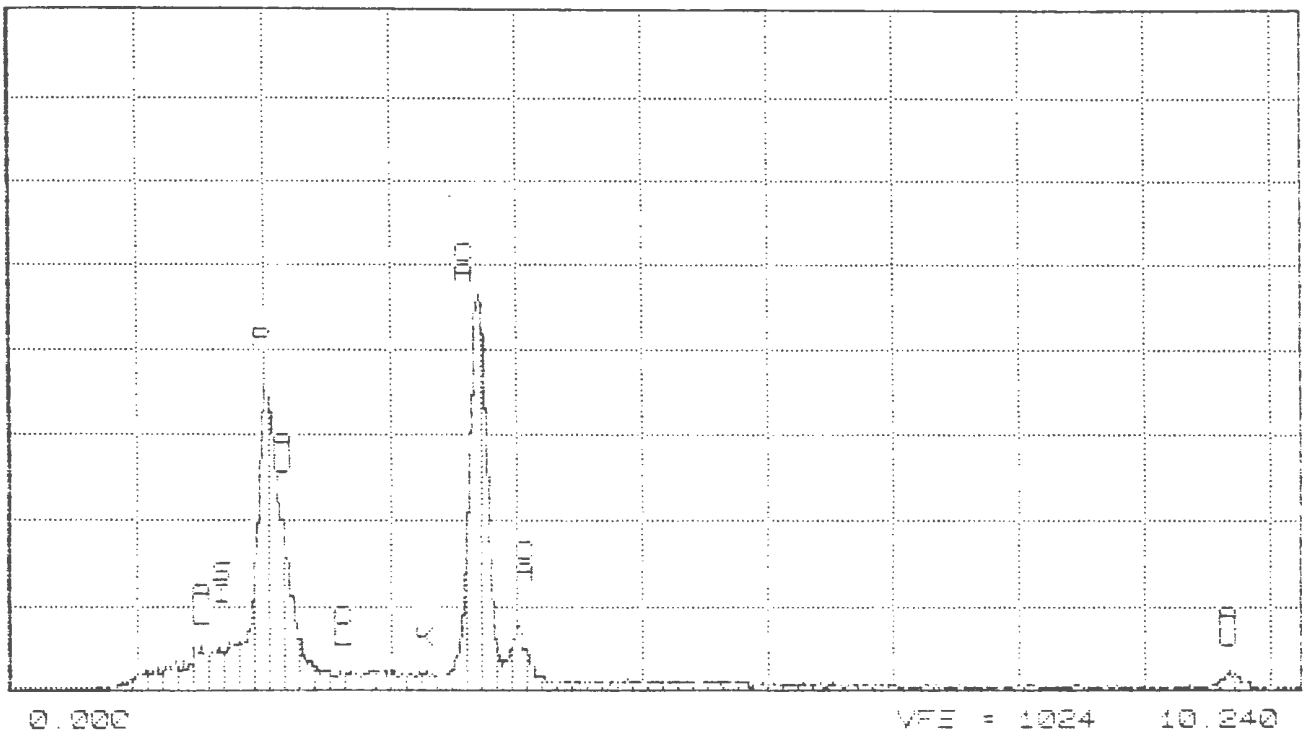
Wilson, J.L., 1975: Carbonate Facies in Geologic History; Springer Verlag, Berlin, Heidelberg, New York, 471 pp..

Young, L.M., 1970: Early Ordovician sedimentary history of the Marathon Geosyncline, Trans-Pecos, Texas. AAPG Bulletin, **54**, 2303-2316.

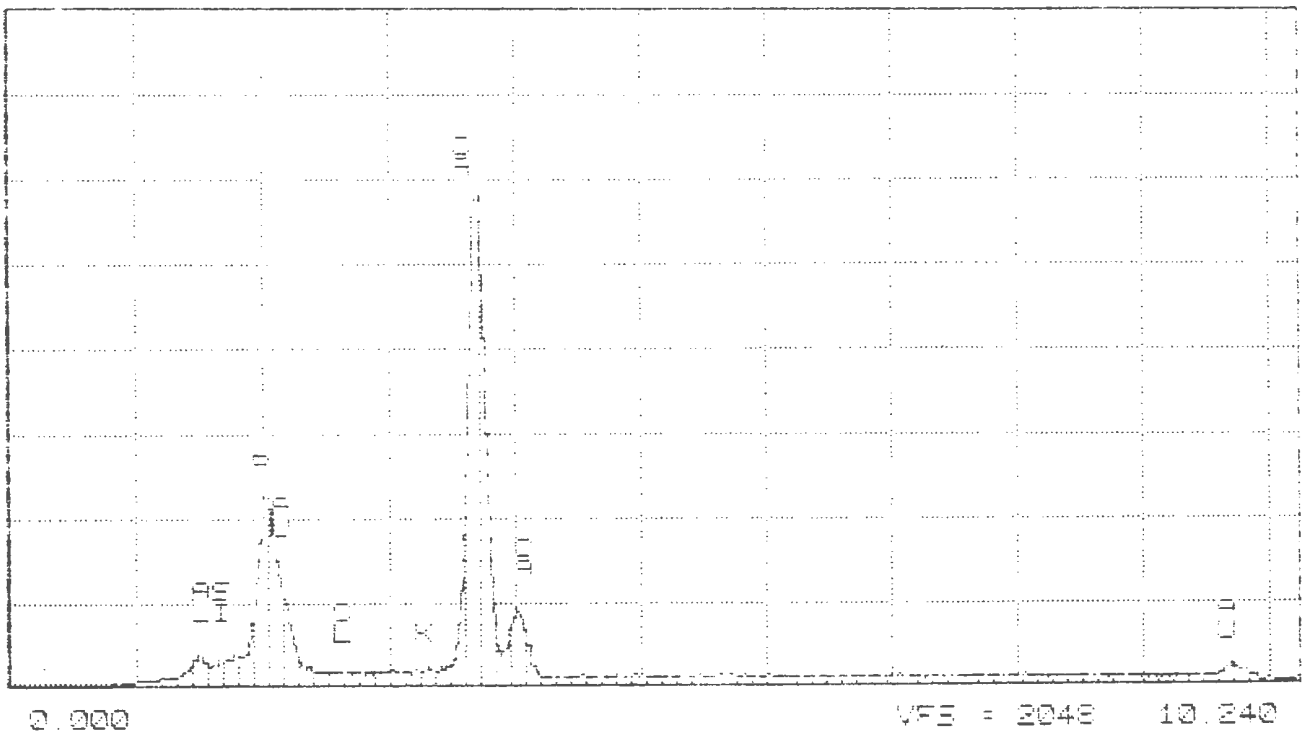
Zen, E-An, 1967: Time and space relationships of the Taconic Allochthon. Geological Society of America, Special Paper, **97**, 107 pp.

APPENDIX 5

COMPOSITION OF CONODONT MATRIX AND CONODONT OVERGROWTH ON SPECIMEN OF *PERIODON FLABELLUM*.



12 CONODONT MATRIX



50 CONODONT OVERGROWTH

APPENDIX 6

PREVIOUS WORK ON COW HEAD CONGLOMERATES

AUTHOR	REMARKS ON COW HEAD CONGLOMERATES
Richardson, in Logan, 1863, pp. 291-292	First report of the unusually large and abundant boulder beds in strata of the Cow Head region. He noted that "it is difficult to decide whether these are sediments deposited in the beds or enclosed transported masses, not withstanding that they are divided into beds with partings of black shale." Found fossils in both, conglomerates and bedded strata which were subsequently described by Billings (1865).
Raymond, 1925	Dated fossils from boulders which Schuchert and Dunbar had collected as equivalent to Table Head faunas.
Schuchert and Dunbar, 1934	Observed that the "phenomenal breccias" contain angular boulders of different kinds of limestone and dolomite of Upper Cambrian, Lower and early Middle Ordovician age partly preserved in form of "large rolled, jagged blocks" and "slab like masses". State that "in any one locality most of the blocks are of a single formation" and that clasts of crystalline sources and older rocks are lacking. Interpreted shale and limestone beds as large blocks. Concluded that conglomerates are tectonic in origin formed either as talus and land slides derived from a fault scarp or breccia in front of moving thrust sheets.
Johnson, 1941	Reported that "several horizons of breccia or intraformational conglomerates as well as the spectacular Cow Head breccia" are intercalated with Lower to Middle Ordovician limestone-shale-sandstone sequences in area between St. Pauls Inlet and Western Brook Pond. He is also credited with the idea of the allochthonous nature of the CHG.
Oxley, 1953	Recognized difficulty in correlating conglomerate horizons from place to place. Accepted tectonic origin of Cow Head conglomerates and suggests

that "thrust breccias" should be treated as tectonic phenomena not as "sedimentary rock units".

Nelson, 1955 — Examined sequence in Portland Creek area; stated that boulders in conglomerates are dominantly derived from one rock unit with very few from over- and underlying formations. Found that southern shore of Cow Head Peninsula is composed dominantly of "Lower Ordovician dolomite blocks" and that from Cow Head to Daniels Habour the "breccia is mainly composed of Table Head limestone." (Statement refers in part to Cape Cormorant Fm.). Suggests that earthquake shocks affecting semi-consolidated mud induced formation of some of the conglomerates but agreed generally with tectonic origin.

Kindle and Whittington, 1958 — Conducted a detailed paleontological study of the CHG at Cow Head, Lower Head and nearby localities and subdivided sequence informally into 14 units. Megaconglomerate horizons of Arenig age comprise beds 10, 12 and 14. Repeated that boulders within a single conglomerate are all of almost similar age and also equivalent to immediately underlying bedded sequence. Observed angular to subangular blocks set in muddy to rarely sandy matrix and report the presence of soft deformed blocks of interbedded limestones and shale and rare lumps of chert, shale and sandstone. Found that 1 in 30 boulders fossiliferous and collected abundant trilobites and brachiopods from these. Concluded that source of conglomerates was region of limestone deposition contributing oolites, calcarenites, calcisiltites, thin- and thickbedded porcellaneous limestone and unbedded masses of light coloured biohermal (?) limestone. Concluded that conglomerates are intraformational and were brought into place as landslides down submarine slopes.

