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ICHNOLOGY AND SEDIMENTOLOGY OF THE BOW ISLAND/VIKING FORMATION, SOUTH-CENTRAL ALBERTA

BY
INDRANEEL RAYCHAUDHURI ©

A THESIS SUBMITTED TO THE FACULTY OF
GRADUATE STUDIES AND RESEARCH IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

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THE UNDERSIGNED CERTIFY THAT THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH FOR ACCEPTANCE, A THESIS ENTITLED **ICNOLOGY AND SEDIMENTOLOGY OF THE BOW ISLAND/VIKING FORMATION, SOUTH-CENTRAL ALBERTA,** SUBMITTED BY INDRANEEL RAYCHAUDHURI IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY.

Dr. S. G. Pemberton - Supervisor

C R Stelck
Dr. C. R. Stelck

Dr. T. F. Moslow

Dr. H. E. Clifford - External Examiner

Date April 18/94

Shufflin' through people like cards
Oh let 'em blow around like sand
Maybe it'll uncover some beauty in their eyes
Maybe it'll give me a place to breathe
Maybe it'll give me some room to stand
I'm hangin' by a thread
Hangin' by a thread...
- american music club

Take a walk
Inside yourself
Get to know the person behind the face
Is it someone you can really love?
Is it somebody who looks down from above
With a view of the rain?...
- Urge Overkill

There's roads and there's roads
And they call, can't you hear it?
Roads of the earth
And roads of the spirit
The best roads of all
Are the ones that aren't certain
One of those is where you'll find me
Till they drop the big curtain

Hear the wind moan
In the bright diamond sky
These mountains are waiting
Brown-green and dry
I'm too old for the term
But I'll use it anyway
I'll be a child of the wind
Till the end of my days

Little round planet
In a big universe
Sometimes it looks blessed
Sometimes it looks cursed
Depends on what you look at obviously
But even more it depends on the way that you see...
-Bruce Cockburn

Seems like folks turn into things
That they'd never want
The only thing to live for
Is today...
I'm gonna put a hole in my T.V. set
I don't wanna grow up
Open up the medicine chest
And I don't wanna grow up
I don't wanna have to shout it out
I don't want my hair to fall out
I don't wanna be filled with doubt
I don't wanna be a good boy scout
I don't wanna have to learn to count
I don't wanna have the biggest amount
I don't wanna grow up...
- Tom Waits/Kathleen Brennan

Plus ça change, plus c'est la même chose
- Voltaire

DEDICATION

This thesis is dedicated in memory of my father,
Dr. Bimalendu Raychaudhuri. I guess when all is said and done,
there must be more to genetics than meets the eye.

ABSTRACT

A study of sixty-nine cores from the uppermost Bow Island/Viking Formations from Townships 22-29, Ranges 18-22w4 has distinguished two major facies associations. Facies Association One (FA1) comprises beds of thoroughly burrowed, very fine grained sandstone, siltstone and shale, interbedded with rare one to fifteen centimetre thick, rippled, very fine grained sandstone. An abundant and diverse trace fossil suite consisting of twenty-three ichnogenera characterises FA1. The overlying Facies Association Two (FA2) comprises rarely to moderately burrowed, very fine grained sandstone, siltstone and shale, interbedded with thickly bedded (0.15-4.0m) low angle laminated, very fine to fine grained sandstones. FA2 is characterised by an ichnofossil assemblage that is impoverished in both diversity (*i.e.* fifteen ichnogenera) and burrowing intensity as compared to FA1. Micro-faulting, synaeresis cracks, structureless/massive sandstones, and soft sediment deformation features are also locally present in FA2.

FA2 is interpreted to represent the sandier upward continuation of FA1 within an overall conformable succession, although locally, evidence suggests that relative lowstand and trasgressive surfaces may separate the facies associations. The upward decrease in burrowing intensity and diversity corresponds to a transition from upper offshore/distal lower shoreface conditions (FA1), to wave dominated delta front conditions (FA2). Trace fossil and sedimentologic analysis indicate that oxygenation, salinity, and turbidity stresses were significant factors during the deposition of FA2. These stresses may have arisen as a result of the introduction of freshwater and associated episodic sedimentation within a wave dominated delta front environment.

The facies associations are stacked to form sandier upwards shoreface and deltaic cycles. Depending on the nature of the FA1-FA2 contact, FA1 and FA2 may represent two stacked parasequences separated by a previously unrecognised discontinuity surface, or alternatively, may represent a single sanding upwards parasequence. Regionally extensive erosive discontinuity surfaces are found at the base of FA1 and at the top of FA2.

Integration of detailed ichnologic analysis with sedimentology has proven to be a powerful tool for differentiation between strandplain and deltaic depositional systems.

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This is probably the most difficult part of the thesis to write. It will also probably be the most widely read part of my thesis, which is kind of sad if you think about it, but understandable nonetheless. I fear I will forget people who helped me along the way, but I suppose that is inevitable. I apologise in advance if, for some reason, I missed out on thanking and acknowledging you. I also apologise in advance for the somewhat colloquial nature of the more personal portions of the acknowledgements.

I owe my greatest acknowledgement to my thesis supervisor, Dr. S. George Pemberton. George put up with me for five years while I undoubtedly drained his patience as well as his research accounts. For this, I will always be grateful. On a technical note, his assistance and guidance were first rate. By Supporting my treks to conferences and field trips, he allowed me the chance to present my work, as well as meet and learn from people in both academia and business; I feel that I most certainly wouldn't be where I am today without his considerable efforts. I thank him for allowing me the opportunity to grow both scientifically and personally. Most of all, I'd like to thank the Bossfella (aka "The Jedi") for teaching me perspective by example- by showing me that there's a lot more to life than our own little worlds. I can honestly say that George is one of the very few people I've known whom I can say that I admire, respect and like.

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Of course, I must thank my own family for supporting me the entire way through this experience. Thanks to Ma, Gopa, Tod, Shaiyon and all extended family for your encouragement. I hope to see you all very soon.

I'd like to express my gratitude to the Natural Science and Engineering Research Council (NSERC Grant No. A0816 to Dr. S. George Pemberton), Alberta Energy Company, Esso Canada Resources Limited, Husky Oil Operations Limited and PanCanadian Petroleum Limited for funding the thesis work.

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Before I proceed, I should forewarn those of you who don't care for a casual writing style that the following is the colloquial portion of the acknowledgements.

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I guess that's it. So until next time, please remember that this thing we call life is merely an exhibition, not a competition; so please- no wagering.

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CHAPTER 1: INTRODUCTION, SCIENTIFIC PROBLEMS, OBJECTIVES, STUDY AREA, STUDY METHODS, AND ECONOMIC RATIONALE FOR RESEARCH

1.1 INTRODUCTION

This study was undertaken to investigate the Lower Cretaceous (Upper Albian stage) Bow Island/Viking interval in south-central Alberta. While numerous studies exist on the Viking Formation of central Alberta (see Chapter two), little has been published on the relationship of the Viking Formation to its approximately equivalent strata in northwestern Alberta (*i.e.* the Paddy and Cadotte Members of the Peace River Formation), or south-central Alberta (*i.e.* the Bow Island Formation). In 1989, a Ph.D. research project at the University of Alberta focusing on aspects of ichnology, sedimentology, and stratigraphy of the Viking-Paddy/Cadotte transition in northwestern Alberta was undertaken by James MacEachern. This M.Sc. study was undertaken to complement recent research on late Albian strata being conducted at the University of Alberta. The purpose of this study was to develop an integrated ichnologic/sedimentologic model for the uppermost Bow Island/Viking Formation in order to better understand the palaeoenvironments.

1.2 SCIENTIFIC PROBLEMS AND SELECTION OF STUDY AREA

1.21 Stratigraphy

It is assumed that the subsurface Viking Formation (Upper Albian) of the Alberta Central Plains and the Bow Island Formation of southern Alberta are approximate stratigraphic and age equivalents (Glass, 1990). Glass (1990) addressed the stratigraphic nomenclature change simply and eloquently, by stating, "The western occurrence of the Viking Formation forms the thin distal part of the northeastward thinning Bow Island-Viking coarse siliciclastic wedge. Thus in southwestern Saskatchewan and southern Alberta the Viking Formation is replaced by a thicker sequence of sandstones and interbedded mudstones and shales referable to the Bow Island Formation.". Because the exact stratigraphic relationship between the Bow Island and Viking Formations is unclear, detailed correlations between the two formations are problematic. The development of a systematic stratigraphic framework was required to allow for more accurate correlations and comparisons. The most useful stratigraphic framework is one that allows depositional systems to be viewed as a continuum. That is, a framework that allows time equivalent sediments to be examined as parts of an overall depositional system. The "skeleton" for such a stratigraphic framework is based on significant physical surfaces visible in outcrop and drill core. Moreover, where cores are referenced to their respective geophysical well logs, these surfaces can be characterised by their well log signatures. Determining what surfaces are key is difficult in itself, however, careful examination of subsurface cores and well logs allow demarcation of bounding surfaces that are correlatable over the study area. These surfaces generally represent major events (*e.g.* transgressive ravinement, transgressive flooding, incision associated with relative lowstands of sea-level *etc.*) that divide the entire Bow Island/Viking interval into a series of stacked sedimentary packages, each of which is linked to its own respective set of clastic depositional systems. This concept of key bounding surfaces is paramount to allostratigraphy and sequence stratigraphy. Elements of allostratigraphy and sequence stratigraphy were employed with a degree of success for the Viking Formation in the Willesden Green field area (Boreen and Walker, 1991). Boreen and Walker (1991) provided a detailed allostratigraphic subdivision, and their results further support the use of sequence stratigraphic/allostratigraphic analysis in other Bow Island/Viking field studies. Hadley (1992) recently proposed an allostratigraphic framework for the Harmattan East and Crossfield fields which appears to be more applicable to the Bow Island/Viking interval in this study by virtue of geographic proximity (Fig. 1.1). The concept of genetically related sedimentary packages bounded by key surfaces has been employed as an element of this study.

Proper understanding of the Bow Island/Viking stratigraphy is extremely important. Observations and results from this study can be compared to pre-existing Bow Island (*e.g.* Cox, 1991; Cox and Williams, 1991; Reinson *et al.*, 1993) and Viking (*e.g.* Boreen and Walker, 1991; Posamentier and Chamberlain, 1990, 1991a,b; Hadley, 1992) studies for the purposes of providing a better regional understanding of the strata.

1.22 Depositional Environments

The Bow Island/Viking interval is composed of a series of marine to marginal marine sandstones, shales, and conglomerates. Locally (especially towards the Foothills belt in western Alberta), non-marine coal and palaeosol deposits have also been observed (Leckie, 1986a; Hadley, 1992). A major goal of this project was to document and interpret the facies and depositional history of the sediments. The interpretation of the sediments was constrained by laterally extensive bounding discontinuities. The causes for the bounding discontinuities, whether autocyclic or allocyclic in nature, were also carefully examined and considered. Genetically related sediments, when approached in this manner, can be viewed in their proper stratigraphic context and overall depositional framework. The facies analysis carried out relied on the combination of ichnologic (*i.e.* trace fossil or ichnofossil) and physical sedimentologic observations.

It has become clear that palaeoenvironmental interpretations cannot be based solely upon primary sedimentary structures. More comprehensive interpretations can be achieved by incorporating ichnology (*i.e.* the study of animal-sediment relationships). Application of trace fossil analysis, in combination with a rigorous sedimentologic investigation, can provide invaluable information regarding original depositional conditions (*e.g.* Moslow and Pemberton, 1988; Jones and Pemberton, 1989). Ichnologic observations such as trace fossil size, morphology, assemblage and diversity, supply indirect evidence of initial sedimentary conditions which may represent one of any number of physical conditions (*e.g.* salinity, substrate coherence, water turbidity, oxygenation, rates of deposition *etc.*). Ichnofossil assemblages may be correlatable with ancient animal communities, which in turn can be employed in determining palaeoecological settings. Moreover, trace-making organisms can modify their behaviour in response to even the slightest environmental change. Recognition of these subtle behavioural inflections contributed information to overall interpretations that are commonly unobtainable from conventional examination of primary sedimentary structures. It was felt that integration of both sedimentology and various ichnologic concepts was required in order to best characterise the depositional history and consequent palaeoenvironmental reconstructions of the Bow Island/Viking sediments.

1.23 Study Area

Taking the above general study goals into consideration with other factors, lead to the selection of the appropriate study area. In order to investigate such things as ichnologic suites, sedimentary facies, depositional environments, key bounding surfaces, and stratigraphy, a significant database of rock (*i.e.* drill core) and well logs is required. The detailed study area comprises Townships 22-29, Ranges 18-22W4; a 1440 miles^2 (~3730 km^2) area which encompasses a number of oil and gas fields, including Wayne-Rosedale, Hussar, and Wintering Hills (Fig. 1.2). On oil industry "picks" cards, the transition from Viking to Bow Island nomenclature takes place from T23 south, and from R18W4 east. Glaister (1959) referred to this nomenclature change as "arbitrary" and placed his limit of the Bow Island Formation in a NW-SE linear trend extending from approximately T27 to T15 (Glaister, 1959, Fig. 2). Glaister's (1959) trend roughly corresponds to a dramatic thinning of the overall top Mannville Group to top Viking Formation isopach north of his trend (M.J. Ranger, pers. comm., 1993). The nomenclature change is, for all intents and purposes, arbitrary, as it is largely a remnant of whatever name the wellsite geologist decided to assign to the Bow Island/Viking interval. The central problem with the Bow Island/Viking transition is that the stratigraphic relationship between the two has not been clearly documented.

The study area is important in terms of aiding in the resolution of the existing stratigraphic inconsistency, although the overall well log character is relatively consistent throughout the study area. As a result, the probable "true" Bow Island/Viking transition occurs just to the north of the study area, as opposed to where the "picks" cards tend to suggest. Unfortunately, the core database north of Township 29 is not particularly good until at least Township 34. Therefore, the study area chosen was the best compromise in terms of importance in Bow Island/Viking Formation stratigraphic nomenclature, palaeogeography, available core and well log data, and lack of published data. No detailed study has been published for the study area, although it has been incorporated in larger studies (*e.g.* Amajor and Lerbekmo, 1980; Beaumont, 1984; Ryer, 1987; Amajor and Lerbekmo, 1990a,b). The well logs and overall isopach thickness of the Mannville Group to top Bow Island/Viking Formation, together with Glass's (1990) observations, suggest that the interval of interest in this study is more amenable to descriptions of the Bow Island Formation as opposed to the Viking Formation. As such, the Bow Island/Viking interval will be referred to as the Bow Island Formation for the remainder of the thesis. It should be noted, however, that the scout tickets in this area dominantly refer to the interval as the Viking Formation.

1.24 Specific Objectives

Specific attention was aimed at two major scientific problems:

The first is the refinement of a core based stratigraphic framework for the uppermost Bow Island Formation in the outlined study area.

There is a major change in stratigraphic nomenclature between what is termed the Viking Formation in the Central Alberta Plains, and what is termed the Bow Island Formation in the Southern Alberta Plains. The Bow Island Formation is commonly ~100m thick, and consists of a series of at least seven stacked marine to marginal marine sandstone, conglomerate and mudstone sequences whereas the Viking Formation is generally a much thinner interval (~50m) that is composed of four to five sanding/coarsening upwards sequences. It has generally been accepted that the Viking Formation in the Central Alberta Plains somehow correlates to the Bow Island Formation in the Southern Alberta Plains. A major objective for this scientific inquiry was to formalise a stratigraphic framework for the Bow Island Formation in the chosen study area as a reference point for other stratigraphic investigations to the south and north of this area (*e.g.* Cox, 1991; Cox and Williams, 1991; Reinson *et al.*, 1993; Hadley, 1992). A current research project at the University of Alberta is focusing on the Viking Formation in an adjacent area north of this study (*i.e.* the Fenn, Chain, and Mikwan areas; see Fig. 1.1). Careful core examination and correlation to well log response was conducted in order to construct a working stratigraphic framework based on core. It is stressed that no detailed cross section work was carried out because the main focus was on the recognition of stratigraphic breaks in core.