Baird, 1960 — Distinguished four types of breccia:
1. Chaotic megabreccia,

	2. shingle breccia, 3. erratic boulder breccia, 4. common limestone breccia. Reports on nature of fragments and points out that within each conglomerate clasts come largely from same source, but that "different beds draw from different sources." Notes, however, that some breccias are made of "variety of limestones" such as a conglomerate he observed at St Pauls Inlet from which he describes lithographic limestone, dolomitic limestone, cherty limestone breccia, argillite, crossbedded arenaceous limestone and chert. From Lower Head he mentions "well rounded fragments of black highly petroliferous argillaceous limestone", chert and boulders of limestone breccia. Also noticed presence of well rounded frosted quartz grains in Cambrian conglomerates (=Bed 6).
Rodgers and Neale, 1963	Considered CHG allochthonous because of great facies contrast to platform carbonates. Concluded that source of conglomerates was to the west because coarsest megaconglomerates are confined to west.
Rodgers, 1968	Suggested that conglomerates were deposited in deeper water seaward from shallow carbonate platform margin and that shelfedge coincides with edge of cratonic basement. Compared setting with Bahama Bank margin and slope.
Whittington and Kindle, 1969	Attributed wide variety of different faunas they found in conglomerates and bedded sequence to different life positions on and above the slope before slumping and turbidity currents united the animal remains. Found trilobites of shallow water aspect together with Levis type faunas typical for carbonate mounds and buildups of shallow and intermediate depth and Atlantic Province genera which lived in deep water.
Fahraeus, 1970	Recognized Lower and Middle Ordovician conodont faunas from the Cow Head and Table Head groups.

	Agreed with correlations suggested by Kindle and Whittington (1958).
Stevens, 1970	Proposed that breccias were derived from "the oversteepened oceanward edge of a carbonate bank that provided detritus from the Middle Cambrian to the Middle Ordovician." Rationalized Humber Arm Super Group according to model of continental margin and its destruction.
Hubert, Suchecki and Callahan, 1977	Considered Cow Head breccia as deposits of gravity controlled viscous mass flows which travelled downslope from narrow carbonate platforms. Contributed grainstone caps on breccias to existence of bottom currents. Recognized that in most conglomerates clasts are similar to limestones interbedded with the breccias and that the shallow water derived clasts were lithified prior to incorporporation in the flow. Assume a peritidal origin for limestones with "birds-eye" structure and postulate that "many of the Cambrian and Ordovician shallow water limestone boulders are solution collapse breccia formed by karstification". Moldic porisity as a result of (vadose) solution of aragonitic fossils and ooids is also implied.
Fahraeus and Nowlan, 1978	First description of conodont faunas including few samples from clasts in conglomerates. Correlate faunas with Balto-Scandia.
James, Stevens and Fortey, 1979	Suggested that megabreccia deposition coincides with changes in shelf sedimentation an/or regressions.
Fortey and Skevington, 1980	Emphasized value of Cow Head fossils from mixed environments for international correlation.
James, 1981	Interpreted large boulders in megaconglomerates as redeposited fragments of algal buildups fringing a carbonate platform margin and points out that these marginal bioherms represent rarely preserved facies which is usually destroyed in orogenic events or by erosion. Mentions similarity to boulders from Levis Fm. (Quebec) and

	other localities around North American craton. Notes mixing of contemporaneous and younger clasts in chaotic proximal facies.
Hiscott and James, 1985	Distinguished 5 facies of conglomerate: Facies A: Grainy cobble to pebble conglomerates; Facies B: oligomict limestone plate conglomerate; Facies C: limestone chip conglomerate; Facies D: exotic boulder conglomerate; Facies E: chaotic megaconglomerate. Interprete megaconglomerates as emplacements of debris flows and calculate a paleoslope gradient between 1° and 15°. Ascribe increasing size of flows to progressive steepening of the carbonate platform margin.
Williams, James and Stevens, 1985	Produced modern map of the CHG, recognized E-W thrust repeated belts, proximal-distal facies, attempted first stratigraphic names, timing of deformation and structural analysis.
James and Stevens, 1986	Recognized proximal to distal facies belts with progressively finergrained conglomerates and increase of shale basinwards (SE). Mega-conglomerates are interpreted as most proximal facies. Described and measured CH rocks in detail and investigated sedimentology and paleontology. Compiled extensive faunal lists on trilobite and brachiopod faunas including faunas from boulders. Established formal stratigraphic nomenclature.
Ross and James, 1987	Reported on brachiopods from boulders of the Ordovician part of the CHG and concluded that they are entirely older than those from the Table Head Group.
Rigby, 1986	Observed archaeoscyphid sponges in Bed 10 and other anthaspidellid sponges in beds 10, 12 and 14.

APPENDIX 7

LOWER PALEOZOIC CONGLOMERATE FACIES OF THE APPALACHIANS

STUDY AND LOCALITY	DEPOSIT AND INTERPRETATION
ST. LAWRENCE VALLEY NAPPES	
Cap-Des Rosiers Fm. Lower Ordovician Quebec, Gaspe Peninsula Aalto, 1972	Flysch pebble conglomerate. Clasts: 98% carbonate, 2% shale; Matrix: suspension settling of sand; deposited on submarine slope adjacent to unstable margin. Interpretation: stratified gravel flow.
Grosses Roches Hendry, 1973, 1976, 1979	Compound conglomerates and turbidites. Clasts: up to 1m in size; Matrix: sandstone; Interpretation: deposition from gravity controlled slides or flows caused by progressive liquefaction.
Cap Enrage Fm. Cambro-Ordovician Gaspe, Quebec Hubert et al., 1970, Davies and Walker, 1974 Lajoie et al., 1974 Johnson and Walker, '79 Hein and Walker, 1982	Conglomerate derived from carbonate shelf to NW (similar to those at Levis-Lauzon, L'Islet Wharf, Grosses Roches). Clasts: 50% limestone, 20% sandstone, 30% other lithologies (granitoid rock fragments, chert), limestone boulders up to 2.5m across. Interpretation: submarine channel complex. channel 300m deep, 10km wide.
Levis Fm. Cambro-Ordovician Quebec Breakey, 1974 Landing and Benus, 1985 Paquette, 1986	Lenticular channel fill deposits, conglomerate sheets, megablock conglomerates. Clasts: derived from Grenville craton, carbonate platform, platform margin and slope. No evidence of meteoric diagenesis. Interpretation: proximal and distal turbidites and debris flows deposited on lower Paleozoic Appalachian continental margin.
Mystic Fm. Lower to Middle Ord. Berry, 1968 Barnes and Poplawski,	One or two conglomerate horizons within Philipsburg thrust slice. Clasts: limestone blocks up to 3.5m accross from edge of continental platform.

1973	Interpretation: similar to boulder beds of Levis Fm.
VERMONT	
St. Albans area Cambro-Ordovician Shaw, 1958	Mill River Conglomerate, Middle Cambrian and Rockledge Conglomerate, Middle Cambrian: limestone conglomerate lenses in slate. Clasts: biohermal limestone, 1 inch to 100 feet boulders, dark grey bedded limestone, dark gray massive limestone, few dolomite clasts and shale phenoclasts. Corliss Conglomerate, Middle Ordovician or older: local conglomerate lenses. Clasts: pale blue biohermal limestone, pebbles to 100 feet long boulders, average 1 ft.; Matrix: blue limestone; Interpretation: Bioherms developed during transgression and were eroded during later exposure.
Northern Champlain Valley Trenton Hawley, 1957	Breccia of limestone blocks, Clasts: light grey calcilutite, fossiliferous calcarenite, dark gray calcilutite, dark gray argillaceous limestone, older clasts; up to 2-2.5 feet across. Matrix: calcareous shale; Interpretation: submarine slides, possibly large mass movements off submarine fault scarp indicated by presence of old clasts.
TACONIC ALLOCHTHON	
New York/Vermont Lower-Middle Ord Deepkill Shale Zen, 1967 Landing, 1976 Landing, 1986	Small conglomerate lenses; Clasts: limestone, chert, shale, dolomite abundant rounded quartz grains (intrabasinal clasts). Matrix: calcareous, carbonaceous, abundant rounded quartz grains. Interpretation. Probably debris flow deposits on distal part of continental slope. Cambrian rocks of Taconic sequence are

	interpreted as deposits of channels and associated deep sea fan (Keith and Friedman, 1977).
HAMBURG KLIPPE	
Cambro-Ordovician SE Pennsylvania Greenwich Slice, Epstein et al. 1972 Lash and Drake, 1984	Rocks of Middle Ordovician flyschoid Windsor Township Fm. with local conglomerate beds. Clasts: shale, mudstone, siltstone, limestone, graywacke. 3m large boulders reported, dominantly Lower Ordovician in age. Matrix: pale green mudstone, Middle Ordovician Interpretation: intrabasinal slump deposits; whole sequence submarine channel-fan deposits on SE-dipping slope.
Late Cambrian- early Ordovician Richmond Slice Virginville Fm. Lash and Drake, 1984	Onyx Cave Mbr. with polymict carbonate clast conglomerate. Clasts: lime mudstone, calcarenite, quartzose limestone, peloidal wackestone, calcisiltite dolostone, up to 25cm long. Matrix: wellrounded, sometimes frosted quartz grains + peloids or mudstone matrix. Interpretation: proximal to distal slope sequence deposited on NW-facing paleoslope, shed from microcontinent in SE.
Cambro-Ordovician Conestoga Valley Lower Ordovician Wrightsville Mbr. Gohn, 1976	Proximal northern and distal southern facies, with lithoclastic limestone. Clasts: 1m , lightcoloured limestones and marbles. Extrabasinal clasts less abundant than intrabasinal clasts. Interpretation: Rocks on N-side of valley: proximal canyon and inner fan, S-side: distal, inner to mid-fan deposits.
MARYLAND	
Cambro-Ordovician Frederick Valley Reinhardt, 1974	Prograding platform margin, mostly Cambrian in age, with megaclastic limestone in Adamstown Mbr. Clasts: micritic and peloidal limestone. oolite, dolomite, 5-50cm long clasts.