The second objective is the interpretation of depositional environments and relative sea-level history of the Bow Island Formation in south-central Alberta based on ichnologic and sedimentologic facies characterisation.

Assimilation of information obtainable from ichnofossils, taken together with primary physical sedimentary structures results in the most plausible palaeoenvironmental interpretation of these sediments, based on exacting ichnologic and sedimentologic (*i.e.* facies) analysis. The nature of key bounding surfaces was also examined. Their interpretation requires ideas regarding the role of relative sea-level rise and fall in the Cretaceous Interior Seaway. This factor, in turn demands consideration of such parameters as tectonics, actual eustatic changes in sea-level, subsidence rates, sediment accommodation space, sediment flux into the basin, and natural processes associated with depositional systems (*e.g.* delta lobe switching, channel abandonment *etc.*). Basically, the importance of allocyclic versus autocyclic geologic processes had to be carefully investigated.

1.3 DATABASE AND STUDY METHODS

The presence of several small oil and gas fields provides an excellent database of Bow Island Formation drill cores to work with. Sixty-nine subsurface cores were examined in detail within and adjacent to the study area, with specific attention paid to the ichnologic features and physical sedimentary structures present in the rocks. The core data was entered into a core logging software package which allowed them to be computer drafted (see Appendix 1). Grain size measurements were made with a Canstrat grain size card and a binocular microscope. In addition, the study area contains extensively drilled large oil and gas fields which produce from the Lower Cretaceous Mannville Group; this provides a huge database of geophysical well logs that pass through the Bow Island Formation. Approximately 500 well logs were examined in the course of this study. The general lithologies obtained from core observations were compared with their respective suites of well logs in order to characterise the actual rock-types represented by the well log signatures. These results were then used as a guide to interpret lithologies from well logs where no tangible core data was available. The majority of the cores penetrated only the upper 10-20m of the Bow Island Formation, which is ~100m thick through most of the study area (see Fig. 1.3). As a consequence of this, very little actual rock data exists for the basal ~80m of the Bow Island Formation; so correlation of the lower/older Bow Island Formation cycles was not specifically carried out.

The facies descriptions and designations proposed in this study are obviously controlled by the available core database and therefore, are dominantly based on observations of the uppermost 10-20m of Bow Island Formation section (*i.e.* the "First Bow Island Sandstone").

1.4 ECONOMIC RATIONALE FOR RESEARCH

Both the Viking and Bow Island Formations are substantial oil and gas reservoirs in Alberta. As of December 1989, the Energy Resources Conservation Board estimates Viking Formation initial reserve volumes of conventional crude oil in place at 2.939 X $10^8 m^3$ (~1.85 billion bbls). Initial volumes of raw natural gas in place in the Viking Formation are roughly 3.89 X $10^{11} m^3$ (~13.8 Tcf). Bow Island Formation reserves are not specifically addressed although it is widely known that many Bow Island fields in southern Alberta have been prolific gas reservoirs since the 1940s and earlier. Producing Viking Formation facies have average porosities of 15-25% in the Wayne-Rosedale (~T27; R20w4) and Wintering Hills (~T25; R17w4) areas, while Bow Island Formation porosities of southern Alberta range from approximately 10-16% (E.R.C.B., 1989). Detailed facies analysis ultimately yields depositional models that can be used in oil and gas exploration and exploitation strategies for significantly porous and permeable hydrocarbon bearing facies. Bow Island/Viking deposition was followed by a widespread transgression of the Colorado Seaway, which resulted in deposition of the unnamed dark shales of the Lower Colorado Group. This transgressive phase reworked existing sediments and moulded them into discrete relict (*i.e.* "cannibalised") sand and conglomerate lenses (commonly referred to in the oil industry as "the Viking Grits"). Careful recognition and characterisation of these distinct sediments in cores and well logs may facilitate the mapping of thin, laterally extensive, but economically viable, unexploited reservoirs. Such an approach has resulted in recompletion of Viking oil wells in the Joarcam Field (~T47-50; R19-22w4) which has added 4.72 X $10^5 m^3$ (~2.97 million bbls) to the initial estimated oil reserves (E.R.C.B., 1989; Posamentier and Chamberlain, 1990). Exploration for natural gas in Bow Island Formation sandstone and conglomerate reservoirs is currently ongoing in the confines of the study area. Moreover, the Bow Island/Viking interval in general has always been an attractive natural gas target (largely due to its shallow burial depths and consequent cheaper drilling costs); a fact supported in a recent article by Trollope (1993), which ranks the Viking Formation the fourth best marketable natural gas reservoir in Alberta. Stratigraphic traps are the norm for Bow Island Formation reservoirs, and so correlation of regional flooding surfaces found in the study area has significant effects on exploration and development strategies. Finally, it is widely known that lowstand associated incised valley-fill deposits exist in the Viking Formation. The Crystal Field (~T43-50; R2-5w5) alone possesses primary oil reserves of 1.62 X $10^6 m^3$ with an additional 5.8 X $10^6 m^3$ under secondary recovery (Reinson *et al.*, 1988). Valley-fill deposits have also been recognised in the Bow Island Formation in southern Alberta (Cox, 1991; Cox and Williams, 1991); the possible existence of undiscovered, potentially economically viable Bow Island valley-fill associated reservoirs within the study area, could not have been ruled out at the beginning of this project.

Obviously, documentation of factors such as facies distributions, stratigraphic trapping mechanisms, and stacking patterns of individual depositional systems, have profound economic ramifications. Such academic research has the potential to aid in better understanding existing Bow Island and Viking Formation reservoirs, and perhaps, even generate new oil and gas exploration prospects.

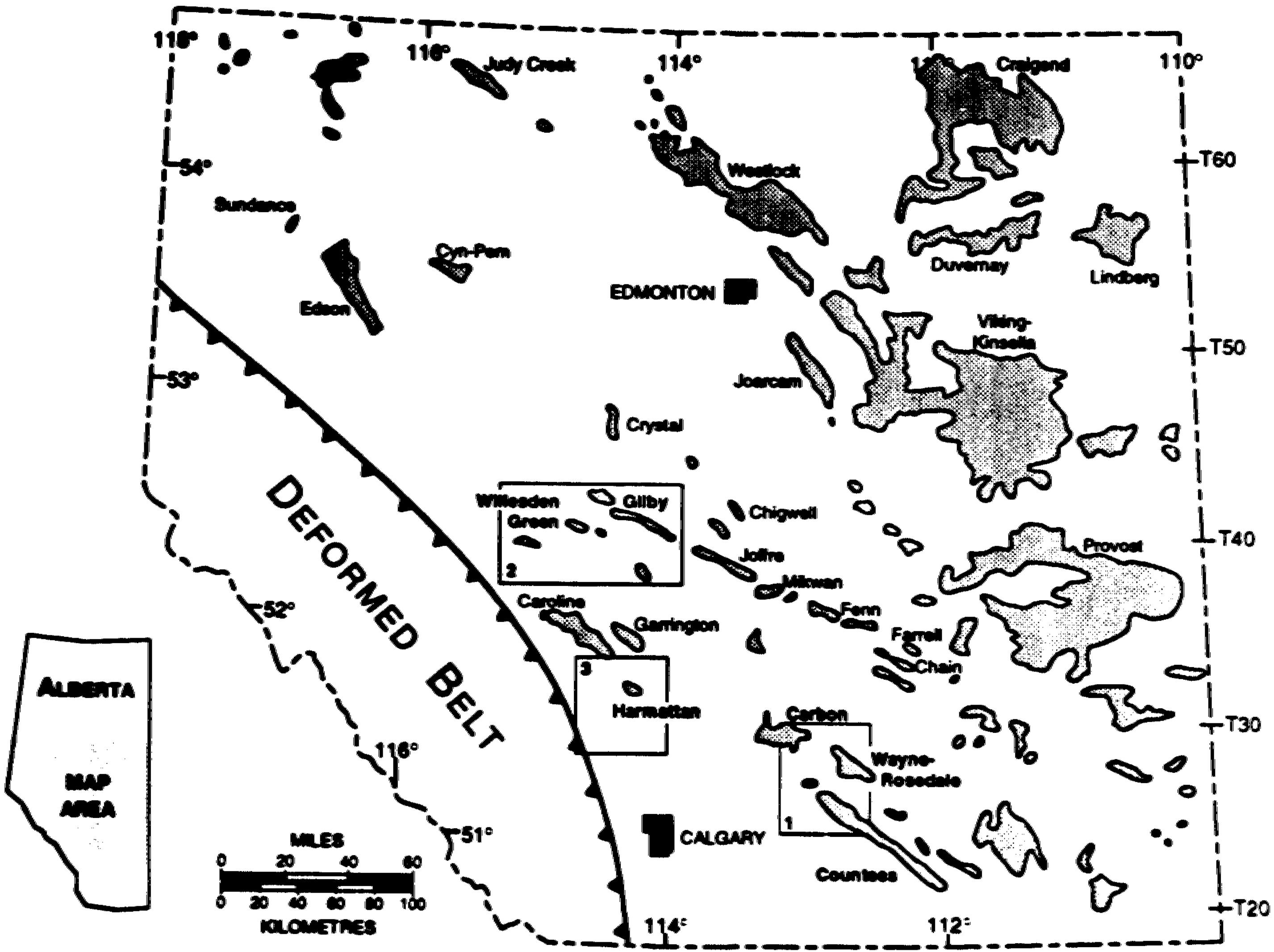


Figure 1.1 Location map of several producing Viking fields; 1: thesis study area; 2: study area covered by allostratigraphy of Boreen and Walker (1991); 3: study area covered by allostratigraphy of Hadley (1992)

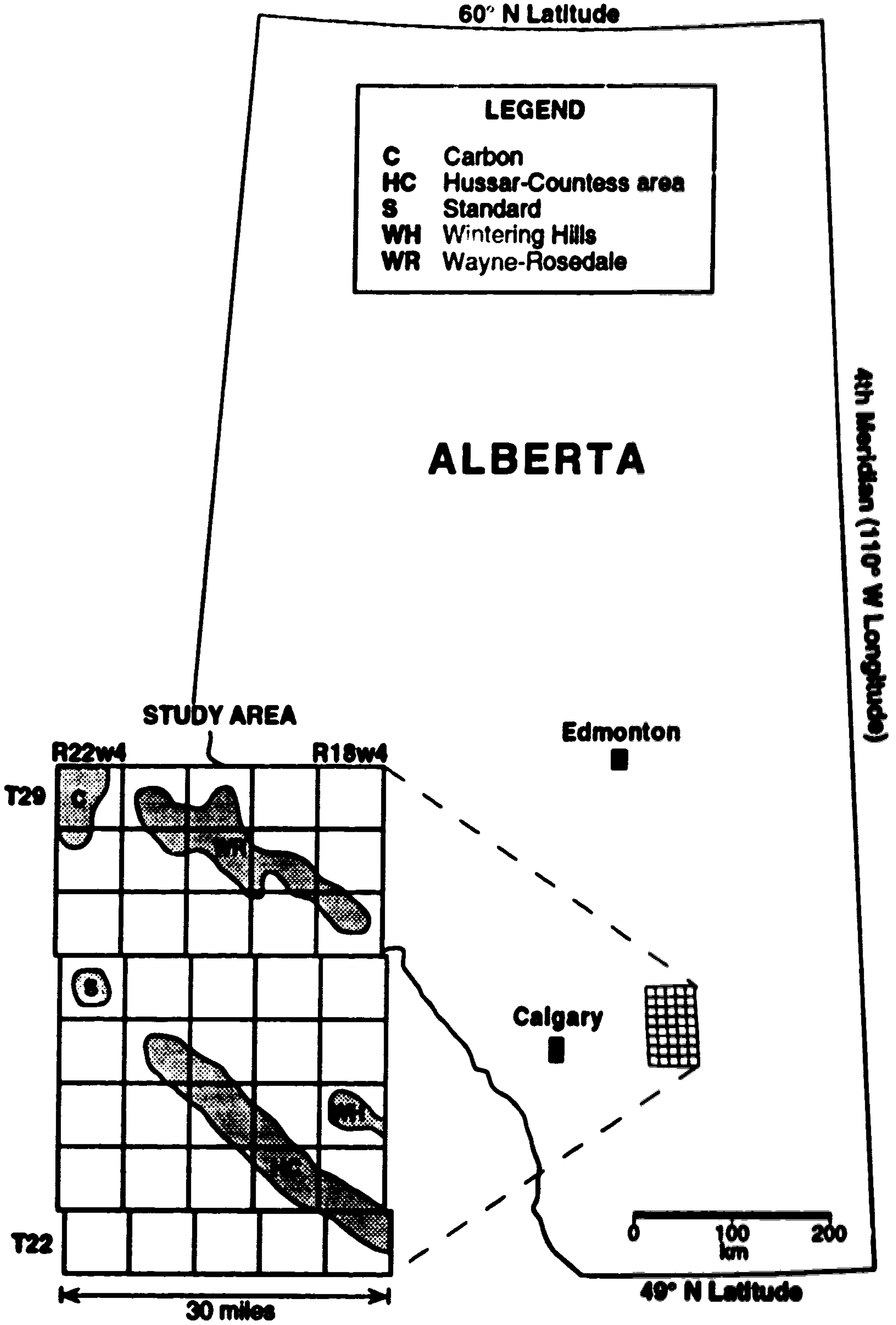


Figure 1.2 Location map of detailed study area, showing the location of several oil and gas fields

TYPICAL GEOPHYSICAL WELL LOG RESPONSE

BOW ISLAND/VIKING FORMATION,
WAYNE-ROSEDALE AREA
14-35-26-20W4

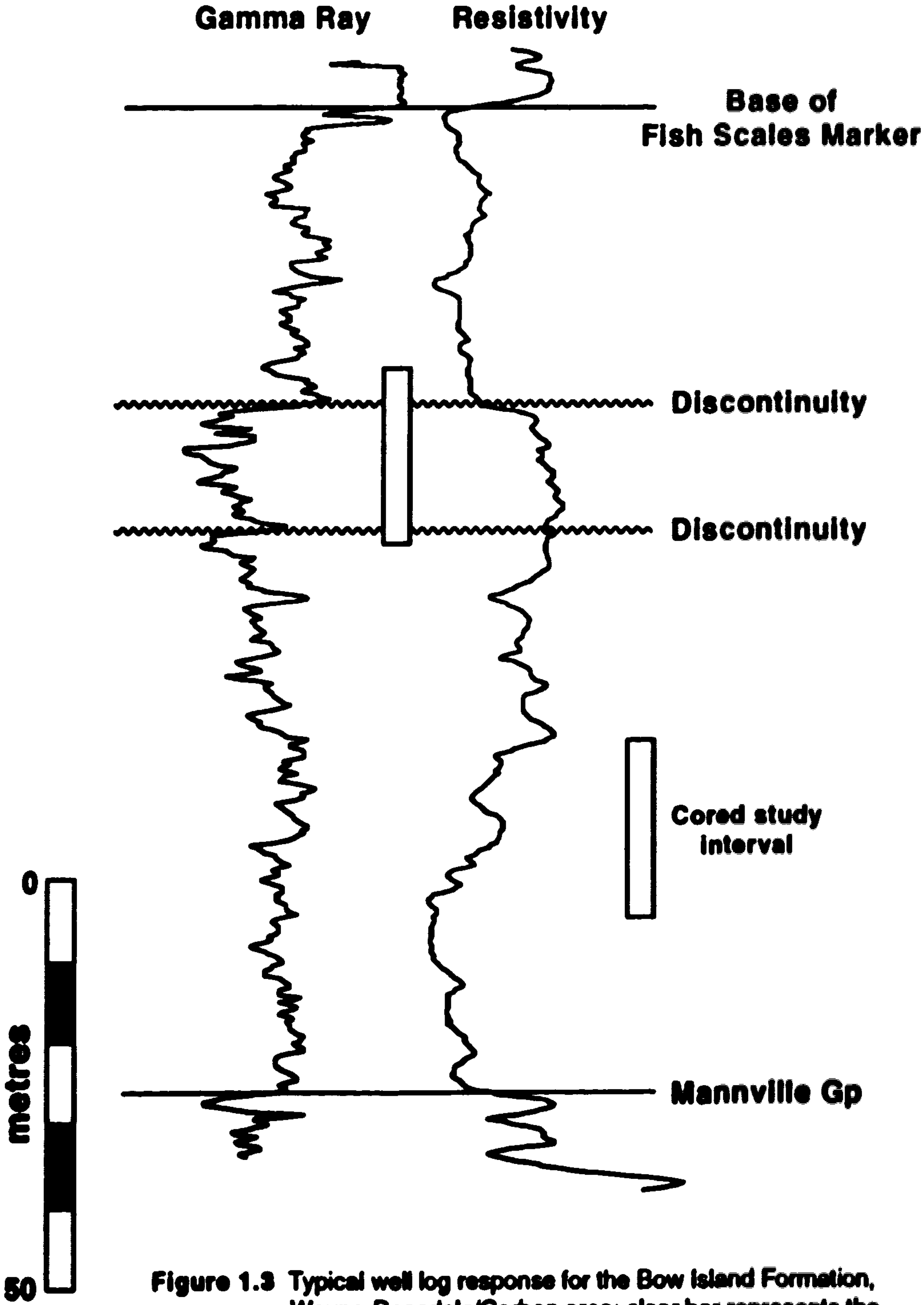


Figure 1.3 Typical well log response for the Bow Island Formation, Wayne-Rosedale/Carbon area; clear bar represents the average cored interval for this study.

CHAPTER 2: BACKGROUND, PREVIOUS WORK, STRATIGRAPHY, PALAEOGEOGRAPHY AND STRUCTURAL SETTING

2.1 INTRODUCTION

Cretaceous shelf and shallow marine sandstone and conglomerate bodies have long been recognised as important oil and gas reservoirs throughout the Western Canada Sedimentary Basin. Consequently, their study, and understanding the processes that affect them has historically been of paramount importance. Cretaceous, long, linear reservoir sandstone and conglomerate bodies are commonly sharp based, continuous for tens of kilometres along strike, and encased in marine shales. Early researchers routinely interpreted them as "offshore bars" that were deposited on the shelf and moulded by shelfal currents. These interpretations had problems explaining such factors as how the sediment was supplied to the shelf, how the sediment was then moulded into coarsening/sanding upwards successions, and how the sand bodies were then encased in marine shales. These problems, amongst others, exist for several Cretaceous aged oil and gas fields throughout Alberta (*e.g.* Downing and Walker, 1988).

DeWiel (1956) and Glaister (1959) were pioneers in recognising the significance of relative sea-level fluctuations on Lower Cretaceous units in the Western Canada Sedimentary Basin. In the early 1980s, work by numerous researchers began to re-discover the importance of relative sea-level fluctuations in the complex depositional histories of these enigmatic, multi-storey sandstone and conglomerate bodies. Since that time, most of the research carried out has stressed the role of relative sea-level fluctuation in the sedimentology and stratigraphy of numerous Cretaceous units including the Turonian Cardium Formation (*e.g.* Plint, 1988; Plint *et al.*, 1986, 1988; Bergman and Walker, 1987, 1988), the Cenomanian aged Dunvegan Formation (*e.g.* Bhattacharya, 1988, 1989, 1992; Bhattacharya and Walker, 1991), and the Viking Formation (*e.g.* Boreen, 1989; Boreen and Walker, 1991; Pattison, 1991a,b). These studies focused on the recognition and correlation of allostratigraphically significant surfaces throughout the respective study areas. The recent research on these and other units has provided conceptual frameworks useful for both exploration and development schemes.

Many Bow Island fields in southern Alberta (*e.g.* Pakowki Lake, Taber, Pendant D'Oreille, Blood *etc.*) have been prolific hydrocarbon producers since their initial discoveries. The name 'Bow Island Formation" is derived from the initial natural gas discovery well (6-15-11-11w4; C.W.N.G. Bow Island No.1 is the type locality) drilled by the Canadian Western Natural Gas Company, just to the northwest of the Bow Island townsite in 1909 (Gammell, 1955; Glass, 1990). This discovery triggered oil and gas exploration in the time equivalent Viking Formation of central Alberta. The Viking Formation was formally named by Dowling *et al.* (1919 *fide* Glass, 1990), and while no type section is officially designated, the name is derived from Slipper's (1918) original designation of the producing sandstone reservoir in the Viking-Kinsella field, near the towns of Viking and Kinsella, Alberta (~T46-47; R11-12w4) (Glass, 1990).

2.2 SUMMARY OF PREVIOUS WORK AND INTERPRETATIONS

Early researchers interpreted many of the producing Cretaceous sandstone and conglomerate bodies as turbidite deposits (Beach, 1955, 1956, 1962; Roessingh, 1959). Others interpreted the Viking Formation deposits as parts of offshore barrier bar/beach/island-spit systems that separated open marine environments from shoreline environments in the Suffield area (~T19-26; R1-16w4) (Tizzard and Lerbekmo, 1975), Joarcam and Joffre (Ryer, 1987), and at various other locations throughout central and south-central Alberta (Amajor, 1984; Amajor and Lerbekmo, 1990a,b). Tidal currents have also been credited with depositing sediments of the Viking Formation (Evans, 1970; Simpson, 1980; Grujenschi, 1984; O'Connell, 1984; Leckie, 1986a; Boreen, 1989; Raychaudhuri, 1989; Davies, 1990). Kroon (1951) suggested that the Bow Island sandstone lenses in the Pakowki Lake area (~T4-5; R7w4) resulted from the filling of depressions in the sea floor as opposed to shoreline sand bars. DeWiel (1956) recognised the role of relative sea-level changes on Viking Formation deposition, supporting a tectonic control by stating, "even the slightest oscillation of the Cretaceous exogeosyncline (Kay, 1951) brought about a considerable lateral displacement of the shoreline without producing a conspicuous disconformity.". Glaister (1959) supported changes in sea-level as the controlling factor in the deposition of the Bow Island Formation, by noting that, "slight fluctuations in sea-level shifted the strand line many miles" and, "The Bow Island sandstones appear for the most part to have been deposited during slow regressions of the sea, followed by rapid transgressions.". Beaumont (1984) was the first to specifically address the importance of relative sea-level rise and fall on regressive-transgressive deposits of the Viking Formation at the Joarcam and Joffre fields. Subsequent work on the Viking Formation focused on the recognition and delineation of discontinuities that enveloped packages of genetically related sediment. The two main stratigraphic schemes that require such an approach are sequence stratigraphy and allostratigraphy, both of which have been applied to the Viking Formation. Sequence stratigraphy was recently applied to the Joarcam Field by Posamentier and Chamberlain (1990, 1991a,b) whereas Boreen and Walker (1991) and Hadley (1992) applied allostratigraphy to the Willesden Green (~T39-44; R5-8w5) and Harmattan-Crossfield (~T28-33; R28w4-5w5) areas respectively. In the context of these types of stratigraphic frameworks, Viking Formation sediments have recently been interpreted as estuarine incised valley fills at Crystal (Reinson *et al.*, 1988; Pattison, 1991a,b,c; Leckie and Reinson, in press), Sundance, Edson (Putnam *et al.*, 1991; Pattison, 1991a,b,c), Cyn-Pem (Pattison, 1991a,b,c) and Willesden Green (Boreen and Walker, 1991; Pattison, 1991b) (Fig. 1.1). Ryer (1987) interpreted Willesden Green and Crystal to be tidal inlet/channel deposits. Gas prone valley fill deposits have also been described in the Bow Island Formation of the Blood Field (~T6; R22w4) in Southern Alberta (Cox, 1991; Cox and Williams, 1991). Alternatively, Bow Island conglomerates and sandstones in the Blood Field have been interpreted as wave formed bodies (Putnam *et al.*, 1991). Viking Formation sediments have been interpreted as shoreface deposits at locales including Gilby A and B (Raddysh, 1988), Joarcam (Power, 1988; Posamentier and Chamberlain, 1990, 1991a,b), Joffre (Downing and Walker, 1988), Chigwell (Raychaudhuri, 1989; Pattison, 1991a; Raychaudhuri *et al.*, 1992), Caroline (Leckie, 1986a; Hein *et al.*, 1986; Davies, 1990), Garrington (Hein *et al.*, 1986; Davies, 1990) and Harmattan (Hein *et al.*, 1986; Hadley, 1992) (Fig. 1.1). Ryer (1987) suggested that the Garrington and Harmattan East fields were representative of wave-dominated delta or strandplain deposits. The Viking Formation sand body at Eureka field, Saskatchewan was recently interpreted to have been deposited downdrift of a deltaic source in "perhaps a few tens of metres of water", as a sand plume, that was then degraded and drowned by a later transgressive event (Pozzobon and Walker, 1990). These interpretations of Viking/Bow Island Formation sediments, together with some interpretations from older work, are summarised in Table 1.

The majority of the aforementioned studies were carried out north of Township 30, with rare studies of the Bow Island Formation in southern Alberta generally concentrated on a geographic area south of Township 20. Furthermore, the studies are primarily based on sedimentary facies analysis and the recognition of stratigraphically significant surfaces (*e.g.* flooding surfaces). The purpose of this study was to examine the transitional Bow Island/Viking Formation area in detail between the bulk of the pre-existing work and integrate ichnology with sedimentology and stratigraphy in hopes that a multidisciplinary approach might resolve the obvious complexities inherent in unravelling Bow Island/Viking Formation palaeoenvironments and their palaeogeographic distributions.

2.3 REGIONAL STRATIGRAPHY AND ALLOSTRATIGRAPHY

2.31 General Stratigraphy

The Viking Formation is uppermost Lower Cretaceous in age, specifically, belonging to the Upper Albian Substage. The Lower Colorado Subgroup of the Alberta central plains comprises, from bottom to top, the Joli Fou Formation, the Viking Formation, and the unnamed shales of the Lower Colorado Subgroup. This corresponds to an overall transgressive-regressive-transgressive cycle in which the Viking Formation represents the regressive phase. The Viking/Joli Fou contact is locally unconformable (Glass, 1990) and the Viking/unnamed Colorado Group shale contact is also unconformable (VE4 of Raychaudhuri, 1989; Boreen and Walker, 1991; Pattison, 1991a; Davies, 1990; Hadley, 1992), although previous workers have considered the contact conformable (Glass, 1990).

2.32 Joli Fou Formation

In southern Alberta, the Joli Fou Formation is rarely present, as it grades into the lower portion of the Bow Island Formation. The Joli Fou Formation thins to the west, where it becomes essentially correlative with lower (*i.e.* Second and Third) Bow Island Sandstones. In addition, the Basal

Colorado Sandstone underlies the Bow Island Formation throughout much of southern Alberta (Banerjee, 1989). The Joli Fou Formation underlies the Viking Formation in the central Alberta Plains, and has been referred to as the Basal Lloydminster shale (Bullock, 1950). Approximate equivalents to the Joli Fou Formation include the Skull Creek Shales of north-central Montana, the Taft Hill and Flood Members of the Blackleaf Formation of northern Montana, and the lower Thermopolis Shale of Wyoming (Glass, 1990; C.R. Stelck, pers. comm., 1994) (Fig. 2.1).

2.33 Viking Formation/Bow Island Formation

Taken together, the Viking and Joli Fou Formations are approximately equivalent to the Bow Island Formation of southern Alberta, where the Lower Colorado Subgroup comprises the Basal Colorado Sandstone (locally), the Bow Island Formation, and the unnamed shales of the Lower Colorado Group. Other approximate equivalents to the Viking Formation include: the Paddy Member of the Peace River Formation of northwestern Alberta, the Pelican sandstone of northeastern Alberta, the Ashville Sand of southern Manitoba, the Newcastle Sandstone of North Dakota and Montana, the Muddy Sandstone of Wyoming, and the "J" Sandstone of Colorado (McGookey *et al.*, 1972; Glass, 1990; Leckie and Reinson, in press; J.A. MacEachern, pers. comm., 1993) (Fig. 2.1). More informal terms have also been applied to the Viking interval including Viking Grits, Viking Chert, and Viking Conglomerate, all of which have been used to describe coarse grained to pebbly facies associated with the Viking Formation. The term Viking Conglomerate, in fact, was first coined to describe the producing pebbly reservoir at 11-11-27-20w4, which lies in the Wayne-Rosedale field area (Glass, 1990) (Fig. 1.1).

Moving westwards into the Alberta Foothills, the Bow Island Formation becomes essentially indistinguishable from sandstones of the Blairmore/Mannville Group, and is unconformably overlain by the Fish Scales Sandstone (Glass, 1990). Specifically, the Bow Island Formation is approximately equivalent to the Ma Butte Formation/Crowsnest Formation interval of the Blairmore Group, and the lower part of the Blackleaf Formation in northern Montana. In ascending order, the Blackleaf Formation comprises the Flood Member, the Taft Hill Member, the Vaughn Member, and the Bootlegger Member. The oil industry has informally separated the Bow Island Formation into (from youngest to oldest) the First, Second, and Third Bow Island Sandstones, although these three main sandstones appear to be made up of several, smaller stacked sandstone bodies. The First and Second Bow Island Sandstones are separated by shaly, commonly bentonitic strata called the Red Speck Zone. The Red Speck Zone is equivalent to the Vaughn Member of the Blackleaf Formation of Montana. The distinctive reddish colouration is imparted by the presence of a low-medium temperature zeolite mineral called clinoptilolite (a fairly stable zeolite similar in structure to heulandite). The clinoptilolite is likely an alteration product of volcanic glass shards found in the associated bentonitic horizons. The implication of these somewhat convoluted stratigraphic relationships is simply that the Basal Colorado Sandstone and Second and Third Bow Island Sandstones are essentially equivalent to the Flood and Taft Hill Members of the Blackleaf Formation. It follows that the Red Speck Zone and its equivalent Vaughn Member, separate the Second Bow Island Sandstone/Taft Hill Member from the overlying First Bow Island Sandstone and its partial equivalent, the Bootlegger Member. The upper portion of the Bootlegger Member is likely equivalent to the basal portion of the unnamed shales of the Colorado Group. These relationships are also suggested by other researchers (Cobban *et al.*, 1959; Lang and McGugan, 1988), although Cobban *et al.* (1959) also suggest that the Vaughn Member/Red Speck Zone is equivalent to the Newcastle Sandstone of Wyoming, and consequently, that the First Bow Island Sandstone is equivalent to the basal Mowry Shale/unnamed shales of the Lower Colorado Group. The composite subsurface core section from southern Alberta of Lang and McGugan (1988) shows no occurrence of the Vaughn Member, and their isopach maps and idealised stratigraphic cross section indicate that the Vaughn Member thins dramatically from WSW (area of Marias Pass, Montana) to ENE (~T6; R11w4). Furthermore, Lang and McGugan (1988), adhering to the stratigraphy of Cobban *et al.* (1959), consider the Vaughn Member to be older than the Taft Hill Member, although their stratigraphic chart shows the Vaughn Member interfingering with both the Taft Hill and Bootlegger Members of the Blackleaf Formation.

Koke and Stelck (1985) correlate the Bootlegger shale with the unnamed shales of the Lower Colorado Group (just below the Base of Fish Scales marker), the top of the Vaughn Member to the top of the Bow Island

Formation, and the top of the Taft Hill Member to the top of the Viking Formation. Similarly, Arnott (1987, 1988) agrees that the entire Bootlegger Member is younger than the Bow Island Formation and instead corresponds to the unnamed shales of the Lower Colorado Group. Obviously, there is some debate as to the exact nature of the stratigraphic relationships.

Informal designations adopted in this work include "upper Bow Island Formation", which essentially refers to the First Bow Island Sandstone, and "lower Bow Island Formation", which roughly refers to the Second and Third Bow Island Sandstones.