	Matrix: dolomitic, microspar or sparry calcite cement, micrite with floating quartz grains. Interpretation: tectonic and depositional breccias. Low angle slope and prograding platform edge with older deepyater Frederick limestone and younger shallow water Grove limestone.
OUACHITA MOUNTAINS	
Oklahoma, Arkansas Stone and Sterling, 1962; King, 1975 Repetski and Ethington, 1977	Exotic bouldery debris in Blakely Sandstone, (Lower Ordovician). Clasts: crystalline rocks, meta-arkose boulders (Th-rich), feldspathic quartzose boulders. Matrix: clay
	Phosphatic conglomerates in Womble Shale (Lower-Middle Ordivician) Clasts: gray shale, brown siltstone, chert. Matrix: shale ranging from siltstone to sandstone. Interpretation: clasts derived from shelfbreak deposited in deeper water.
MARATHON REGION	
Lower Ordovician Marathon Limestone Young, 1970 King, 1937	Three boulder beds present. Clasts: mostly of shallow water origin. 1. Sandstone, trachyte, chert, limestone dolomite, siliceous dolomite. (up tp 3m). 2. Mottled dolomite, dolomitic siliceous dolomite, chert, limstone, arkose, subarkose (up to 125 x 150m). 3. Subarkose, dol. sil. limestone, dolomite, pisolitic limestone, trachyte, chert. Interpretation: Steep shelf margin, channels 2m deep, 10m wide. Deposits thinning from NW to SE.
Middle Ordovician Woods Hollow Shale Wilson, 1954	Mainly fine grained with lenses of breccia. Clasts: mottled limestone, fine grained sandy limestone with some calcirudite, brown weathering medium grained limestone.

limestone coquina and dolomite. Most clasts late Cambrian and Tremadoc in age.
Matrix: Middle Ordovician shale.
Interpretation: derived from up faulted Middle Ordovician fault scarp.

APPENDIX 8

ANCIENT EXAMPLES OF MEGACONGLOMERATES.

AUTHORS AND LOCALITIES	CHARACTERISTICS AND INTERPRETATION
Boirie and Souquet, 1982 Debroas, Lagier and Souquet, 1983 France, NW Pyrenees Turonian-Conacian Mendibelza Fm.	Structure: Carbonate megaconglomerate with distal facies. Thickness: over 100m Transport: 10km or more into basin. Interpretation: Canyon fill and fan deposits at base of fault scarps along Iberian platform margin. Record seismic activity.
Cook et al., 1972 Pray et al, 1967 Canada, Alberta, Jasper Ntl. Park Upper Devonian Mount Hawk and Perdrix formations	Structure:Megabreccia sheets and channels Thickness: 3-20m thick; Transport: up to 15 km into basin. Interpretation: debris flow.
Cook, 1965 Cook et al., 1972 U.S.A., Nevada, Roberts Mtns., Hot Creek Range, Lower Mississippian, Lake Valley	Structure: allodapic limestone and fine-drained conglomerate. Thickness: - Transport: - Interpretation: debris flow.
Davies, 1977 Canada, Arctic Archipelago Sverdrup Basin, Middle Pennsylvanian to Lower Permian Hare Fjord Fm.	Structure: debris sheets Thickness: 30m Transport: 8km into basin Interpretation: debris flows
Enos, 1977 N.E. Mexico, Golden Lane Lower Cretaceous Tamabra Limestone	Structure: beds and channels, shell debris Thickness: - Transport: 2-15km into basin. Source: rudist reefs. Interpretation: debris flow
Hoffman, 1968 – N.W.T.,	Structure: breccia with clasts up to 5m. Thickness: -

Great Slave Lake
Lower Proterozoic,
Pekanatui Formation

Transport: 5-15km into basin.
Source: carbonate shelf.
Interpretation: debris flow

Mountjoy and Playford, 1972
West Australia,
Canning Basin,
Upper Devonian,
Napier Virgin Hills

Structure: channels and sheets of breccia.
Thickness: -
Transport: up to 4km into basin and interreef areas.
Interpretation: debris flows, rolled blocks, reef talus.

Conaghan et al., 1976
Australia, New S. Wales
Orange, Wellington,
Middle Devonian
Nubrigyn Fm.

Structure: megabreccias
Thickness: -
Transport: 10's of km
Interpretation: debris flow

Pray and Stehli, 1962
U.S.A., West Texas,
Delaware,
Middle Permian,
Bone Spring

Structure: channels with shallow to U-shaped sides, 1-30m deep.
Thickness: up to 10m.
Transport: several km into basin.
Source: reef flank.
Interpretation: debris flow.

APPENDIX 9

RECENT DEBRIS FLOW DEPOSITS

STUDY AND LOCALITY	DEPOSIT AND INTERPRETATION
Mullins, et al., 1986 West Florida, carbonate platform margin.	Large scale truncation surface, slide scar Size: 120 km across, 30 km wide; involved strata: 300-350m late Paleogene and early Neogene strata. Age: collapse in Middle Miocene. Trigger: rapid sediment accumulation during relative sea-level high. Interpretation: large scale platform margin collapse.
Crevello and Schlager, 1980; Exuma Sound, Bahamas	Large debris sheet (20-30km wide). Size: 6400 km^2 Transport: 100km in sheet form, then channeling occurred. Age: Quaternary Trigger: undetermined Interpretation: debris flow
Bleifnik et al., 1983 Blake-Bahama Basin	Debris flows and turbidites grading into each other; intraclastic chalk unit. Size: 300km across basin, constrained by chanels. Clasts: 4-5cm in size, derived from shallow and deep water sources in S and E! Age: Miocene Trigger: tectonic activity along Great Abaco Fracture zone, sediment overloading, sea level changes.
Scientific Party, 1985; Bahamas Archipelago	Report 30m thick Miocene debris flow deposits in Straits of Florida and on southern Blake Plateau (Abaco Episode)
Paull and Dillon, 1980 Blake Escarpment, west Florida.	"Bench" at foot of Blake Escarpment Size: 2000km^3 of material involved. Age: major erosion in post-Miocene. Trigger: deep current steepened and

possibly oversteepened wall;
initiated collapse and
turbidity currents.

Interpretation: Escarpment walls
erosional in origin,
land-ward retreat of 5-15 km.

APPENDIX 10

Macrofossils reported from clasts in beds 10, 12 and 14. Compiled from James and Stevens (1986) and Ross and James (in press).

Faunas from clasts in Bed 10

TRILOBITES

Cow Head Peninsula.

Punka sp.
Uromyostrom sp.
Gog sp. nov.
Trinodus sp.
asaphid pygidium
cf. *Protopresbynileus* sp.
? *Peligurus* sp.
Ampyx sp.
raphiophorid trilobite
cf. *Ectenonotus* sp.
remopleuridid trilobite
Bolbocephalus sp.
illaenid trilobite
Benthamaspis sp.
cf *Psalakilus* sp.
Goniophrys sp.
harpid trilobite
pliomerid trilobite

Stearing Island.

Leiostegium sp.
Symphisurina sp.

SPONGES

Cow Head Peninsula.

Archaeoscyphia sp.

Faunas from clasts in Bed 12.

TRILOBITES

Cow Head Peninsula.

Nileus **sp.**
Telephina **sp.**
Kawina **cf.** *vulcanus*
illaenid trilobite
agnostid trilobite
Trinodus **sp.**
Lonchodomas **sp.**
Strotolopis **sp.**
Sphaerocoryphe **sp.**
Symphysurina **sp.**
Petigurus **sp.**
Oopsites **cf.** *hibernicus*
Gog catilus
Illaenus **sp.**

Stearing Island

Benthamaspis diminutiva
Isoteloides **sp.**
Catochia **sp.**
Benthamaspis **sp.**
Strotactinus **sp.**
Sycophantia **sp.**
nemoplsurid trilobite
one clast with:
Carolinites genacinata
Oopsites hibernicus
Niobe ornata

BRACHIOPODS

Cow Head Peninsula

Orthidiella **cf.** *O. costellata*
Pleurorthis **sp. (aff. sp. 1 Cooper)**
Pleurorthis? **aff.** *P. imbecilis*
Pleurorthis fascicostellata
Orthidium **sp.**
Archaeorthis **sp.**
Idiostrophia valdari
Leptella sordida
Orthidium fimbriatum
Pleurorthis **sp. 1**

Camerella tumida
Orthis hyppolite
Camerella calcifera
Camerella breviplicata

SPONGES

Anthaspidella sp.
Archaeoscyphia sp.
Psarodictyum sp.

GASTROPODS

Maclurites sp.

Faunas from clasts in Bed 14

TRILOBITES

Cow Head Peninsula

Nileus sp.
Presbynileus sp.
Remopleurides sp.
illaenid trilobite
Bathyurellus sp.
Ampyx sp.
Raymondaspis sp.
harpid trilobite
ceraurid trilobite
Ectenotus cf. *westoni*
Illaenus cf. *tumidifrons*
"Cheirurus" prolificus
"Lichas" jukesi

3 faunas at Jim's Cove:
1. Lower Head Boulder Fauna (Whittington, 1963).
2. Upper Cassinian (*Gog*) Fauna Fortey, 1975).
3. Valhallan Fauna (Fortey, 1975, 1980).

Stearing Island

Valhallan Fauna (Fortey, 1980)

Lower Head

phi-boulder: *Carolinites* sp.
pliomerid pygidium
lambda-boulder: *Parabolinella* sp.