2.34 The unnamed shales of the Lower Colorado Subgroup

No formal name has been given to the dark shales that overlie the Bow Island/Viking interval. Cross bedded medium grained sandstone beds, thin conglomeratic beds, and pebbly sandstone beds are commonly found in the basal portions of the interval (*i.e.* the Viking Grits). The unnamed shales overlie the Viking Formation, and pass upwards into the Base of Fish Scales Zone. The Base of Fish Scales marker has been designated the top of the Viking alloformation (Boreen, 1989; Boreen and Walker, 1991; Hadley, 1992). As no formal name exists for these shales, they have been referred to as the Lloydminster Shale (Tizzard and Lerbekmo, 1975; Amajor and Lerbekmo, 1980; Hein *et al.*, 1991), the Post Viking Shale and the Shaftesbury Shale (Stelck and Koke, 1987), the Lower Shaftesbury (Stelck, 1958), the Colorado Formation (Boethling, 1977a; Beaumont, 1984), and the Lower Colorado shales (Leckie and Reinson, in press) (*cf.* Fig. 2.1). For the purposes of this study, the unnamed shales of the Colorado Subgroup will be referred to as the Lower Colorado shales. The Lower Colorado shales are essentially equivalent to the upper portion of the Bootlegger Member and Mowry shale of Montana, the Shell Creek and Mowry shales of Wyoming, and the Big River Formation of Saskatchewan (McGookey *et al.*, 1972; Simpson, 1975, 1982; Glass, 1990).

2.35 Chronostratigraphy

Very little work has been done regarding the chronostratigraphic dating of the Bow Island Formation and its equivalents. Folinsbee *et al.* (1963) did some of the pioneering work in the field of potassium-argon (*i.e.* K-Ar) geochronology on volcanic ash beds. Folinsbee *et al.* (1963) extracted sanidine and biotite crystals from bentonite beds of the Mowry shale (*Neogastroplites* megafaunal zone) near Casper, Wyoming. The sanidines revealed a date of 94-97Ma and the biotites gave a date of 86-96Ma. The sanidine dates were considered more reliable because biotite tends to give dates younger than the actual dates due to what is termed "argon leaking" (Folinsbee *et al.*, 1963; H. Baadsgaard, pers. comm., 1993). Tizzard and Lerbekmo (1975) extrapolated these dates and estimated the age of the Muddy Sandstone (~Viking/Bow Island equivalent) to be 96-98Ma. Three sanidine dates and two biotite dates averaged 101Ma and 96Ma respectively for samples collected by Tizzard and Lerbekmo (1975). Tizzard and Lerbekmo (1975) attributed the somewhat older dates to impurities contaminating the analysed sanidine crystals. Regardless, they concluded that their dates were in agreement with those they extrapolated from the work of Folinsbee *et al.* (1963). Moreover, Tizzard and Lerbekmo (1975) suggested that the true radiometric age for the Viking Sandstone is 100±2Ma. Weimer (1984) noted that radiometric ages derived from bentonites associated with the Joli Fou-Viking-Lower Colorado shale cycle suggest that the cycle was deposited between 96-98Ma. The major implication being that the entire Bow Island-Lower Colorado shales package was deposited in approximately two million years. Weimer (1984) also suggested that the regressive Viking phase is likely a result of the 97Ma sea level drop of Vail *et al.* (1977). Cant (1989) concurred that the regressive Viking Formation resulted from an Albian sea level drop, but places the age of the drop at 98Ma.

2.36 Biostratigraphy

2.36.1 Megafaunal zones

Megafossils were only observed in one core in the study area. The paucity of megafossils is largely a function of the relatively small core samples that provided the rock database for this study. Obviously, the likelihood of encountering an ammonite, for example, in a three to four inch vertical tube of rock is not great. Nevertheless, Stelck and Armstrong (1981) did find megafossils in drill cores of the Bow Island-Lower Colorado shales interval in southern Alberta. The ammonite *Neogastroplites septimus* was found in the Fish Scale Zone at 6-34-10-22w4 (~3318'), and the pelecypod *Posidonia nahwisi* was found just 15cm above the conglomerate that marks the top of the Bow Island Formation at 11-24-11-23w4 (~3833.5′) (Stelck and Armstrong, 1981). Stelck (1958) found few megascopic fossils in the Viking Formation, stating, "The writer's fossil list for the Viking sand phases is brief and includes a small limpet-gastropod; cycloid, ctenoid and ganoid fish-scales and other fish remains; sporitoid-like bodies and comminuted plant fragments...". Lang and McGugan (1988) listed *Inoceramus* fragments and prisms, fish scales, spines and teeth, shell fragments, and comminuted plant debris as the only megafossils visible in their composite subsurface section of southern Alberta.

The lower Bow Island Formation (~Taft Hill Member/Joli Fou equivalent level) overlies the uppermost Mannville Group (*Stelckiceras liardense* Zone), and belongs to the *Inoceramus comancheanus* Zone (Caldwell *et al.*, 1978; Koke and Stelck, 1985). The Lower Colorado shales belong to the *Neogastroplites* Zone (Cobban *et al.*, 1959; Koke and Stelck, 1985) (Fig. 2.2). *Inoceramus comancheanus* is a pelecypod that migrated northwards from the Gulf of Mexico during Joli Fou time (Stelck, 1958). Most of the upper Bow Island Formation and its equivalent Viking Formation belong to a zone in which no megafauna occur, and this zone persists into the basal portion of the Lower Colorado shales as well (Koke and Stelck, 1985). Stelck (1958) pointed out that dating the Viking Formation is difficult due to the lack of good mega- or microfossil assemblages, and consequently, that the position of the Viking sand phases can only be constrained by the more correlatable, more populous microfossil assemblages characteristic of the Joli Fou Formation and of the Lower Colorado shales.

2.36.2 Microfaunal zones

Although no microfaunal zonation of the Bow Island-Lower Colorado shales interval has ever been published, microfaunal zones for the equivalent Joli Fou-Viking-Lower Colorado shales interval do exist. These zones are based on arenaceous foraminiferal assemblages. Microfossils are present in the Viking Formation, but not in great quantities (Stelck and Koke, 1987). As a result, most of the microfossil work on the Viking Formation of central Alberta is based on shaly Viking equivalents in northeastern British Columbia (*e.g.* Stelck, 1975, 1991; Koke and Stelck, 1984, 1985; Stelck and Koke, 1987; Stelck and Leckie, 1990). The Joli Fou

Formation overlies the uppermost Mannville Group (*Gaudryina nanushukensis* Zone), is early Late Albian in age, and belongs to the *Haplophragmoides gigas* Zone (Stelck, 1958; Caldwell *et al.*, 1978). The Lower Colorado shales are late Late Albian in age and belong to the *Miliammina manitobensis* Zone (Stelck, 1975; Caldwell *et al.*, 1978). The *Miliammina manitobensis* Zone has been divided into three Subzones (in ascending order): *Verneuilina canadensis, Haplophragmoides postis goodrichi,* and *Bulbophragmium swareni* (Caldwell *et al.*, 1978; Stelck, 1991). The contact between the *Bulbophragmium swareni* Subzone and the overlying *Textularia alcesensis* Zone is indicated by the Fish Scale marker bed (*i.e.* the Base of Fish Scales Marker). The basal portion of the *Textularia alcesensis* Zone straddles the Albian-Cenomanian boundary (Caldwell *et al.*, 1978). These basic relationships are illustrated in Figs. 2.2 and 2.21.

The work of Bullock (1950) found that there was no distinct or abrupt microfaunal change between deposition of the Viking Formation and the surrounding shales of the Joli Fou Formation and Lower Colorado shales. Bullock (1950) characterised the Joli Fou sea as a shallow, slightly brackish, transgressive sea, whereas the Lower Colorado sea was characterised as a static, shallow water sea. Alternatively, microfossil studies by Leckie and Reinson (in press) suggest that the basal shales of the Lower Colorado sea were deposited in restricted, brackish, and/or stressed environments, which yielded to predominantly more normal marine conditions upwards. Interpretations based on ichnology of the Lower Colorado shales came to similar conclusions (MacEachern *et al.*, 1992b).

2.37 Allostratigraphy

Recent research emanating from McMaster University in Hamilton, Ontario has applied allostratigraphy to the Joli Fou-Viking-Lower Colorado shale interval in central Alberta (*e.g.* Boreen, 1989; Boreen and Walker, 1991; Hadley, 1992). Allostratigraphy is a stratigraphic framework based on the recognition of allostratigraphic units; an allostratigraphic unit is defined as, "a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities." (North American Commission on Stratigraphic Nomenclature, 1983). Boreen and Walker (1991) stressed that their allostratigraphy is informal and therefore they use allomember and alloformation with lower case letters. Boreen and Walker

(1991, Fig. 3) define the base of the Viking alloformation as their BV (*i.e.* Base of Viking) well log marker which they picked as the first major rightward deflection on resistivity well logs. The top of the Viking alloformation is considered to be the Base of Fish Scales Zone condensed horizon (Boreen and Walker, 1991). Leckie and Reinson (in press) have recognised two prograding cycles and two (possibly three) unconformities in the Viking Formation of southern Alberta, and have correlated them to the Paddy and Cadotte Members of the Peace River Formation of northwestern Alberta. This, however, seems unlikely because biostatigraphically, the Cadotte Member is older than the Joli Fou Formation (C.R. Stelck, pers. comm., 1994). Comparison of these two stratigraphic schemes has yet to be completed. The work of Boreen and Walker (1991) represents the only published allostratigraphic subdivision of the Viking Formation (Fig. 2.3), but for the purposes of this study, the allostratigraphy of Hadley (1992) is more applicable and appropriate (Fig. 2.4).

2.4 PALAEOGEOGRAPHY

2.41 Foreland Basin, Tectonics, Source of Sediment

The Alberta Foreland Basin formed during the Middle Jurassic, as the Intermontane superterrane was accreted to the western margin of the North American craton, triggering the Colombian orogeny (Ricketts, 1989; Cant, 1989). The westernmost portion of the basin underwent maximum subsidence (*i.e.* creation of the Alberta Foredeep along the Alberta/British Columbia border) as a flexural response to continued crustal loading associated with additional accretionary events and sediment input into the basin (Fig. 2.5). These elements facilitated the development of a shallow epeiric seaway which persisted in various configurations throughout the Cretaceous.

Bow Island Formation sediments were deposited into the Western Interior Seaway, on a broad, shallow "ramp" of the Alberta Foreland Basin. Sediment was derived from the uplifted Cordilleran rocks in the west and southwest, and dispersed eastward and northeastward. The thick Bow Island clastic wedge in southern Alberta fills accommodation space created by maximum basin subsidence (*cf.* Fig. 2.5). Ultimately, both the sediment accommodation space and the sediment source were tectonically controlled;

consequently, so were the sedimentation patterns and thickening/thinning of the Bow Island Formation.

The presence of the Crowsnest volcanics in southwestern Alberta, the largely bentonitic non-marine deposits of the Vaughn Member, and the numerous bentonite horizons in the Bow Island-Lower Colorado shales interval all attest to volcanic activity concomitant with deposition of the Bow Island Formation. This volcanism is associated with the emplacement of the Idaho Batholith in central Idaho, and its equivalents in Canada. Age determinations made from rocks of the Idaho Batholith range from 217-38Ma, with the majority of dates concentrated in the Cretaceous (McGookey *et al.*, 1972). The intrusion of batholiths and associated volcanism during the Cretaceous is most likely the source of the bentonite horizons and the Red Speck Zone in the Bow Island Formation.

Cant (1989) noted that the dominant coarse clastics of the Mannville/Blairmore Group contrast markedly with the dominantly shaly Alberta/Colorado Group; he ascribed this dramatic change in sedimentation to an overall decrease in activity of the Cordilleran orogenic belt, coupled with a world wide eustatic rise in sea level. Monger (1989, Fig. 2.3) showed a break in time between accretion of the Intermontane (~167Ma) and Insular (~98Ma) superterranes of the Canadian Cordillera. The smaller Bridge River terrane was accreted to the southwestern margin of the growing Cordillera between the two superterranes at ~100Ma, although its role, if any, in deposition of the Bow Island Formation is unknown and difficult to discern (Monger, 1989, Figs.2.3, 2.4; P. Erdmer, pers. comm., 1993). Mid-Cretaceous sediments were derived from the uplifted and eroded Omineca Belt and Cache Creek terrane; this implies that Bow Island Formation sediments were also sourced from these areas (Monger, 1989, Fig. 2.12b). Jones (1961) postulated that Viking sediments of southwestern Saskatchewan were derived from the Selkirk Mountains, British Columbia; he was at least partially right, as the Selkirk Mountains lie in the Omineca Crystalline Belt (S. Gilmour, pers. comm., 1993).

2.42 Western Interior Seaway

Reviews of the Albian palaeogeography of the Western Interior Seaway can be found in McGookey *et al.* (1972), Williams and Stelck (1975), Stelck (1975), Stott (1984), Vuke (1984), Koke and Stelck (1985), Stelck and

Koke (1987), Cant (1989) and Leckie (1989). The Joli Fou seaway was periodically continuous from boreal Arctic regions to the Gulf of Mexico (Williams and Stelck, 1975; Koke and Stelck, 1985; Stelck and Koke, 1987); this allowed a mixing of boreal and Gulfian faunas (Fig. 2.6). Evidence for a continuous Joli Fou seaway lies in the fact that boreal-affiliated *Haplophragmoides gigas* foraminifera were found together with Gulfian-affiliated *Inoceramus comancheanus* within the Joli Fou Formation (Williams and Stelck, 1975). The remainder of Albian time was characterised by a partially landlocked interior Mowry/Lower Colorado shale seaway that was open to the north and closed at its southern end in the vicinity of central Colorado (McGookey *et al.*, 1972, Fig. 17; Williams and Stelck, 1975) (Fig. 2.7). A palaeogeography during deposition of the Viking Formation is also given by Leckie (1989) (Fig. 2.8). Stott (1984) includes the Joli Fou-Viking/Bow Island-Lower Colorado shales interval in his, "Second Clastic Wedge", and provides a series of four palaeogeographic maps that span the interval (Fig. 2.9).

2.5 STRUCTURAL SETTING

As previously discussed, accretionary events and their accompanying orogenic activity played a large role in overall basin development and fill. Some of the major structural elements of western North America are shown in Figure 2.10. The study area lies just to the east of the deformed Cordilleran Belt, but west of the Sweetgrass Arch. No significant thinning of the Bow Island Formation occurs in the region of the Sweetgrass Arch, and so it is unlikely that the Sweetgrass Arch was a major factor during Bow Island deposition (M.J. Ranger, pers. comm., 1993). A structure map created slightly northwest of the study area, in the Harmattan-Crossfield vicinity (~T28-33; R28w4-5w5) showed a shallow regional southwesterly dip of Viking/Bow Island strata of 11m/kilometre (~0.63°) (Hadley, 1992).

Drill cores and well logs used in this study did not reveal any sign of large scale structural disturbance (*e.g.* fault repetition of the Bow Island interval), although some cores did exhibit synsedimentary microfaulting and soft sediment deformation features.

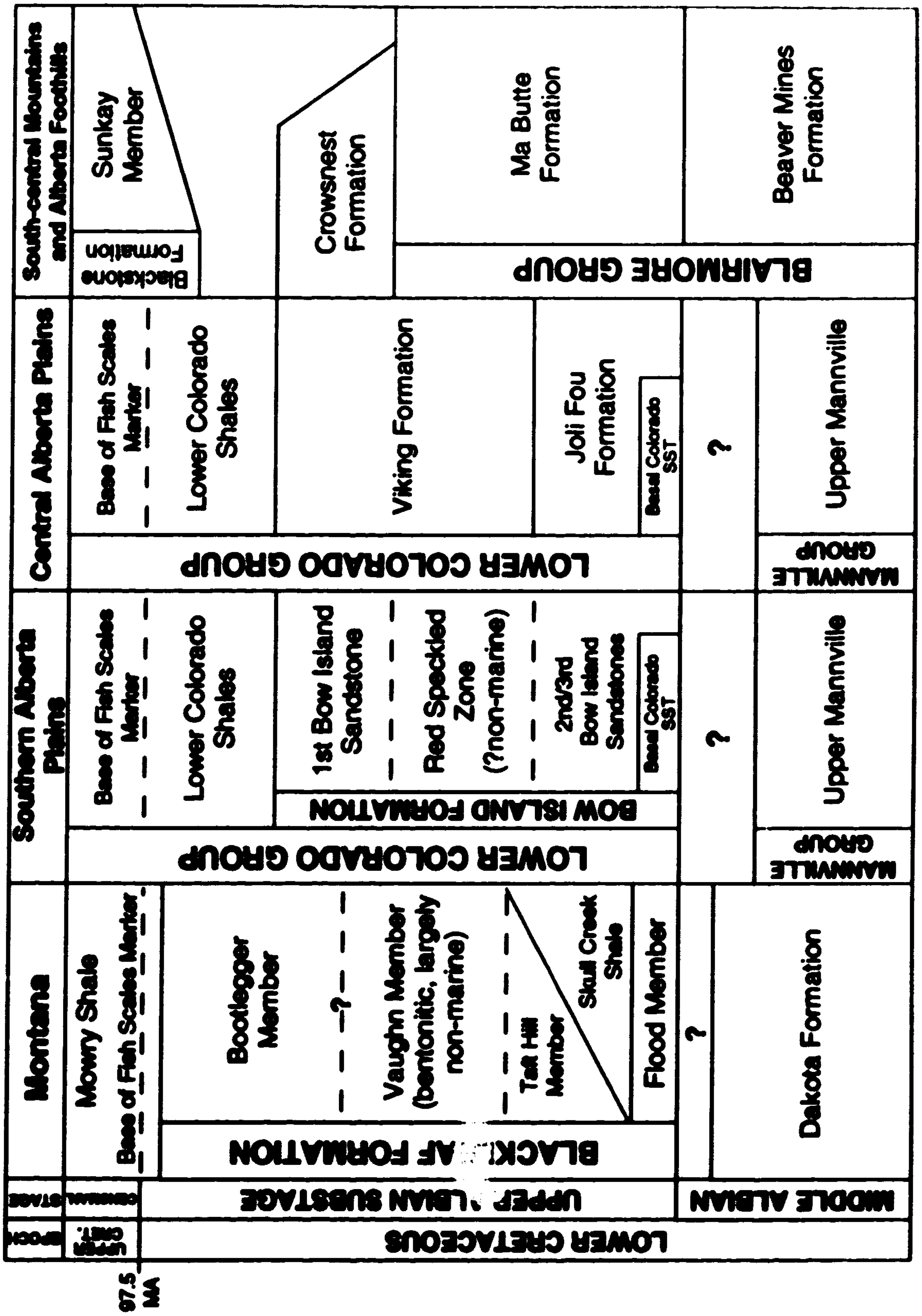


Figure 2.1 Lithostratigraphic chart with Albian stratigraphy of Southern Alberta correlated with some adjacent areas

STAGES	SELECTED MOLLUSCAN INDICES	FORAMINIFERAL	
		ZONES	SUBZONES
CENOMANIAN		*Flabellammina gleddiei*	*Haplophragmoides spiritense*
	Dunveganoceras hagei		*Ammobaculites pacalis*
	Dunveganoceras albertense *Dunveganoceras* cf. *conditum*	*Verneuilinoides perplexus*	*Gaudryina irenensis*
	Acanthoceras athabascense		*Ammobaculites gravenori*
	Beattonoceras beattonense	*Textularia alcesensis*	
ALBIAN	*Neogastroplites maclearni*		
	Neogastroplites muelleri	*Miliammina manitobensis*	*Bulbophragmium swareni*
	Neogastroplites cornutus *Neogastroplites haasi*		*Haplophragmoides postis goodrichi*
			Verneuilina canadensis
	Inoceramus comancheanus	*Haplophragmoides gigas*	
	Stelckiceras liardense	*Gaudryina nanushukensis*	*Ammobaculites wenonahae*
	Pseudogastroplites sp. *Gastroplites allani*		*Ammobaculites* sp.
	Gastroplites kingi *Arcthoplites macconnelli*		*Haplophragmoides multiplum*
	Arcthoplites irenensis		*Marginulinopsis collinsi*-*Verneuilinoides cummingensis*
			Trochammina mcmurrayensis
	Pachygrycia		*Rectobolivina* sp.

Figure 2.2 Molluscan and foraminiferal Zones for the Albian Stage, Western Interior of North America [modified from Caldwell*et al.* (1978)].

Substage	MOLLUSCAN ZONES		FORAMINIFERAL SUBZONES	FORAM ZONE
	Neogastroplites maclearni		Base of Fish Scales Marker	
UPPER ALBIAN SUBSTAGE	*Neogastroplites americanus*	LOWER COLORADO SHALES	*Bulbophragmium swareni*	*Miliammina manitobensis*
	Neogastroplites muelleri			
	Neogastroplites cornutus			
	Neogastroplites haasi		*Haplophragmoides postis goodrichi*	
			Verneuilina canadensis	
		BOW ISLAND FORMATION	*Reophax troyeri*	*Haplophragmoides gigas*
			Trochammina umiatensis	
			Trochammina depressa	
			Reophax tundraensis	
			Haplophragmoides gigas phaseolus	
	Inoceramus comancheanus		*Haplophragmoides gigas gigas*	
			Haplophragmoides uniorbis	
MID ALBIAN	*Stelckiceras liardense*		*Ammobaculites wenonahae*	*Gaudryina nanushukensis*
	Gastroplites allani		*Ammobaculites* sp.	
	Gastroplites kingi		*Haplophragmoides multiplum*	
	Pseudopulchellia pattoni			

Figure 2.21 Correlation of Molluscan Zones and Foraminiferal Zones/Subzones within the Upper Albian Substage, and its relationship to the Bow Island Formation [modified from Stelck and Koke (1987), Stelck (1991), and C.R. Stelck (pers. comm., 1993)]

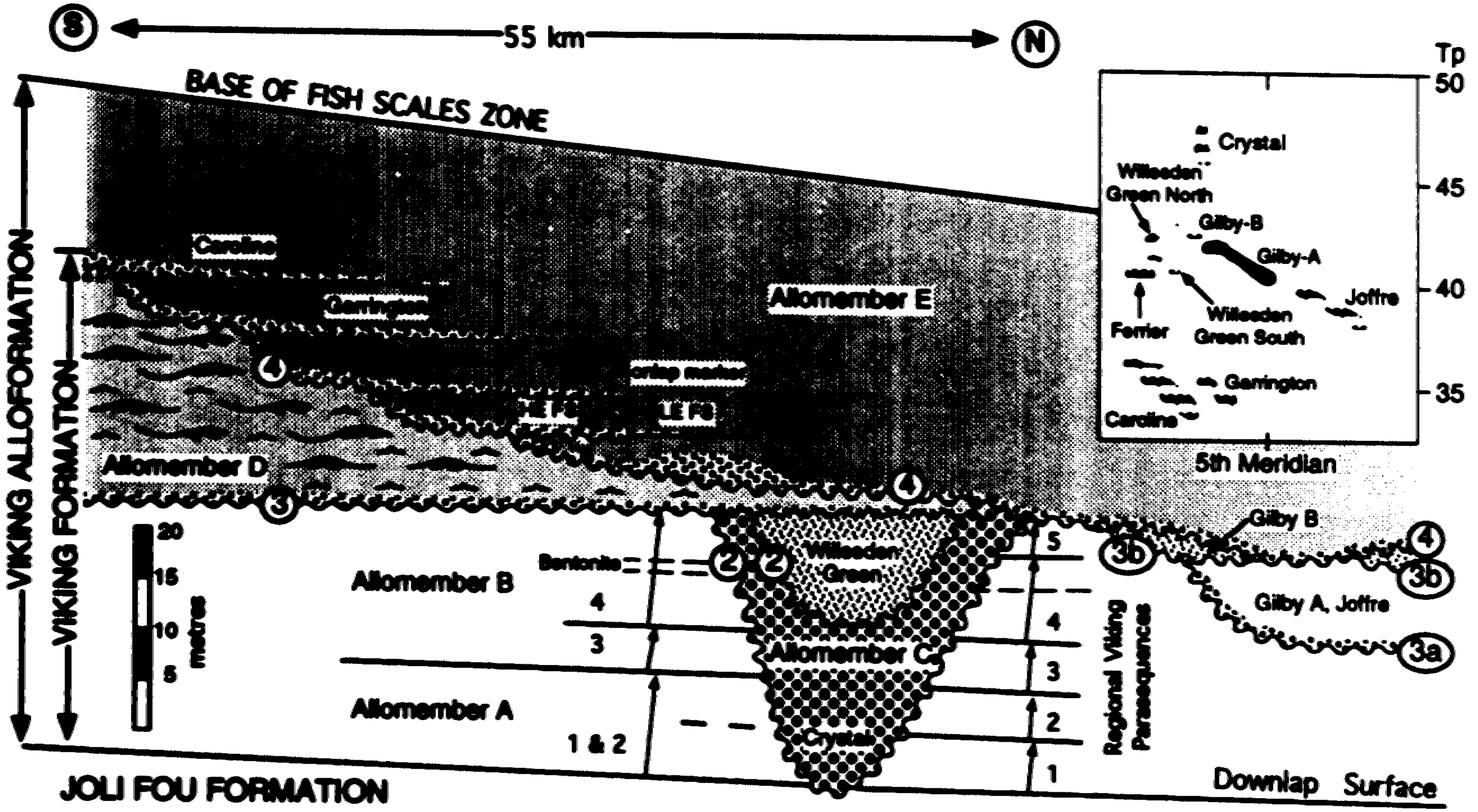


Figure 2.3 Allostratigraphy of the Viking Formation [modified from Boreen and Walker (1991)]

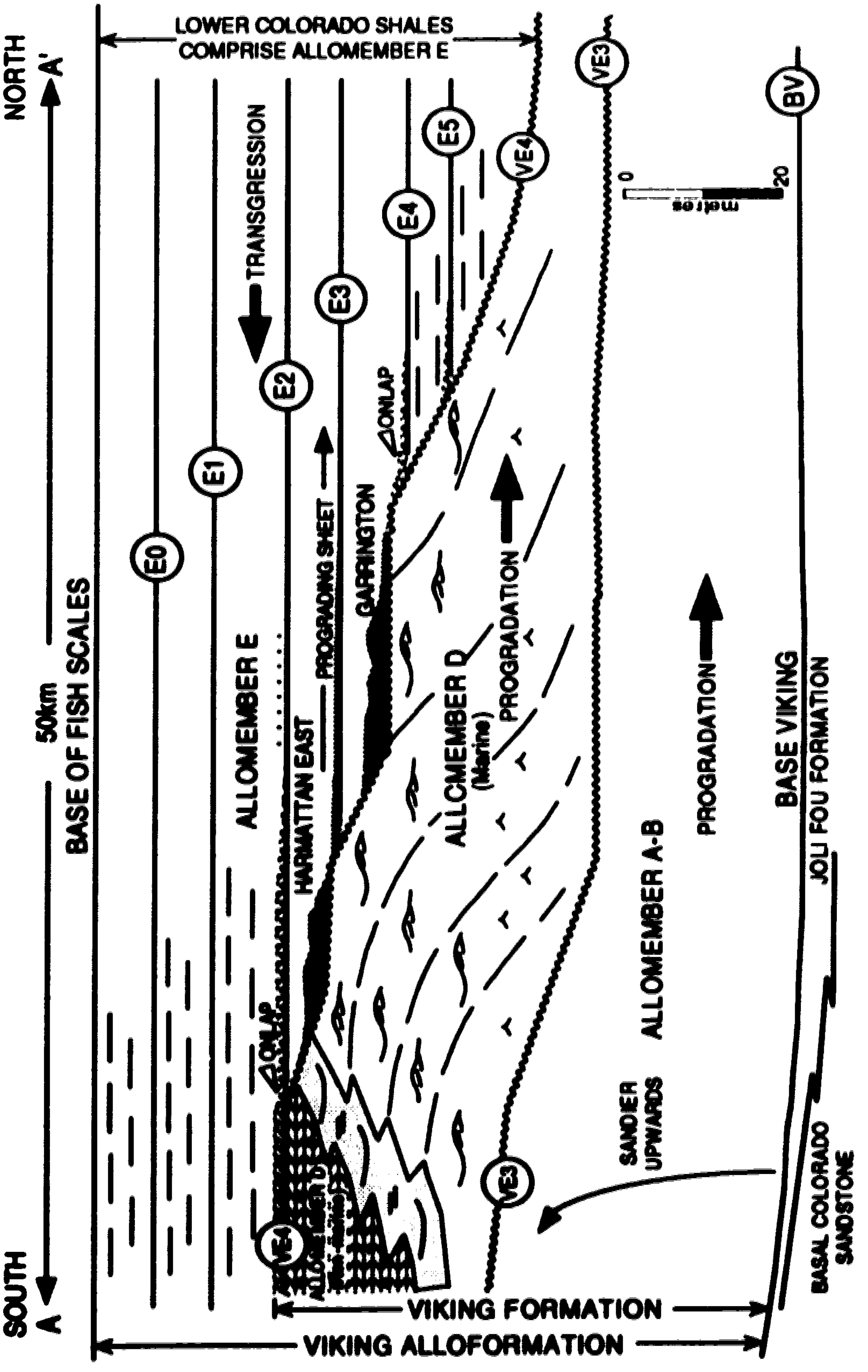


Figure 2.4 Viking Formation allostratigraphy proposed for the Harmattan area [modified from Hadley (1992)]