BRACHIOPODS

Cow Head Peninsula

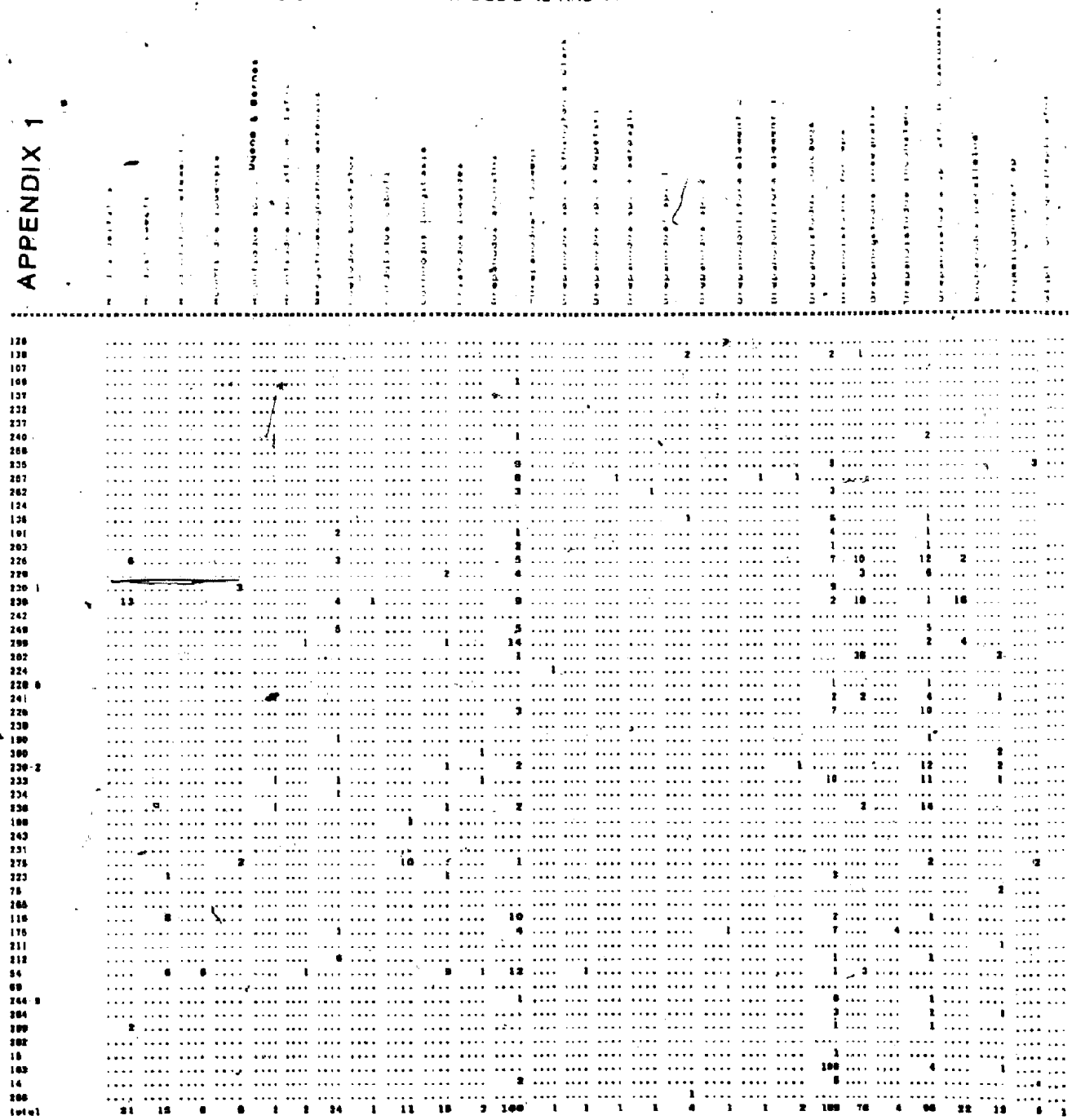
Petroria sp.
Orthambonites sp.
Orthidiella sp.

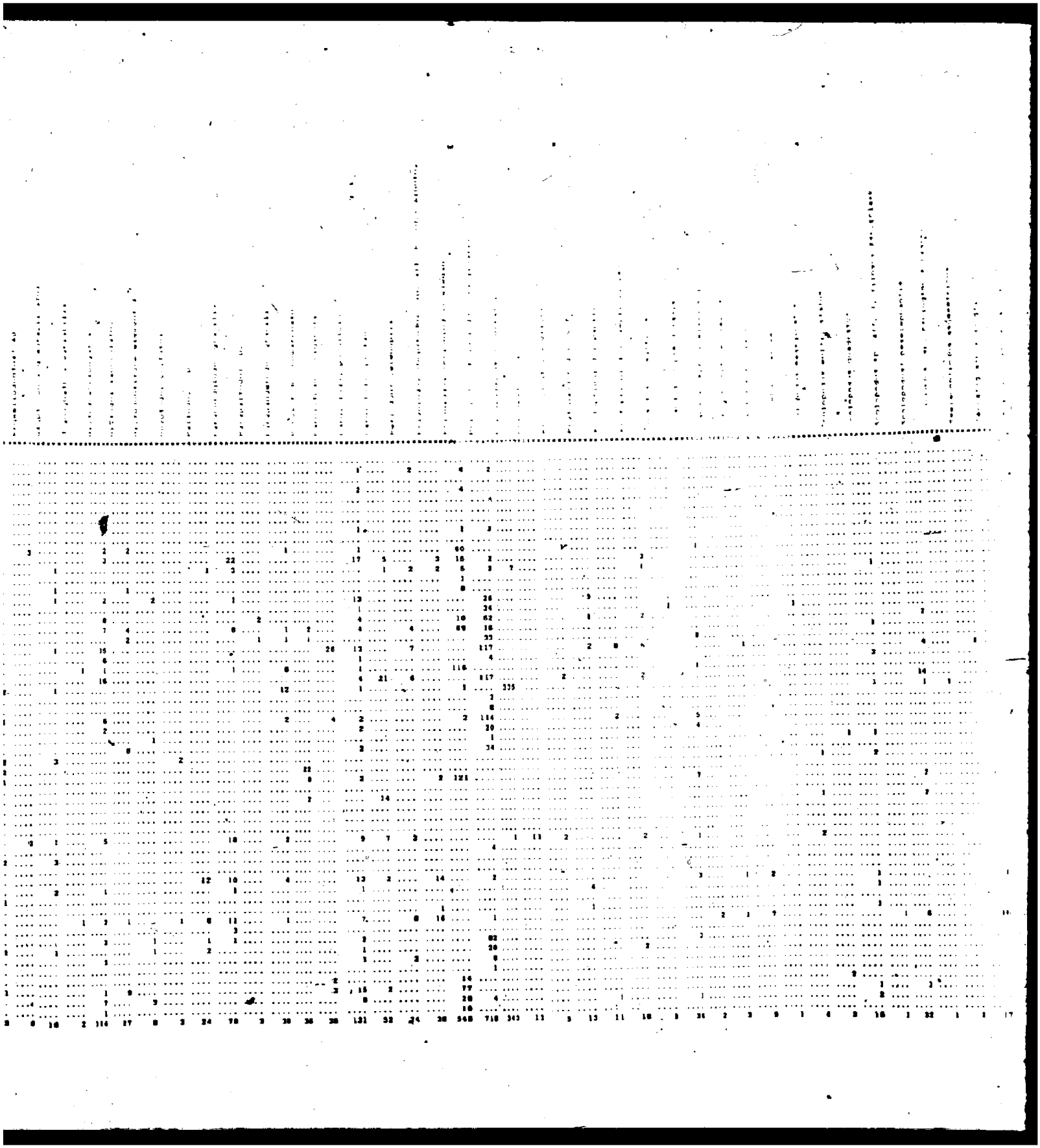
Lower Head

alpha-boulder: Whittington, 1963
phi-boulder: *Orthidiella* sp.
Orthidium sp.
Petroria sp.
Parambonites sp.

APPENDIX 1

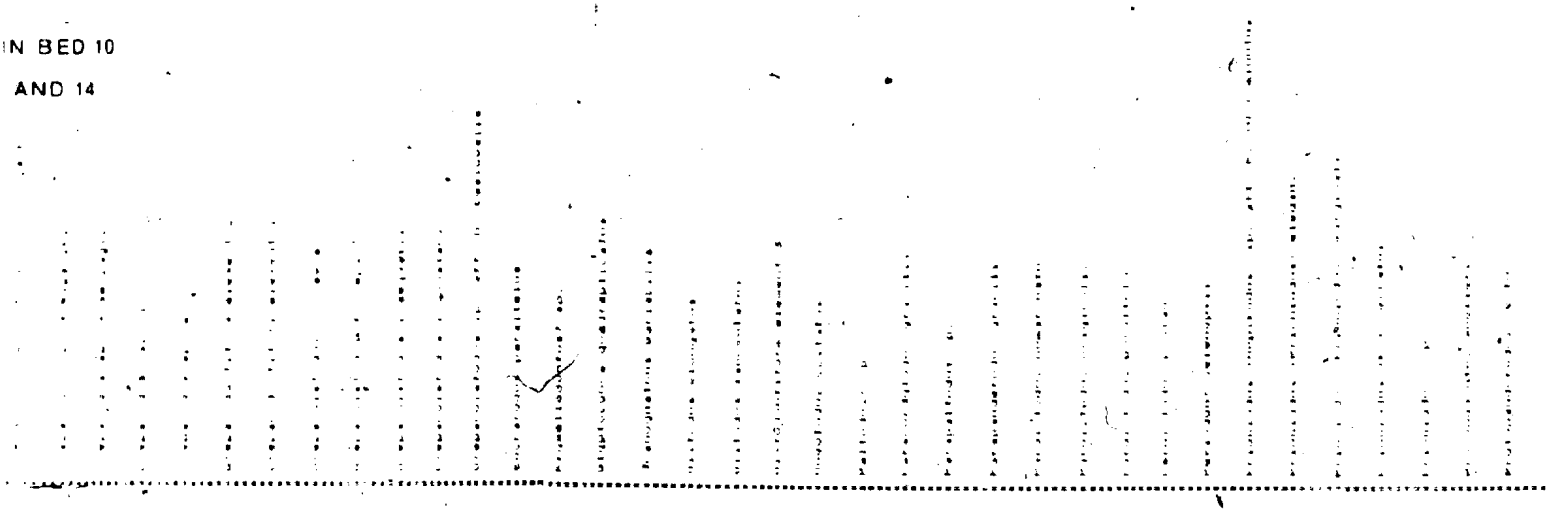
CONODONTS FROM PENECONTEMPORANEOUS CLASTS IN BED 10
AND FROM CLASTS OF BED 9-AGE FOUND IN BEDS 12 AND 14