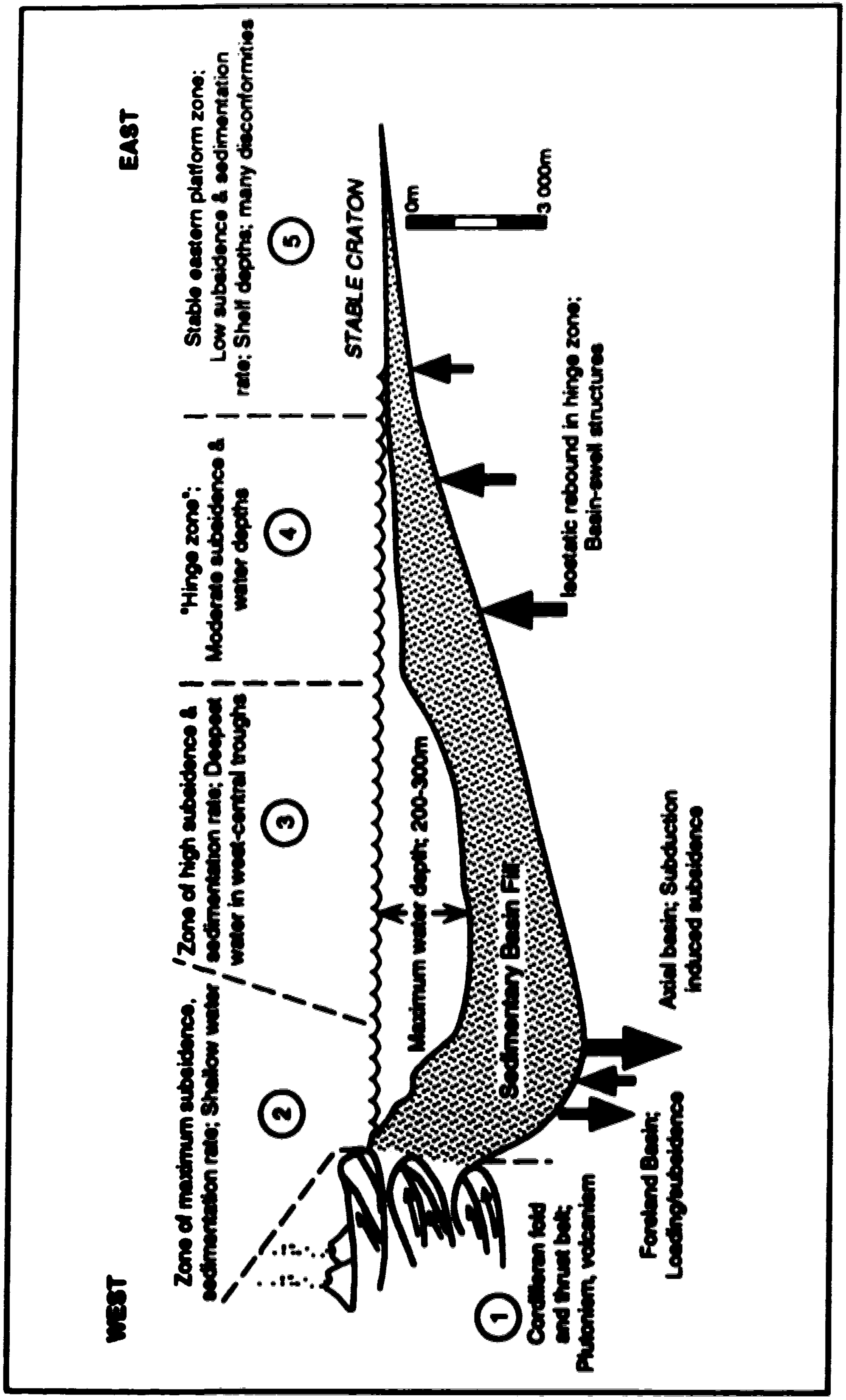
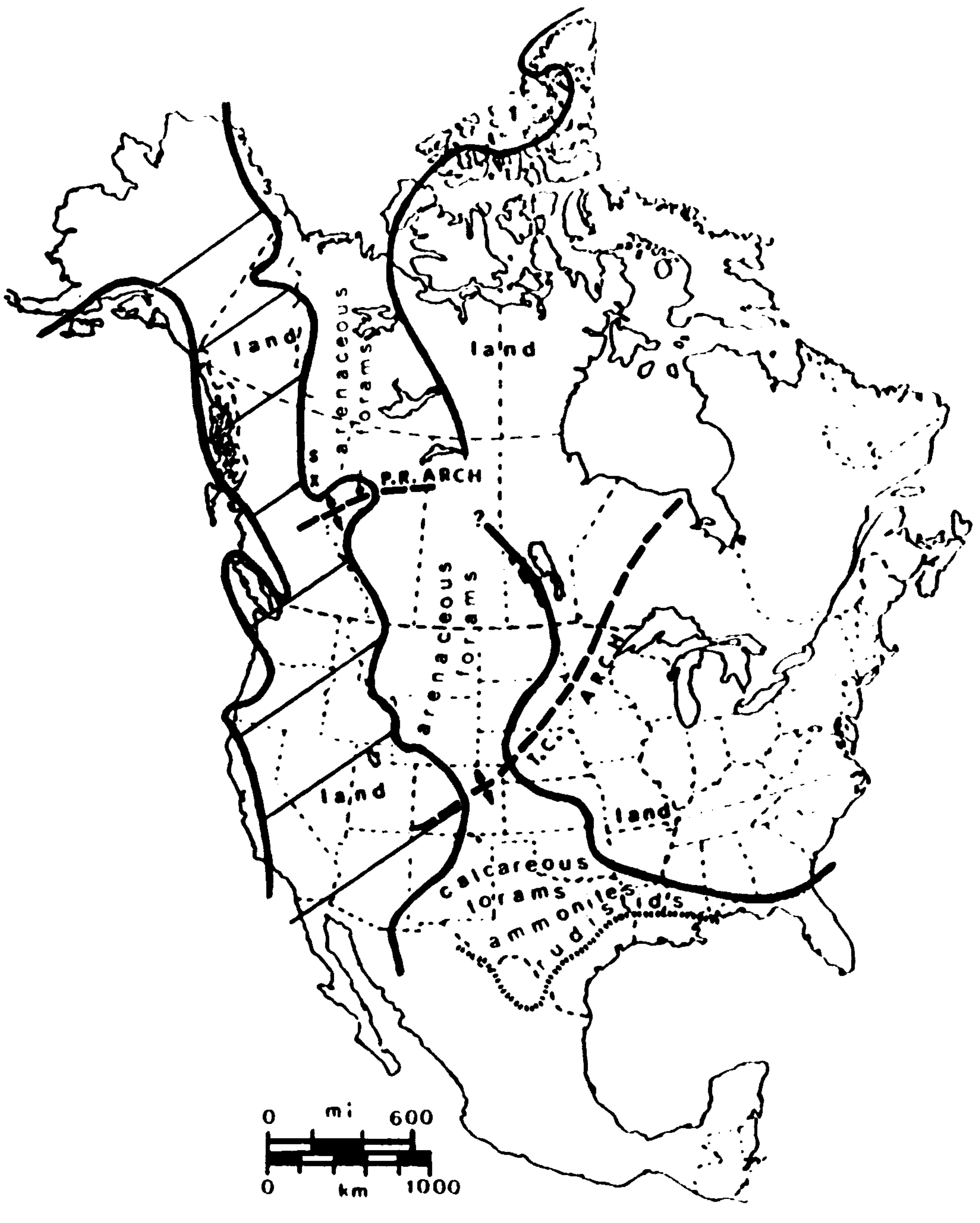
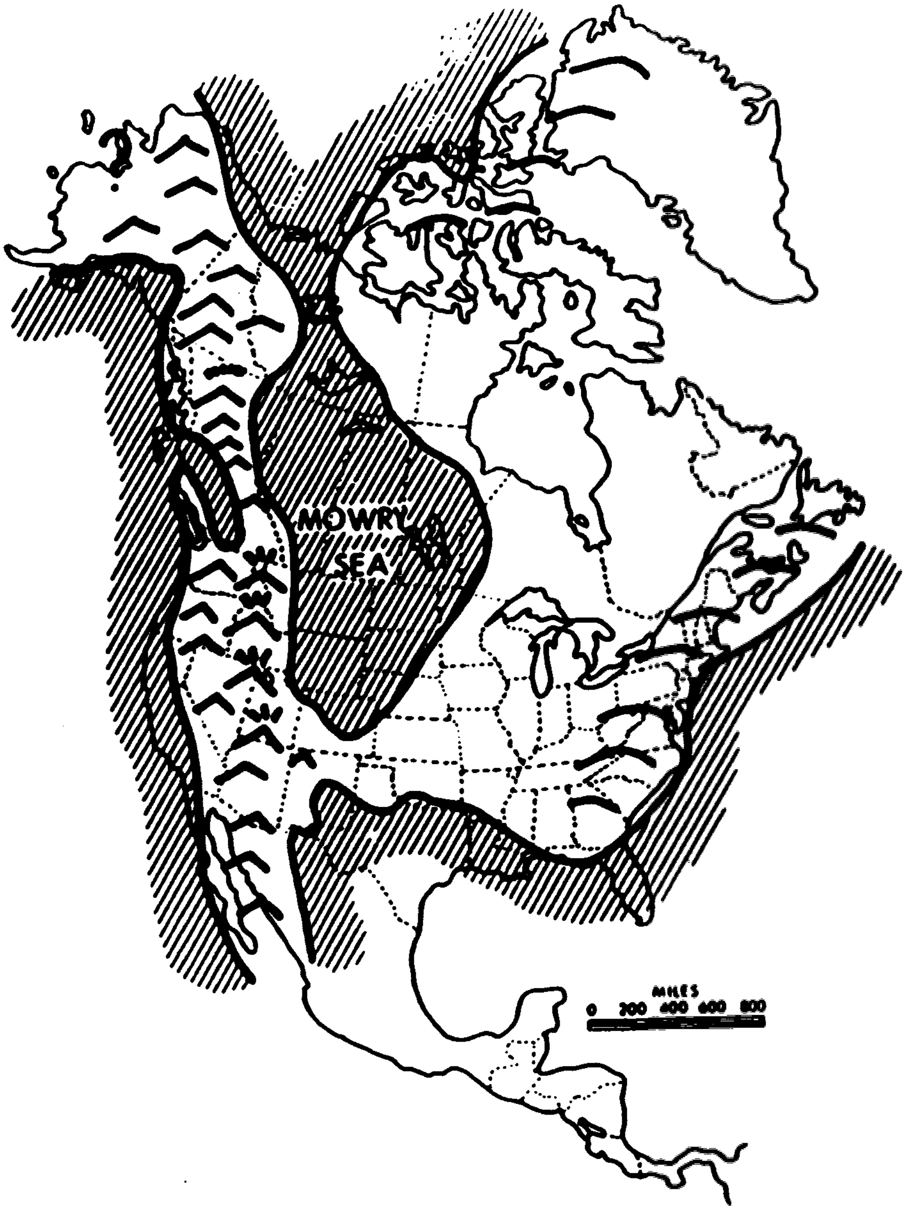


Figure 2.5 Schematic cross-section of the Alberta Foreland Basin [modified from Leckie (1989)]



Early Late Albian Seas (~Joli Fou Seaway)
***Inoceramus comancheanus* time**

Figure 2.6 Map showing the palaeogeography of the Joli Fou seaway in early late Albian (~*Inoceramus comancheanus*) time [modified from Koke and Stelck (1985)]



Late Late Albian Seas (~Lower Colorado/Mowry Seaway)
Neogastroplites cornutus **time**

Figure 2.7 Map showing the palaeogeography of the Lower Colorado Seaway in late late Albian (~Neogastroplites cornutus) time [modified from Williams and Stelck (1975)]

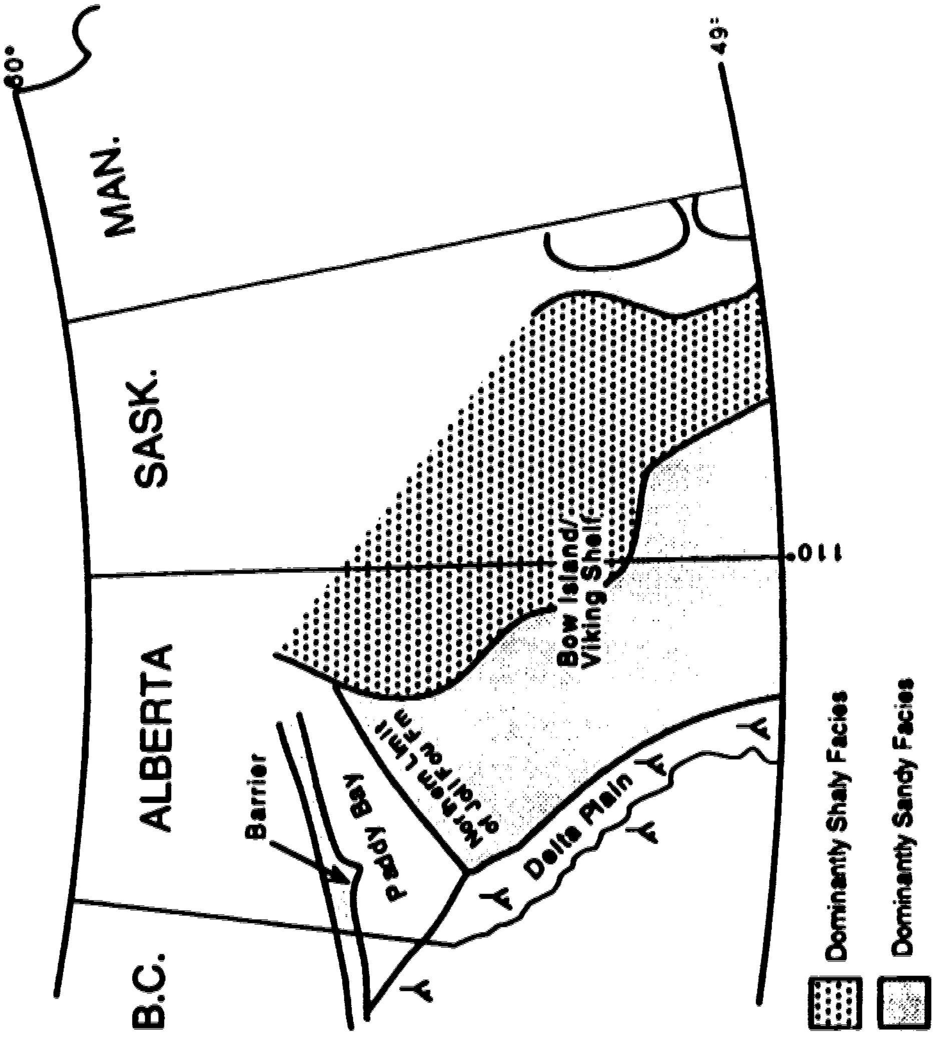


Figure 2.8 Palaeogeography during deposition of the Bow Island Fm, Viking Fm, Paddy Member and Newcastle Sandstone [modified from Leckie (1989)]

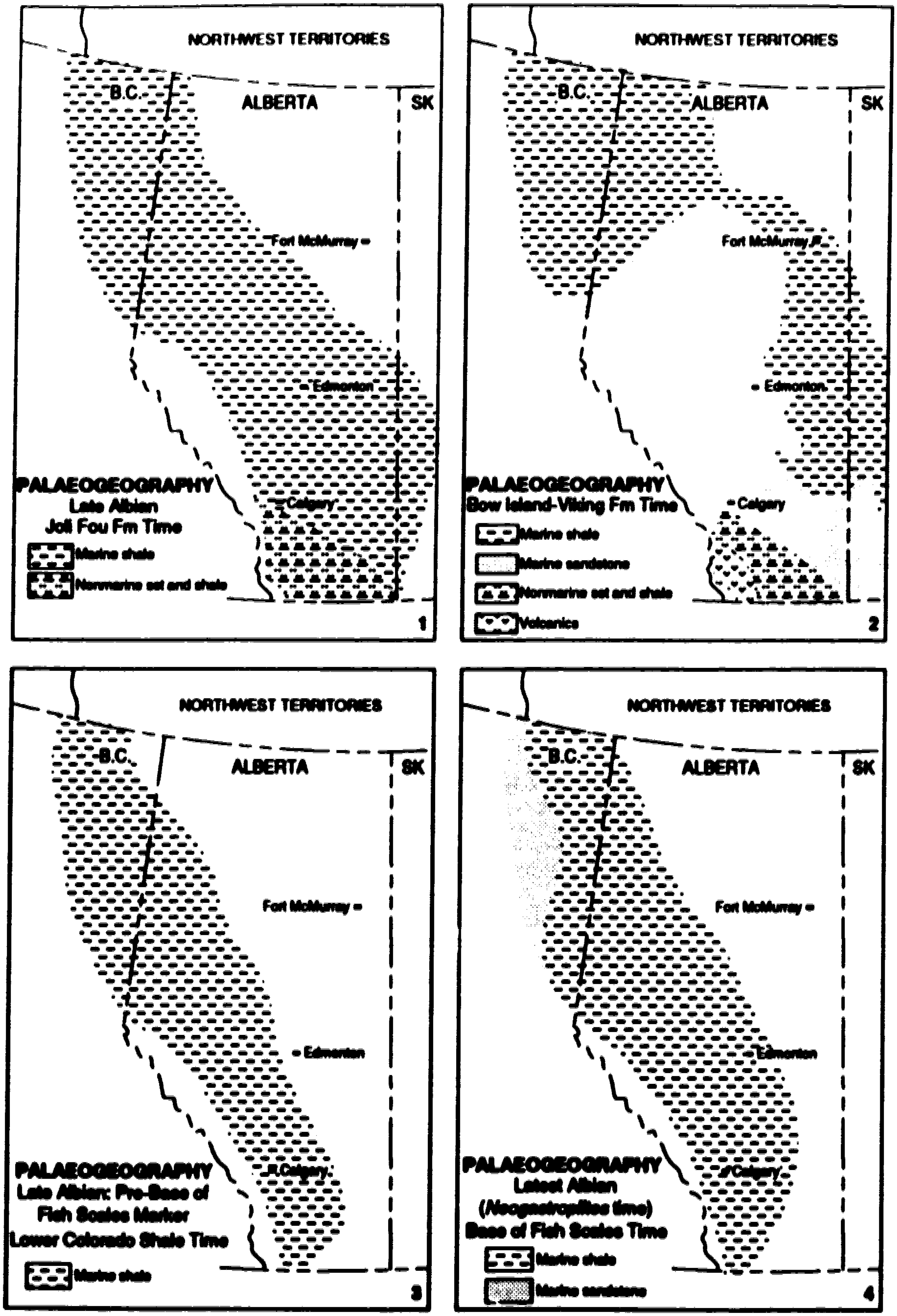


Figure 2.9 Palaeogeography during the Upper Albian Substage [modified from Stott (1984)]

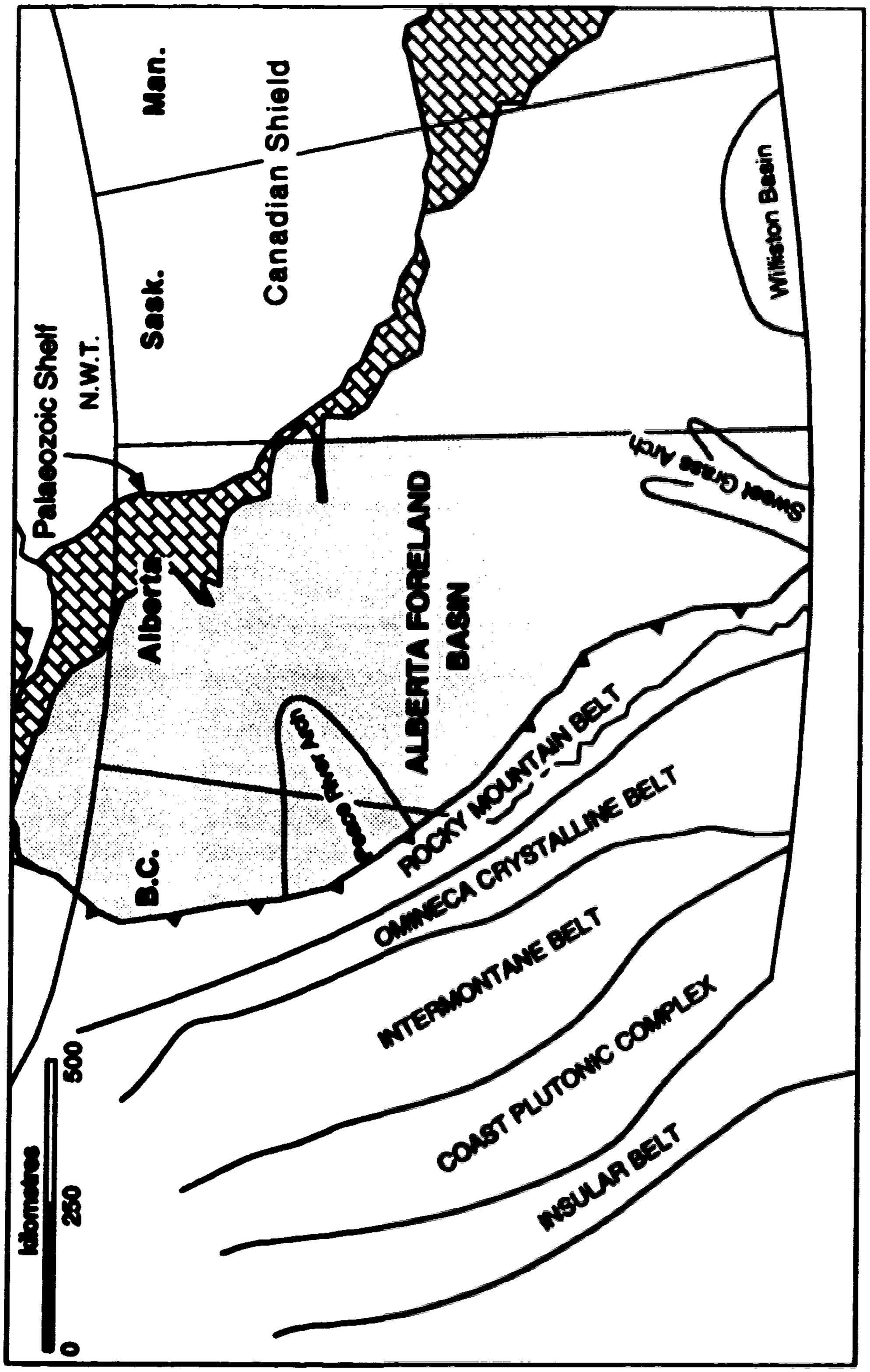


Figure 2.10 Map showing the major structural elements of the Alberta Foreland Basin [modified from Cant (1989)]

Table 1: The following three pages contain a brief summary of studies carried out on the Bow Island and Viking Formations, including the authors, the field areas worked on, and interpretations.

TABLE 1: Summary of Previous Work

AUTHOR/DATE	STUDY AREA	PROCESSES/DEPOSIT TYPE
Kroon (1951)	Southern Alberta	Sand infilling seafloor depressions
Badgeley (1952)	Central Alberta	Delta/offshore bars
Hunt (1954)	Joarcam field	Bottom currents/storm waves/offshore sand bar
Beach (1955/56/62)	Southwest Alberta	Turbidity currents/earthquake induced submarine slides/tsunamis/turbidites
Gammell (1955)	Central & Southern Alberta Plains	Regression/step-wise transgression/sand bars/sand filling seafloor depressions
DeWeil (1956)	Alberta	Tectonics/regression/longshore currents/bars/shifting strandline
Stelck (1958)	Alberta	Storm currents/shoreface/bars
Glaister (1959)	Southern Alberta	Sea-level change/regressions
Renaud (1959)	Provost field	Sand bar
Roessingh (1959)	Southern Alberta	Hydroplastic deformation/turbidity currents
Jones (1961/62)	SW Saskatchewan	Regression/transgression/slumping/mud flows/nearshore environment/neritic environment/littoral environment/delta/tidal flat/?beach
Evans (1970)	Dodsland/Hoosier fields SW Saskatchewan	Tidal currents/sand ridges/"far-from-shore marine environment"
Shelton (1973; *fide* Reinson *et al.*, 1983)	Joffre field	Barrier bar
Tizzard and Lerbekmo (1975)	Suffield area	Regression/offshore prograding barrier bars (not emergent)
Simpson (1975)	SW Saskatchewan	Storm-tidal currents/beach-sand ridges
Lerand and Thompson (1976)	Provost field (Hamilton Lake pool)	Regression-transgression/shallow marine/prograding shoreline or laterally migrating marine bar or shoal/barrier island/tidal flat/tidal inlet channel
Koldijk (1976)	Gilby B field	Pebbly-granular storm deposits/offshore bar
Boethling (1977b)	Alberta/Saskatchewan	Transgression/tidal and storm currents/reworked offshore bar and sheet sands/shoreface-lower foreshore
Amajor (1980/84/86)	Central Alberta/ SW Saskatchewan	Tide and storm-generated currents/deltas/barrier islands/offshore bars

TABLE 1: Summary of Previous Work (continued)

AUTHOR/DATE	STUDY AREA	PROCESSES/DEPOSIT TYPE
Reinson *et al.* (1983)	Joffre field	Storm-generated density currents/tidal currents/offshore bar complex
	Caroline field	Density currents/tidal currents/prograding wave dominated shoreface
Grujenschi (1984)	West-central Alberta (Viking & Cardium Fms)	Increased tectonism/tides/climate/southward flowing marine currents/long, narrow, parallel sand bars
Beaumont (1984)	Joarcam-Joffre fields	Transgressively reworked shoreline sediment/offshore bars/drowned deltas
	Eastern Alberta	Deltas
Slatt (1985)	Joarcam-Joffre fields	Reworked shoreface sediments/offshore bars (after Beaumont, 1984)
Farshori and McKay (1986)	Giroux Lake field	Fluvial supply reworked by storm, longshore and tidal currents/shallow marine environment/shelfal storm ridge/offshore bar or shoal
Leckie (1986a)	Caroline field	Regression/storm currents/prograding wave dominated shoreline/transgression/tidal currents-debris flows/reworked shoreface
Hein *et al.* (1986)	Harmattan field	Sediment gravity flows/submarine cut and filled shelfal valleys/shoreface
	Garrington field	Sheet sandstones/ridge and swale deposits
	Caroline field	Prograding shoreline/barrier island system
Ryer (1987)	Joffre-Joarcam fields	Offshore barrier island-spit complex
	Willesden Green-Crystal fields	Tidal inlet/tidal channel deposits
	Garrington-Harmattan East fields	Wave dominated deltas or strandplains
Downing and Walker (1988)	Joffre field	Storm currents/lowstand incised shoreface/transgression
Lang and McGugan (1988)	N. Montana/S. Alberta (Blackleaf Formation)	Deltaic, floodplain, coastal plain deposits/marine-bar system/hyposaline and normal marine conditions
Power (1988)	Joarcam field	Storms/reworked shelf/incised shoreface
Raddysh (1988)	Gilby fields	Waves-longshore currents/incised shoreface
Reinson *et al.* (1988)	Crystal field	Transgression-tidal currents/tidal channel fill in larger estuarine channel-bay complex
Boreen (1989), Boreen and Walker (1991)	Willesden Green	Transgression-tidal currents/estuarine valley-fill/incised shoreface

TABLE 1: Summary of Previous Work (continued)

AUTHOR/DATE	STUDY AREA	PROCESSES/DEPOSIT TYPE
Raychaudhuri (1989); Raychaudhuri *et al.* (1992/93)	Chigwell field	Transgressively incised low energy shoreface
Amajor and Lerbekmo (1990a)	Central/south-central Alberta	Prograding shorelines/migrating offshore sand ridges
Amajor and Lerbekmo (1990b)	Central/south-central Alberta	Waves, longshore, tidal currents/storm and gravity induced currents/barrier islands/backbarrier/lagoons/ tidal flat/deltas/offshore sand ridges-bars
Davies (1990)	Caroline-Garrington	Storm-tidal currents/incised shoreface
Pozzobon and Walker (1990)	Eureka field, Saskatchewan	Transgressed-reworked sand plume associated with delta distributary/offshore ridge
Posamentier and Chamberlain (1990/91a,b)	Joarcam field	Lowstand shoreface deposit
Pattison (1990/91a, b,c/92)	Crystal/Sundance-Edson/Cyn-Pem fields	Tidal currents/estuarine valley-fill/shoreface deposits
Putnam *et al.* (1991)	Sundance-Edson fields Blood field, S. Alberta (Bow Island Formation)	Transgression/estuarine valley-fill/progradational shoreface environments Waves/wave formed sand bodies/wave influenced shoreline fed by nearby channels
Cox (1991), Cox and Williams (1991)	Blood field, S. Alberta	Tidal currents/estuarine valley-fill
Hein *et al.* (1991)	Garrington field	Progradational lower shoreface-shelf sandstones/shelf ridge complex/sediment gravity flows/sandy debris flows/Storm-littoral currents/offshore ridge
Hadley (1992)	Harmattan-Crossfield	Storm dominated prograding shoreface
Raychaudhuri and Pemberton (1992/93)	South-central Alberta	Open marine to storm dominated restricted marine conditions/?delta
MacEachern *et al.* (1992)	Various Viking fields, Alberta	Transgression/transgressive erosion/stillstand progradation
Pemberton *et al.* (1992)	Crystal field	Tidal currents/estuarine valley-fill/shelf and shoreface deposits
Reinson *et al.* (1993)	Alberta, Viking Fm S. Alberta, Bow Island Formation	Progradational successions/incised valley-fills Stacked shelf to shoreface cycles/coastal plain/shallow marine transgressive deposits
Leckie and Reinson, in press	Crystal field	Transgression-tidal currents/estuarine valley-fill

CHAPTER 3: FACIES, FACIES ASSOCIATIONS, ICHNOLOGY AND SEDIMENTOLOGY

3.1 INTRODUCTION

Facies analysis was necessary in order to best interpret the observed rocks. This chapter deals with detailed description of the observed facies, with respect to their lithologic, ichnologic and sedimentologic features. Some of the facies are stacked in recurring packages. These packages are referred to as "Facies Associations", and the two main Facies Associations in this study will be discussed in this chapter (*i.e.* FA1 and FA2). Facies Associations are defined as, "... groups of facies that occur together and are considered to be genetically or environmentally related." (Reading, 1986). The Facies Associations are also stackable into bigger scale sedimentary packages which must be interpreted on the basis of their facies-oriented elements, as well as their context in a stratigraphic framework. Aspects of the stacking patterns and regional bounding disconformities are discussed in Chapter 4.

3.2 FACIES DESCRIPTIONS

Observed sediments in the study area have been divided into sixteen facies based primarily on the ichnologic and sedimentologic characteristics they exhibit. Grain size was determined using a Can-Strat card. A comparison of Can-Strat grain size with actual phi and millimetre grain size is given in Table 2. It should be noted that where maximum and average pebble diameters are given, the diameters represent minimum diameters because the cores only provide two-dimensional views of pebbles which conceivably have even greater diameters in the unobserved third dimension. At least twenty-five types of trace fossils were encountered in the cores logged as part of this study, and their ethological classification, trophic strategy and possible phylogeny are briefly summarised in Table 3.

3.3 FACIES 1: Black shale with minor dispersed silt

Lithology and Sedimentary Features: Facies 1 comprises black shale and/or mudstone (depending on the fissility of the rock at any given well location), with a minor amount of dispersed silt and lower very fine-grained sandstone (Fig.3.1A,B). The facies is increasingly less fissile with increasing silt content. No physical sedimentary structures are visible, although there are extremely rare millimetre scale sharp based discontinuous lenses of siltstone/lower very fine-grained sandstone. Locally, thin zones of shale are siderite cemented.

Ichnology: No obvious trace fossils were visible, but possible *Planolites* were observed. Vague burrow mottling was apparent near the rare siltstone/lower very fine-grained sandstone beds.

Interpretation and Discussion: This facies was deposited in an offshore marine environment where deposition was almost entirely from suspension fallout. The interpretation is largely based on the context of the facies within overall shoaling upwards shoreline cycles. Sand and silt was likely supplied partially from suspension fallout, and possibly from storm-generated currents. The sand and silt, then, would represent the most distal deposition of major storms acting on a correlative shoreline.

The lack of any significant burrowing suggests two possible scenarios: a) the existence of environmental stresses, b) a lack of lithologic contrast with which to highlight the burrows. The most likely explanation is the lack of lithologic contrast. Sampling for microfossils in this facies yielded robust arenaceous marine foraminifera (J.A. MacEachern, pers. comm., 1993; C.R. Stelck, pers. comm., 1993). Further aspects of apparently reduced burrowing intensities in this and similar facies is addressed in the discussion of Facies 14 and by MacEachern *et al.* (1992b).

3.4 FACIES 2: Burrowed shaly sandstone

Lithology and Sedimentary Features: This facies is dominantly lower fine-grained sandstone with only a minor amount of shale (Fig. 3.1C). Bedding features were obliterated due to the total sediment homogenization caused by the activities of burrowing organisms. The sediment contains swelling clays which appear to be bentonitic or smectitic in nature. Other features include glauconite, pyritised nodules, and organic detritus.

Ichnology: This facies is characterised by a very high burrowing intensity that imparts a thoroughly mottled or churned appearance to the rock. Trace fossils found include *Terebellina, Teichichnus, Planolites, Palaeophycus, Thalassinoides* and possibly *?Subphyllachorda*. The overall appearance of the facies suggests dominance by *Teichichnus*.

Interpretation and Discussion: This facies is only visible in one core within the study area (6-15-24-20W4) because the 6-15-24-20W4 core is the only one in the study area that penetrates the basal portion of the Bow Island Formation. The core likely represents the basal portion of the Third Bow Island sandstone. Although only seen in one core, the corresponding geophysical well log respose is consistent throughout the study area; so indirect evidence suggests its designation as a facies. The unit grades out of essentially black shales (Facies 1). The intense burrowing suggests that the facies was deposited in a well oxygenated, nutrient-rich, marine environment. The abundant glauconite supports a marine interpretation. The trace fossil assemblage and burrowing intensity also suggest a low energy, lower shoreface environment. Burrowing intensity and the lack of preserved sedimentary structures indicate that the sand was probably deposited slowly, in thin beds, such that the abundant types of organisms inhabiting the lower shoreface environment were able to maintain their pace of burrowing with the rate of sand deposition. The sand was most likely supplied by weak and/or infrequent storms.