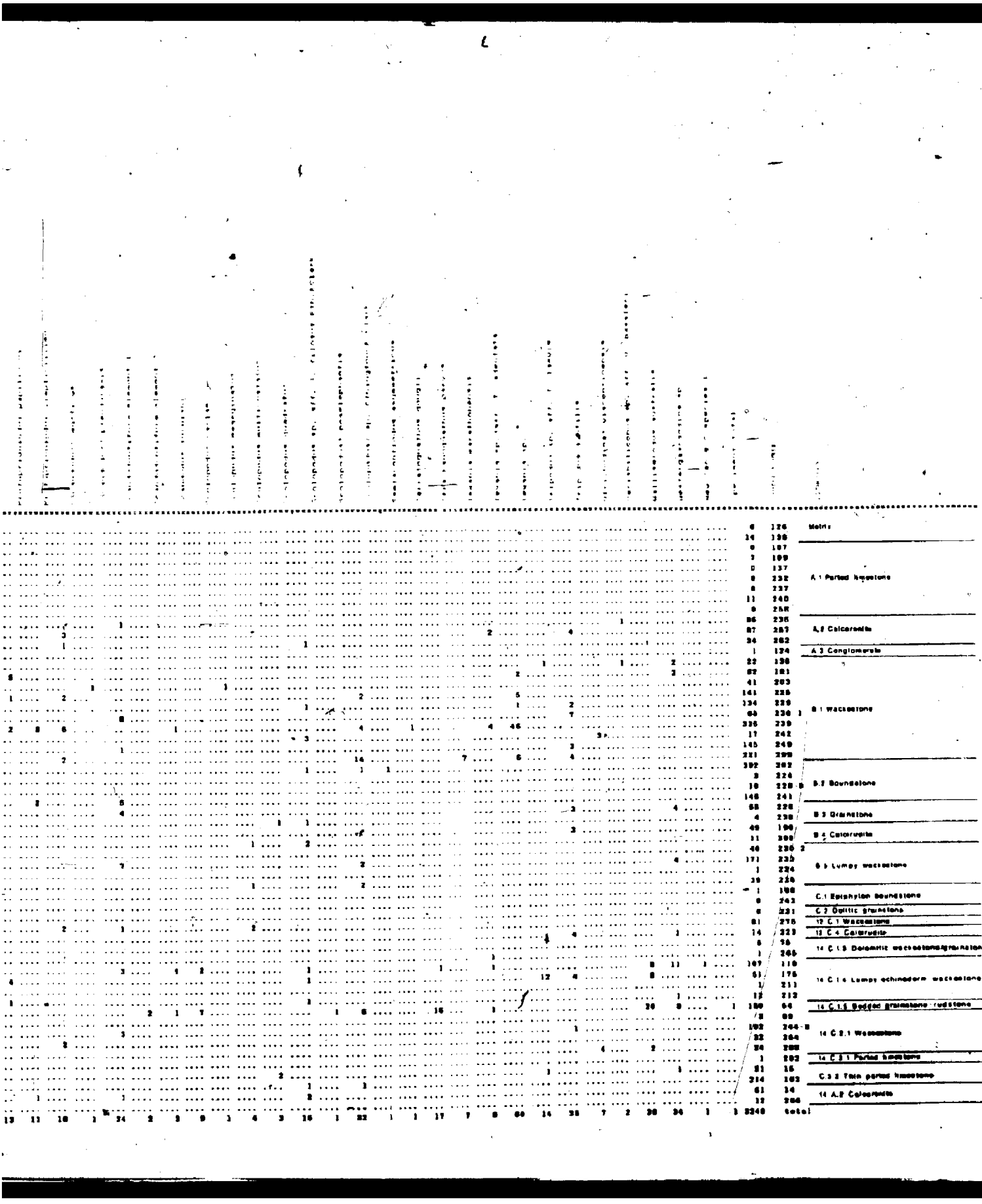




S IN BED 10

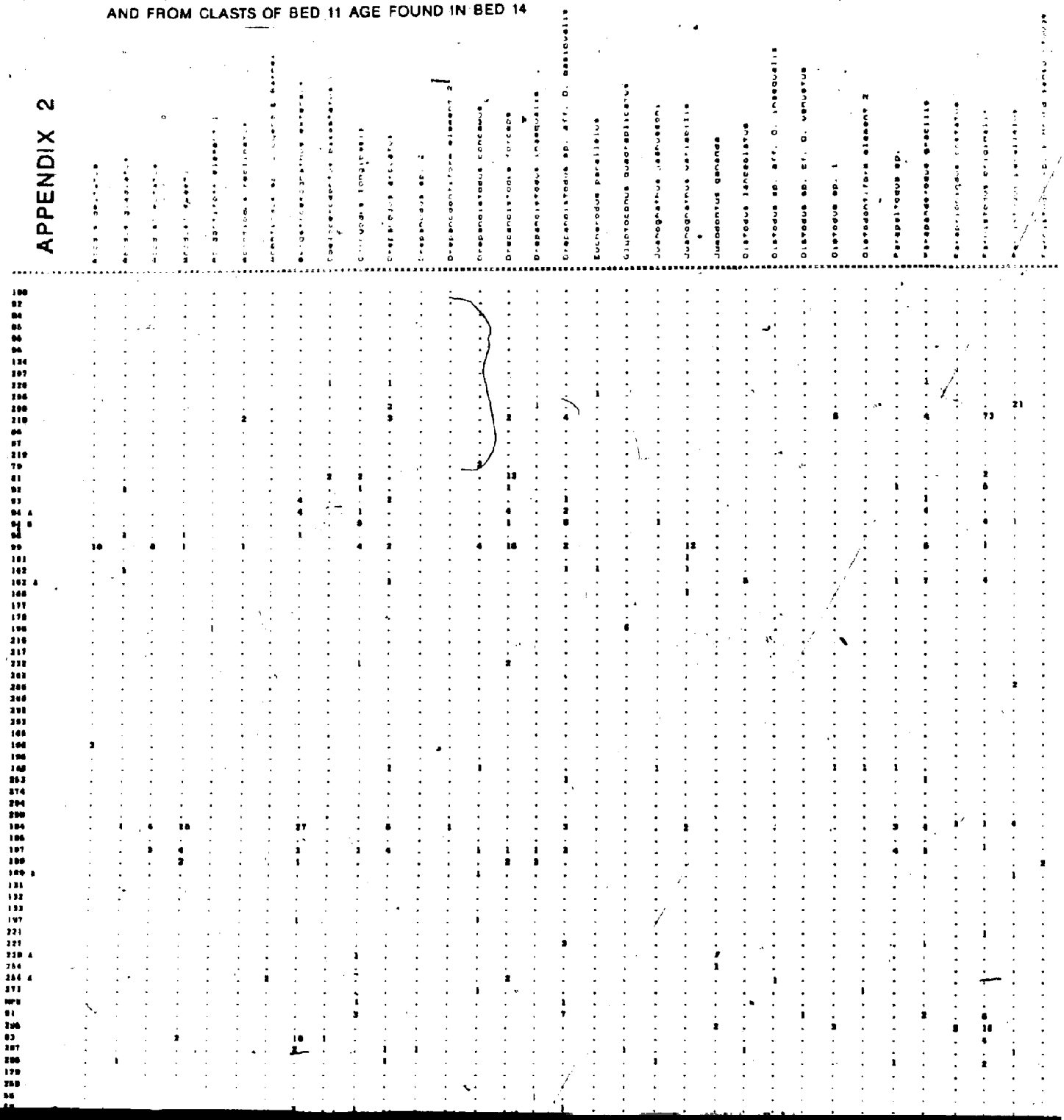
12 AND 14

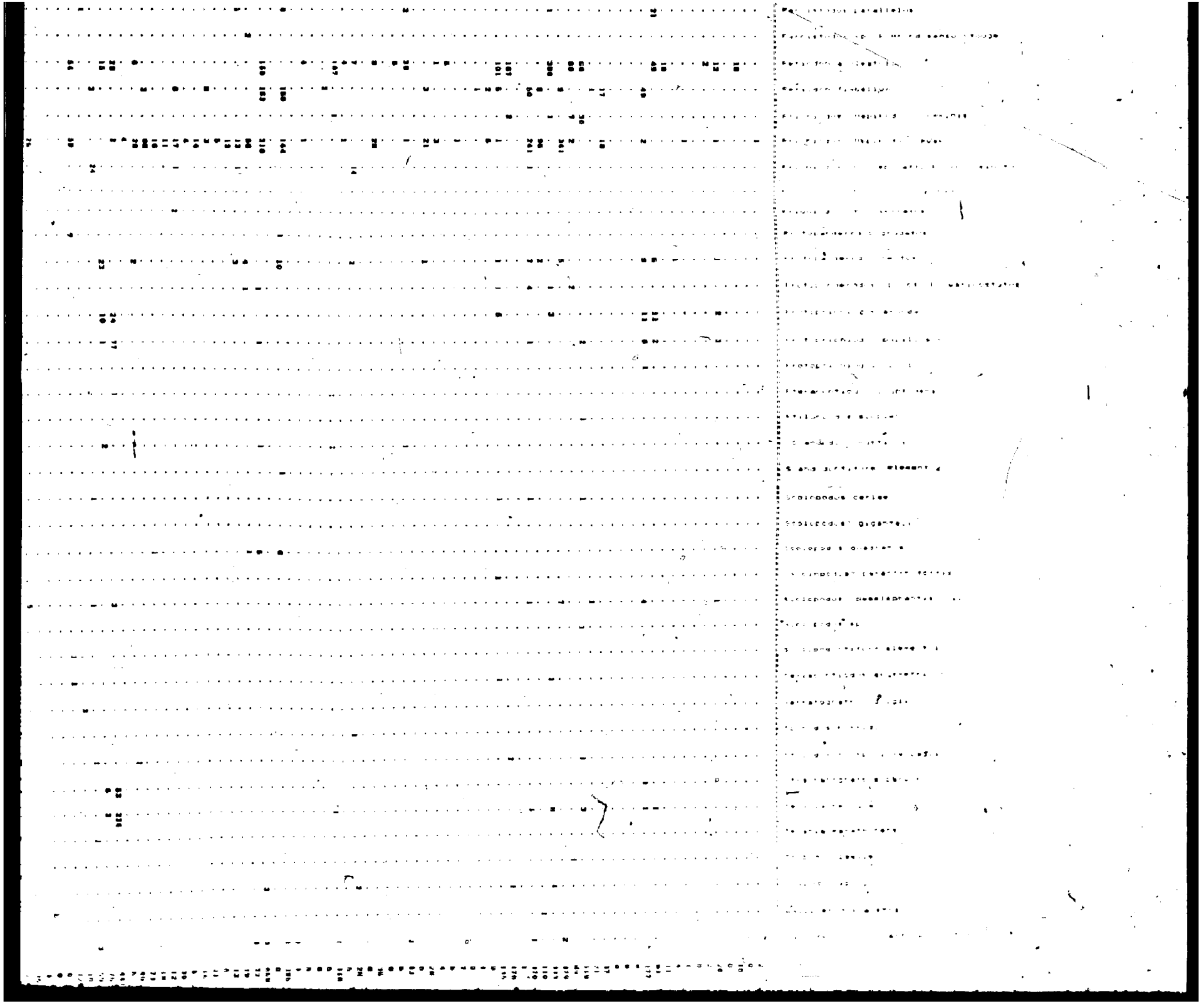




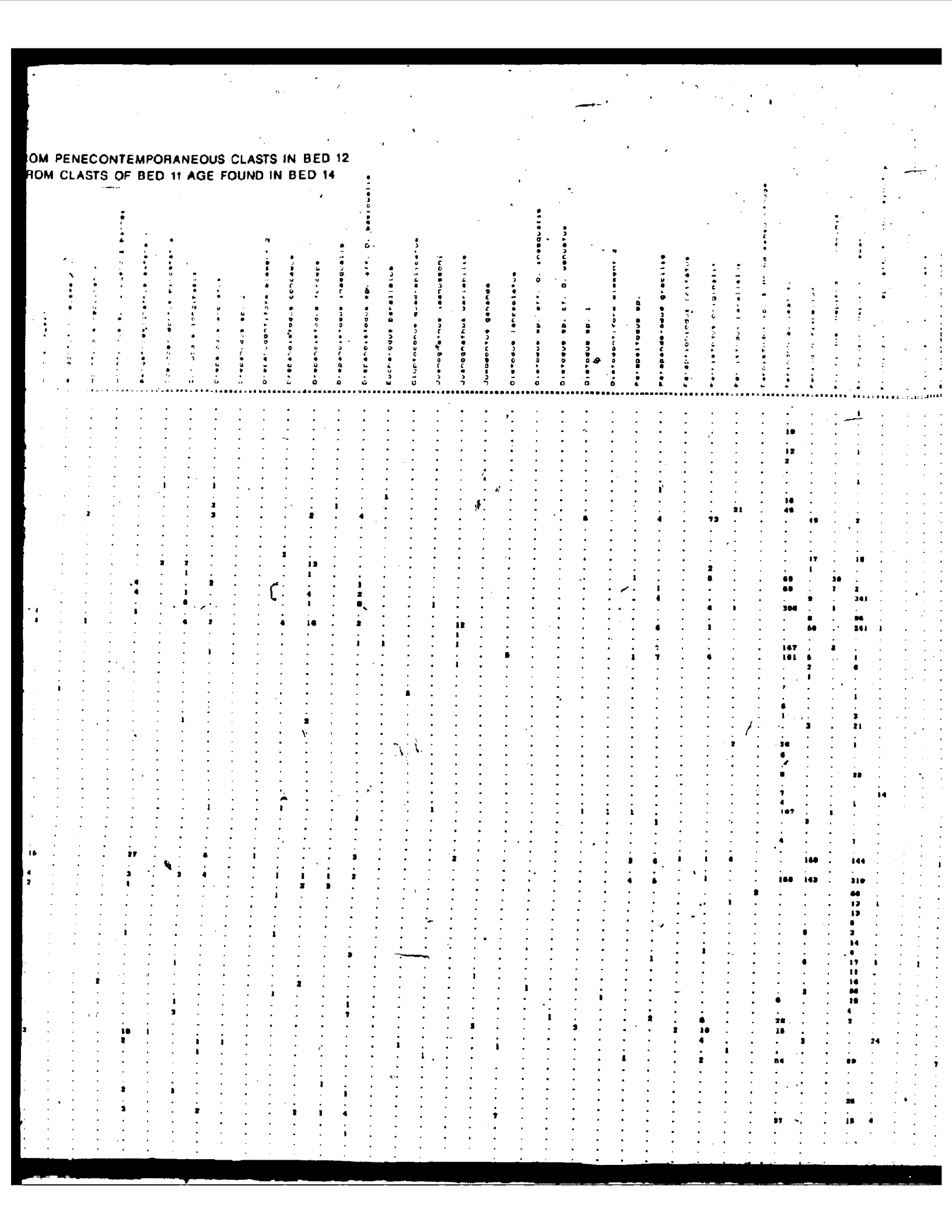
APPENDIX 2

CONODONTS FROM PENECONTEMPORANEOUS CLASTS IN BED 12
AND FROM CLASTS OF BED 11 AGE FOUND IN BED 14

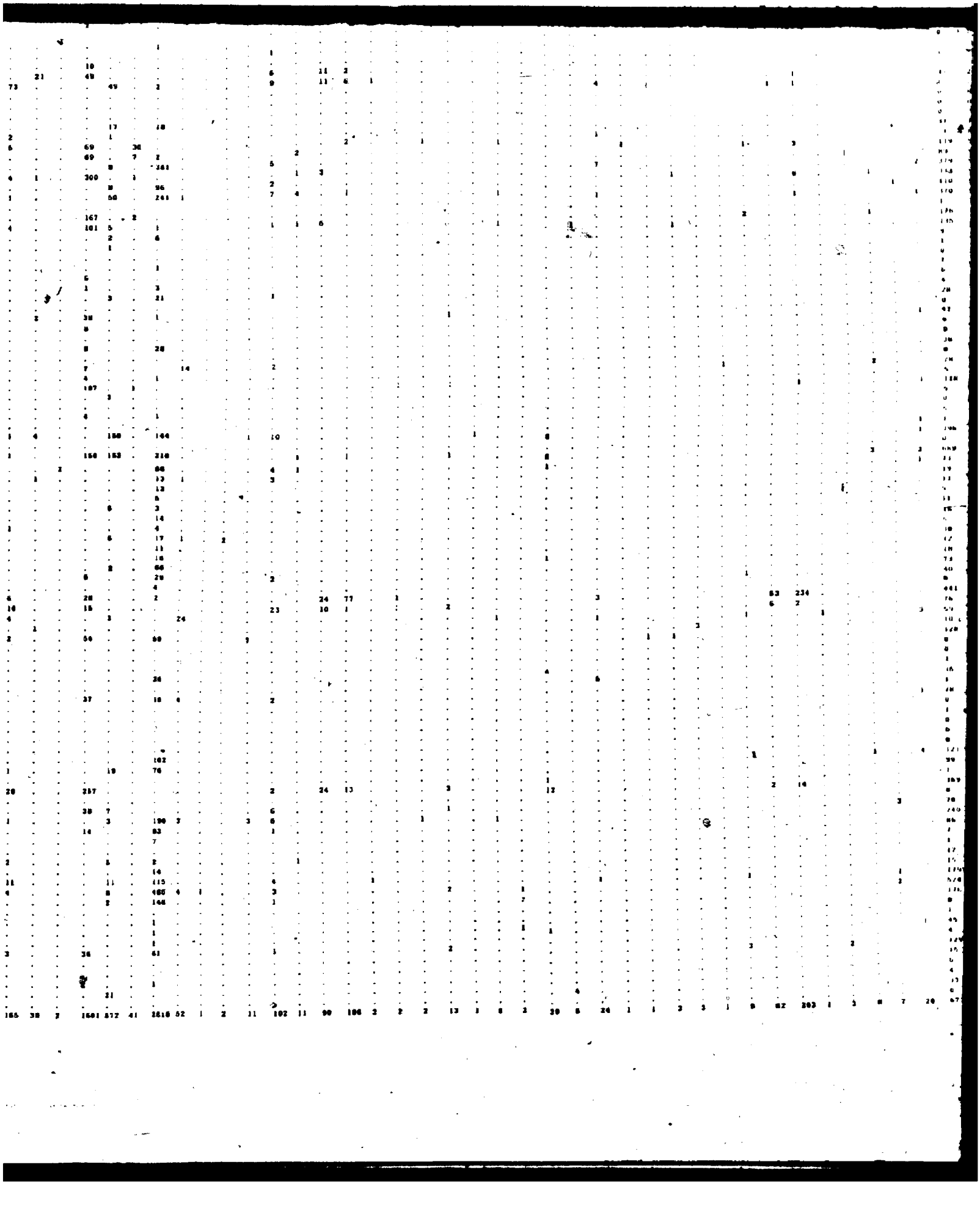


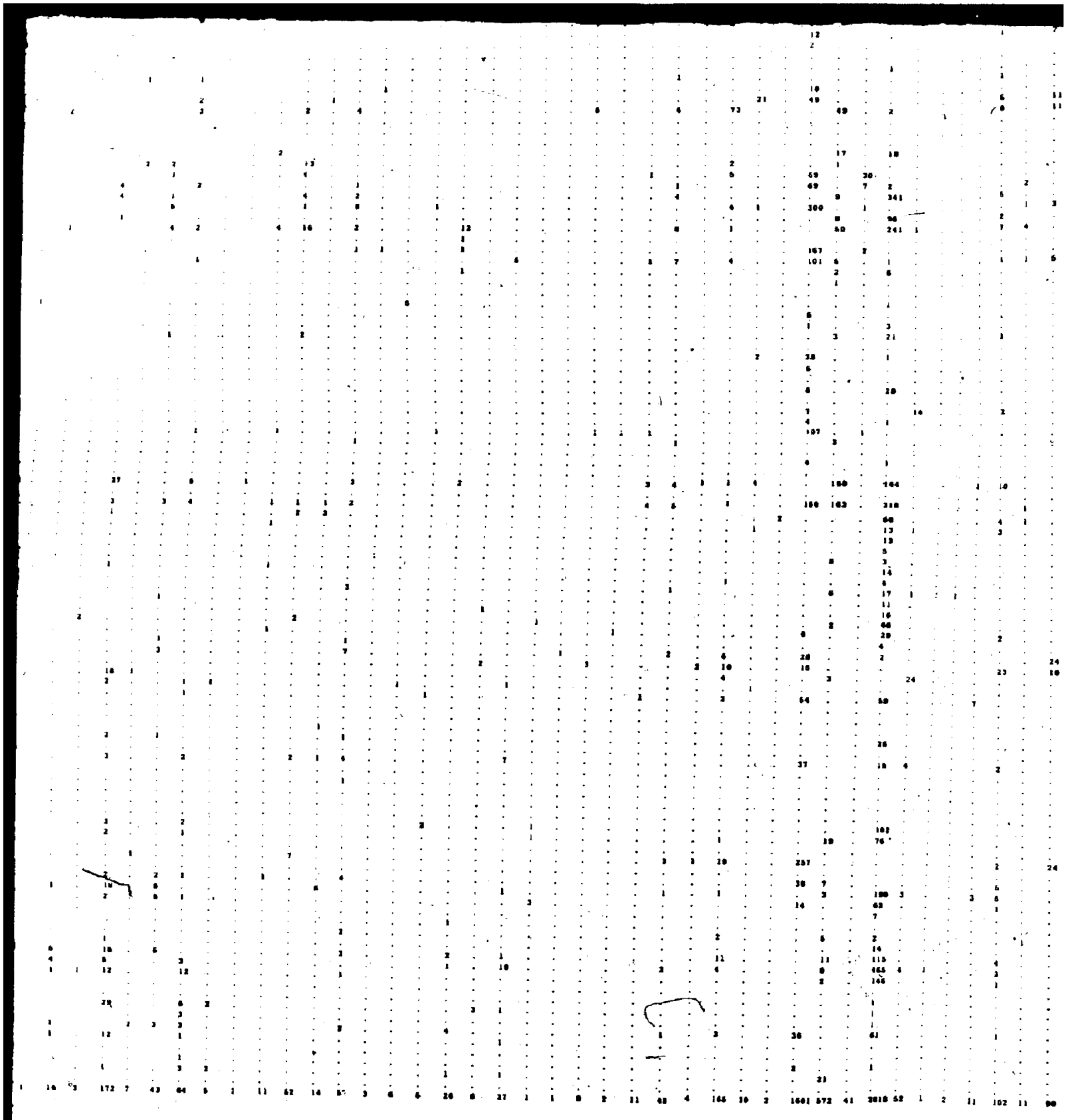


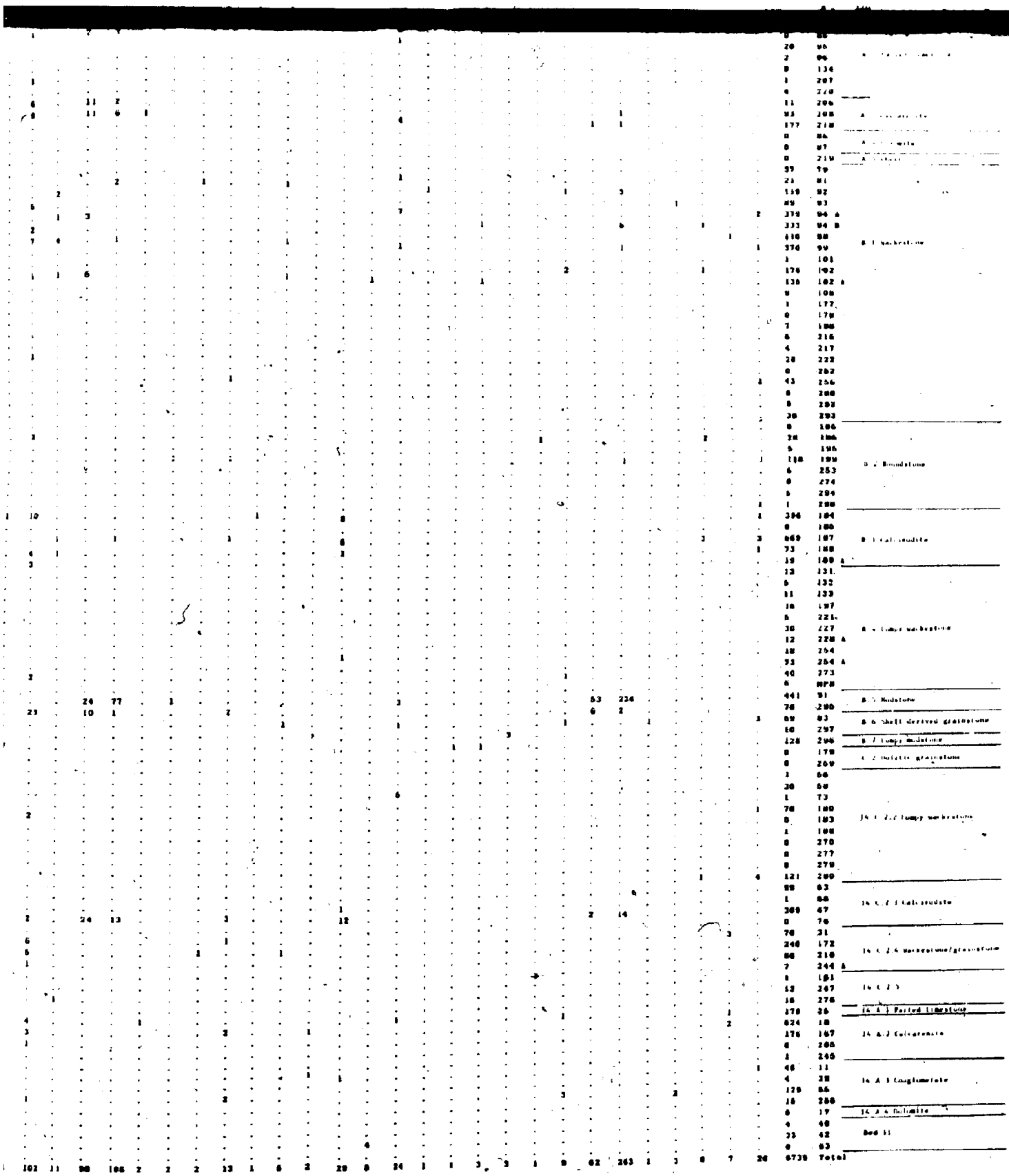
OM PENECONTEMPORANEOUS CLASTS IN BED 12
ROM CLASTS OF BED 11 AGE FOUND IN BED 14

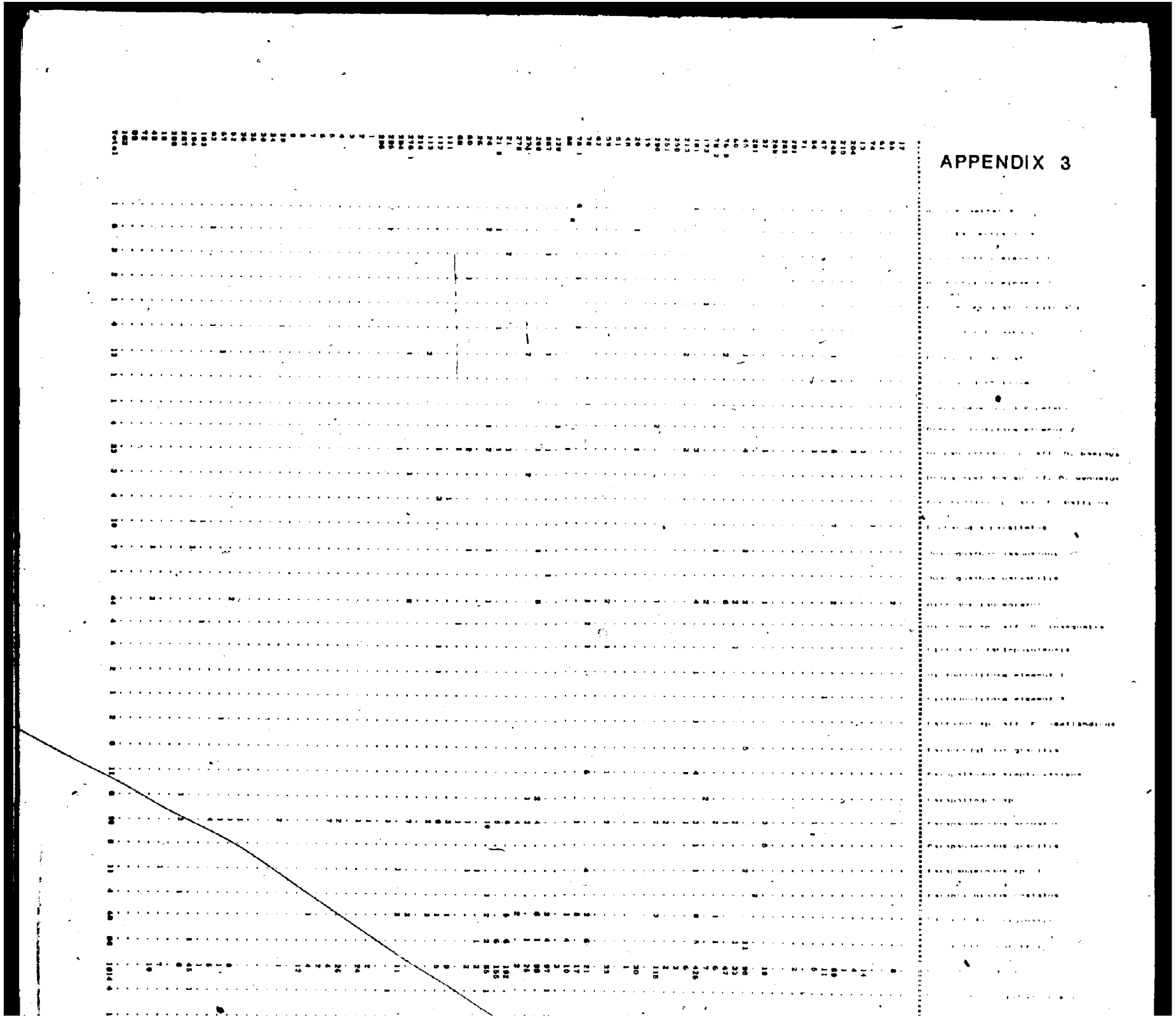


| | | |

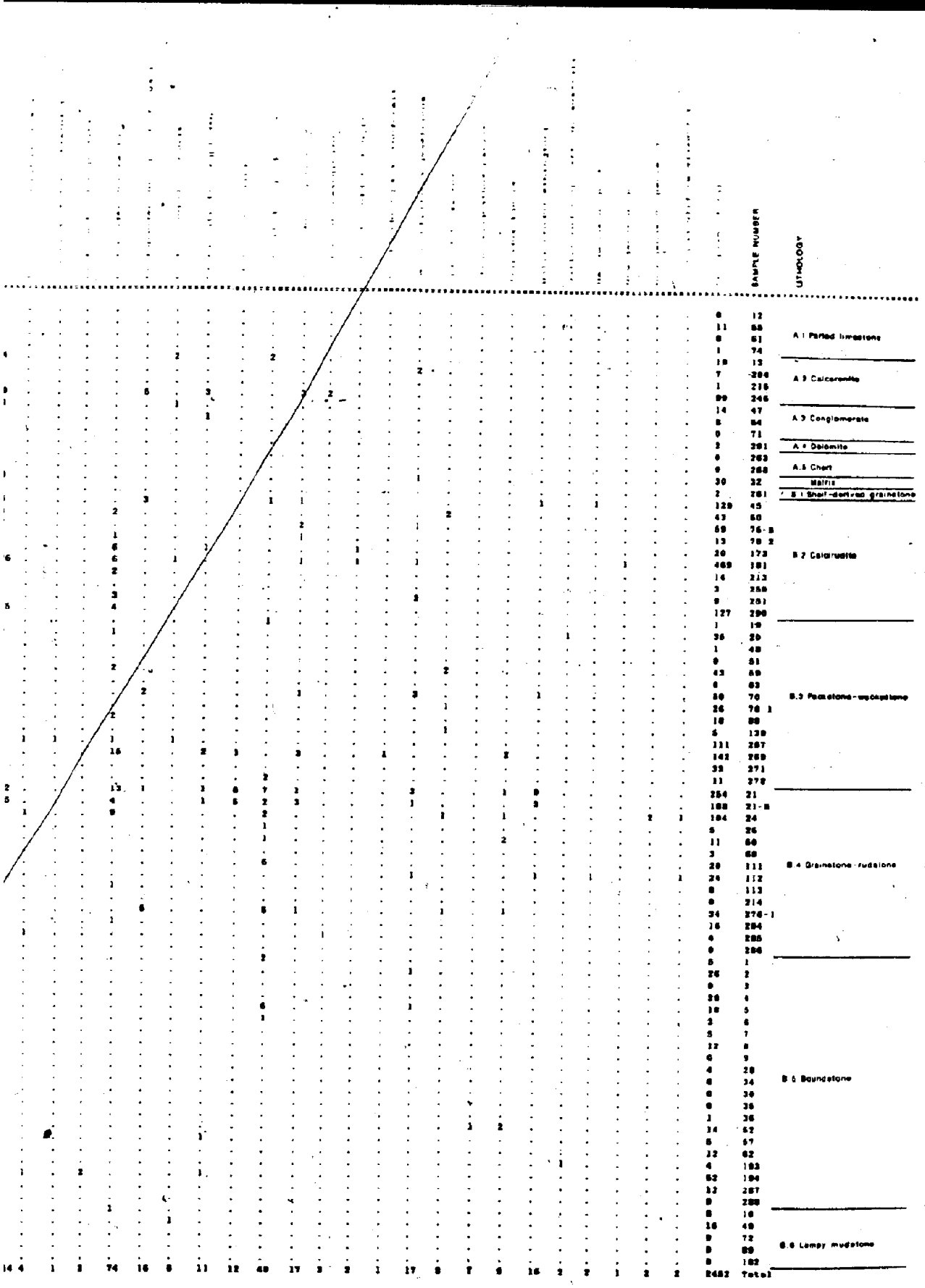






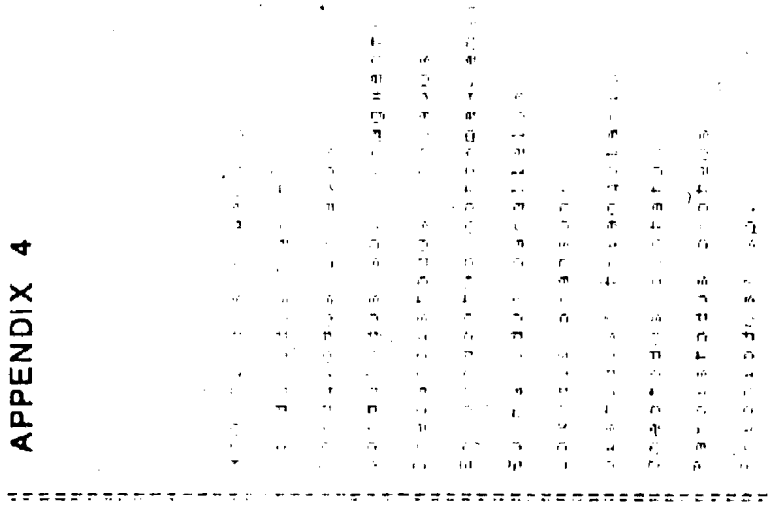


APPENDIX 3


SAMPLE NUMBER
LITHOLOGY
A.1 Parted limestone
A.2 Calcarenite
A.3 Conglomerate
A.4 Dolomite
A.5 Chert
Matrix
B.1 Shelf-derived grainstone
B.2 Calcirudite
B.3 Packstone-wackestone
B.4 Grainstone-rudstone
B.5 Boundstone
B.6 Lumpy mudstone
Total

CONODONTS FROM OLDER CLA

APPENDIX 4



44	.	.	.	.	.	.	.	.	.	.	.	.
162	.	.	.	.	.	.	.	.	.	.	.	.
16	.	.	.	.	.	1	.	1	1	.	.	.
142	.	.	.	.	.	.	.	.	.	.	.	.
166	1	.	.	.	2	.	1	.	.	1	2	.
283	.	.	.	.	.	.	.	.	.	.	.	.
164	.	.	.	.	.	.	.	.	.	.	.	2
192	.	1	.	.	.	.	.	.	.	.	.	.
27	.	.	4	.	.	2	.	.	.	.	.	.
29	.	.	.	1	.	.	.	.	.	.	.	.
33	.	1	.	.	.	.	.	.	.	.	.	.
41	.	1	2	.	.	6	.	.	.	.	.	.
252	.	.	.	.	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.	.	.	.	.
37	.	.	.	.	.	.	.	.	.	.	.	.
38	.	.	.	.	.	.	.	.	.	.	.	.
Total	1	3	6	1	2	9	1	1	1	1	2	2

STS IN BED 14

.	.	.	.	0	44	C.1.1 Oolite
.	.	.	.	0	162	
.	13	.	6	22	16	C.1.2 Lumpy Nula-wackestone
.	.	.	.	0	142	C.1.3 Dolomitic wackestone/grainstone
.	.	.	2	9	166	w. wellrounded quartz grains
.	.	.	.	0	283	
.	.	.	1	3	164	Epiphyton boundstone
.	.	.	.	1	192	
.	.	.	.	6	27	
1	.	.	.	2	29	
.	.	1	.	2	33	C.3.3 Old clasts of parted limestone
.	.	.	.	9	41	
.		.	.	0	252	
.	.	.	.	0	22	A.3.5 Conglomerate w.
.	.	.	.	0	37	flat mudstone pebbles
.	.	.	.	0	38	
1	13	1	9	54	Total	