3.5 FACIES ASSOCIATION ONE (FA1)

FA1 comprises beds of thoroughly burrowed very fine grained sandstone, siltstone, and shale (Facies 3), interbedded on a larger scale with rare one to fifteen centimetre thick very fine grained sandstones (Facies 4). FA1 increases in sand content upwards, from thoroughly burrowed, *Helminthopsis*-rich, silty and sandy shales into sandier shales above. The intense biogenic mottling commonly obscures any vestige of physical sedimentary structure, although some remnant laminae are rarely preserved. Although the interbedded portion is thoroughly burrowed, local variations in the intensity exist. These moderately to poorly burrowed interbedded intervals tend to be more common stratigraphically higher within FA1, and can be considered transitional between FA1 and FA2. This transitional interval is also found locally within the basal portions of overlying FA2 and will be discussed as a part of FA2. The contact between FA1 and FA2 is ordinarily very sharp, and is based on an increase in the thickness of sandstone beds, and the abrupt change in burrowing intensity (Fig. 3.5A).

The trace fossils found in FA1 include the following twenty-three forms: *Anconichnus, Palaeophycus, Macaronichnus, Polykladichnus, Cylindrichnus, Terebellina, Asterosoma, Rhizocorallium, Zoophycos, Ophiomorpha, Thalassinoides, Planolites, Chondrites, Helminthopsis, Teichichnus, Bergaueria, Skolithos, Rosselia , Arenicolites, Diplocraterion, Gyrolithes, Siphonichnus* and (?)*Phycodes*. Although not all these ichnogenera are represented in a single drill core, they have all been recognised in FA1 sediments. Distinctive trends in the distribution of these twenty-one ichnogenera exist within FA1, and are summarised in Table 4. Detailed facies descriptions of FA1's constituent facies are given below.

3.51 FACIES 3: Thoroughly Burrowed Sandstone, Siltstone and Shale

Lithology and Sedimentary Features: This facies comprises burrowed lower to upper very fine-grained sandstone, siltstone and dark shale, and is found throughout the study area (Fig. 3.2A,B). It is dominantly shaly, dark grey in colour, with sand and silt content ranging between 10-35%. The sand and silt content normally averages between 15-20%. Rare millimetre to 2cm thick lower very fine-grained sandstone beds are locally present. These beds may be discontinuous on the scale of the core, thereby locally giving this facies a "shredded" appearance. The sandstone beds are generally sharp based (probably loaded bases) with burrowed or diffuse tops, and are characterised by wavy parallel laminations. These laminations are commonly accentuated by finely comminuted organic detritus (*i.e.* platy plant material) and locally have small coaly or woody fragments associated with them. Possible fern leaf imprints were observed on a bedding plane at 6-9-27-18W4. A very fine grained siderite cement and up to 10cm thick sideritic horizons can also be found in this facies. Locally, this facies has interstitial swelling clays; this seems to be restricted to zones around thin bentonite beds (Facies 16). Minor pyrite is also present. Moving stratigraphically upwards within any single core, Facies 3 becomes interbedded with Facies 4 to create Facies Association One (*i.e.* FA1).

Ichnology: The burrowing intensity ranges from common to abundant in this facies. In addition, actual numbers of individual trace fossil forms are high. This facies is found in essentially all the observed cores, and contains the most diverse assemblage of trace fossils in the study area. This facies has been informally referred to as "the regional Viking" by industry and academic geologists alike. The facies is characterised by an ichnofossil assemblage comprising the following sixteen ichnogenera: *Arenicolites* (Fig. 3.4A), *Asterosoma* (Figs. 3.3D,H,I), *Bergaueria* (Fig. 3.3E), *Chondrites* (Figs. 3.3B,D; 3.4B,D), *Diplocraterion*, *Helminthopsis* (Figs. 3.3A,B,G,I; 3.4C), *Ophiomorpha* (Figs. 3.3F,G), (?)*Phycodes* (Figs. 3.4F,G), *Planolites* (Fig. 3.3B), *Rhizocorallium*, *Rosselia* (Fig. 3.4C), *Skolithos* (Figs. 3.3A; 3.4A), *Teichichnus* (Figs. 3.3D; 3.4A), *Terebellina* (Figs. 3.3C,H), *Thalassinoides* (Fig. 3.3G) and *Zoophycos* (Fig. 3.3G). Of these, *Helminthopsis*, *Planolites*, *Chondrites*, *Terebellina* and *Asterosoma* are by far the dominant ichnogenera present. *Teichichnus*, *Ophiomorpha*, *Thalassinoides*, *Zoophycos*, *Rhizocorallium*, *Rosselia* and (?)*Phycodes* are common; and *Skolithos*, *Bergaueria*, *Diplocraterion* and *Arenicolites* are rare. Dense concentrations of *Helminthopsis* are ubiquitous in this facies and although *Helminthopsis* and *Chondrites* are not mutually exclusive, dense concentrations of each are not commonly found together. Although not every one of the sixteen ichnogenera mentioned are found in any single drill core, they can all be found associated with this facies somewhere within the study area. *Planolites* is locally pyritised.

Interpretation and Discussion: The physical sedimentary features indicate that the sandstone beds, where present, were deposited in an overall upper offshore to distal lower shoreface by storm-generated oscillatory currents. The facies was deposited below fairweather wave base, but the presence of the discontinuous sandstone beds suggests that the environment was within storm wave base. The wavy parallel laminations found in the sandstone beds represent combined flow/asymmetrical oscillation ripples. The finely comminuted organic detritus was also brought into this environment by the storm-generated currents and incorporated into the oscillation/combined flow ripples. The wavy parallel laminations could alternatively be interpreted as remnants of hummocky cross stratification. Other, probably weaker, storms brought sand into the environment but not in sufficient amounts to deter complete reworking by organisms. The discontinuous nature of the sand "lenses" suggests that very little sand was being transported into this environment, and that the rippled "lenses" are locally interpreted to be sediment starved ripples. The loaded bases indicate that the underlying muddy substrate was soupy, allowing for the sand to "sink" into the mud, creating load cast ripples. Rare bentonitic horizons suggest that periodic volcanic ashfalls were penecontemporaneous with the deposition of this facies. The minor pyrite indicates that conditions were locally reducing.

The diverse ichnofossil assemblage reflects deposit feeding or grazing trophic strategies, both of which are amenable to the *Cruziana* ichnofacies (Pemberton and Frey, 1984). Furthermore, the *Thalassinoides* and *Ophiomorpha* observed are horizontally oriented; such burrows tend to become progressively more vertically oriented with increasing energy conditions on a shoreface (*i.e.* from the lower shoreface to the upper shoreface). The relative importance of horizontal and vertical burrow morphologies in shoreface sediments and ichnofacies designations is discussed in greater detail in Frey and Pemberton (1984). The less common ichnogenera are all thought to be dwelling structures of suspension feeders or passive carnivores.

The paucity of *Skolithos, Diplocraterion* and *Arenicolites*, as well as the absence of vertical or steeply inclined expressions of *Thalassinoides* and *Ophiomorpha*, are consistent with an upper offshore to distal lower shoreface setting, due to dominantly low energy, quiet water conditions that do not favour suspension feeding organisms (*cf.* MacEachern and Pemberton, 1992). The predominance of deposit feeding and grazing behaviours, the high diversity of trace fossils, the abundant burrowing intensity, and the sedimentary structures all indicate that these sediments are fairweather marine deposits within well oxygenated, nutrient-rich, upper offshore to distal lower shoreface environments.

3.52 FACIES 4: One to Fifteen Centimetre Thick very fine Grained Sandstones

Lithology and Sedimentary Features: This facies is made up of sandstone beds that range in grain size from lower to upper very fine-grained, with the dominant grain size being lower very fine (Fig. 3.2C,D). The sandstone beds exhibit low angle undulatory to wavy parallel laminations, normally accentuated by finely comminuted organic detritus. In some of the thicker beds, low angle inclined parallel laminations are evident. In rare instances, some of the thicker bedded sandstones exhibit convolute bedding (*e.g.* 7-1-27-20W4). Similar to the sandstone beds/lenses in Facies 3, these sandstone beds locally have ripped up coaly or woody fragments. In addition, they may contain glauconite or small ripped up sideritic clasts. This facies is interbedded with Facies 3, with beds of Facies 4 generally becoming more abundant and thicker upwards within FA1. The sandstone beds are on average 1-5cm thick near the base of FA1, getting up to 10-12cm thick on average moving stratigraphically upwards within FA1.

Ichnology: This facies has a diverse ichnofossil assemblage comprising the following fifteen ichnogenera: ***Anconichnus*** (Fig. 3.4F), ***Asterosoma***, ***Cylindrichnus*** (Fig. 3.3C), ***Gyrolithes*** (Fig. 3.2D), ***Macaronichnus*** (Figs. 3.4E,F), ***Ophiomorpha*** (Figs. 3.4B,C), ***Palaeophycus*** (Fig. 3.4B), ***Planolites*** (Fig. 3.4H), ***Polykladichnus*** (Fig. 3.3C), ***Rhizocorallium*** (Figs. 3.4B,D), ***Siphonichnus***, ***Teichichnus*** (Fig. 3.4A), ***Terebellina***, ***Thalassinoides*** and ***Zoophycos***. Seven of these ichnogenera are essentially restricted to the sandstones of FA1; of these, the two most common are ***Anconichnus horizontalis*** and ***Palaeophycus***, with ***Polykladichnus***, ***Cylindrichnus***, ***Macaronichnus simplicatus***, ***Gyrolithes*** and ***Siphonichnus*** being the others. ***Polykladichnus*** and ***Cylindrichnus*** are rare, whereas ***Gyrolithes*** and ***Siphonichnus*** are extremely rare, as each is only found in one core within the study area. ***Asterosoma***, ***Ophiomorpha nodosa***, ***Ophiomorpha irregulaire***, ***Planolites***, ***Rhizocorallium***, ***Teichichnus***, ***Terebellina***, ***Thalassinoides*** and ***Zoophycos*** are common to both the sandstone beds (this facies) and the thoroughly burrowed intervals (Facies 3) that comprise FA1. The ***Ophiomorpha***, ***Planolites*** and ***Thalassinoides*** which occur in the sandstones are commonly reburrowed by ***Anconichnus horizontalis*** or ***Helminthopsis*** (Figs. 3.4F,H).

Interpretation and Discussion: The low angle undulatory to wavy parallel laminations are interpreted as oscillation to combined flow ripples and are thought to represent distal storm deposits in an upper offshore to lower shoreface setting. Locally, the ripples appear to have small scale foreset laminae within overall wavy bedform morphologies; hence their interpretation as possible combined flow ripples. These sharp based sandstone beds commonly have burrowed tops [*i.e.* "parallel laminated-to-burrowed units" of Howard (1971a,b); colloquially referred to as "laminated to scrambled" or "lam-scram"] and in general, the number and thickness of the sandstone beds increase upwards within FA1. The observed increase in number and thickness of beds of this facies within FA1 is interpreted as reflecting increasingly shallower water conditions, such that the environment lay more commonly within storm weather wave base, but still within the lower shoreface. Storm effects were felt more significantly in this part of the lower shoreface, thereby explaining the thicker and more abundant beds of Facies 4. The low angle inclined parallel laminated sandstone beds in excess of 10cm thickness are interpreted to be either larger scale oscillation ripples or small scale hummocky cross stratified (*i.e.* HCS). These beds were also deposited by storm-generated currents and are most commonly associated with the lower shoreface. A more complete discussion of HCS is covered in the interpretation of Facies 6. The occurrence of convolute laminations in this facies is rare, and they likely formed as a result of rapid deposition related to storm-generated currents. It is envisioned that storm-generated wave setup at the shoreline ultimately resulted in a seaward flowing bottom currents that moved sand from the foreshore to the lower shoreface. The sediment likely had a large proportion of interstitial water which escaped upon or shortly after deposition, rendering the sandstone bed with convolute laminations.

The burrowing of the sandstones is generally quite sparse and represents biogenic reworking of the tops of distal storm deposits. The deposits are not necessarily the result of single events, but rather, may represent amalgamated storm beds. The occurrence of *Anconichnus horizontalis* in the tops of thin rippled sandstones corresponds to taphonomic-sediment association 1 of Goldring *et al.* (1991). Furthermore, Goldring *et al.* (1991, Fig.16) restricted such an occurrence to the upper offshore to offshore transitional position on a shoreface profile, lying above storm (*i.e.* maximum) wave base but below fairweather (*i.e.* minimum) wave base. It is generally thought that burrowing organisms are capable of completely reworking sand beds up to fifteen centimetres thick in an upper offshore to distal lower shoreface setting, barring rapid burial by a subsequent event bed (Kranz, 1974; Wheatcroft, 1990). It follows, then, that in order for a storm generated sand to be preserved in such an environment, it would have to be thicker than fifteen centimetres. Opportunistic organisms (*i.e.* r-selected species) colonise the sandy substrate but are unable to totally homogenise the sand; hence, the physical sedimentary structures of the sands are at least partially preserved. The organisms that colonise the storm sands may have been transported into the upper offshore/lower shoreface environment by the same storm induced currents responsible for transporting the sediment from the nearshore to the offshore (for details, see Pemberton *et al.*, 1992b). As a result, the ichnology of the storm sands is superimposed onto the resident fairweather ichnofossil community, and so the ichnofossil signatures of the two subenvironments do not necessarily bear any resemblance to one another. This may explain why the seven ichnogenera that are restricted to the sandstones are both rare and unique with respect to the resident fairweather ichnofossil suite of the thoroughly burrowed sandstone, siltstone and shale intervals. These opportunistic organisms may be displaced great distances from their customary environments and consequently, may die shortly after colonising the storm sand. In such cases, the colonising organisms are commonly referred to as a community of "doomed pioneers" (Föllmi and Grimm, 1990). The reburrowing of pre-existing trace fossils in the sandstones probably represents a later stage of opportunistic feeding whereby the makers of *Helminthopsis* and *Anconichnus horizontalis* feed off either the organic material found in wall linings of the original opportunistic suite of ichnofossils, or the organic material left behind by the original opportunistic assemblage. The ichnology of storm deposits is discussed in greater detail by Frey (1990) and Pemberton *et al.* (1992b).

3.6 FACIES ASSOCIATION TWO (FA2)

In contrast to FA1, the overlying FA2 comprises unburrowed to moderately burrowed interbedded very fine grained sandstone, siltstone, and shale (Facies 5) that is itself interbedded on a larger scale with discrete, thickly bedded (0.15-4.0m) low angle laminated very fine- to fine-grained sandstones (Facies 6). FA2 is widespread within the study area and is characterised by an ichnofossil assemblage that is impoverished in both quantity and, to a lesser extent, diversity as compared to FA1. Portions of FA2 may be thoroughly burrowed, although the burrowing intensity overall is much less than in FA1. FA1 is sharply overlain by FA2 in most cores, and this contact is locally demarcated by chert pebble conglomerate (Facies 7 or Facies 13). Where present, the conglomerate is commonly overlain by a thin zone of highly burrow mottled rock (Facies 3). Generally, this burrowed zone gradationally passes upwards into thinly interbedded Facies 5. Locally, moderately burrowed, thinly interbedded Facies 5 directly overlies the conglomerate. Where unburrowed to rarely burrowed, Facies 5 consists of sharp based 3-15cm thick very fine-grained sandstone beds that grade upwards into equally thick dark shales (Figs. 3.5B,C,D). These thinly interbedded portions of Facies 5 locally contain 1-2cm thick stringers of granules and/or small, rounded pebbles (average 5-10mm in diameter). Thinly interbedded Facies 5 most commonly occurs near the base of FA2. Thicker amalgamated sandstone beds (Facies 6) and slightly coarser sand (lower to upper fine-grained) become progressively more dominant upwards within FA2. Some of the thickly bedded very fine- to fine-grained sandstone beds exhibit soft sediment deformational features including microfaulting, ball and pillow structures, oversteepened laminations, apparently structureless sandstones and convolute laminations. In addition, there are some fining upwards pebbly beds associated with the soft sediment deformed sandstone beds. The ichnogenera found in FA2 include the following fourteen forms: *Chondrites*, *Planolites*, *Bergaueria*, *Terebellina*, *Rhizocorallium*, (?)*Lockeia*, *Anconichnus*, *Teichichnus*, *Palaeophycus*, *Asterosoma*, *Helminthopsis*, *Zoophycos*, *Thalassinoides* and *Ophiomorpha*. Fugichnia (*i.e.* escape traces) are also common. As with FA1, noteworthy distribution tendencies exist for the ichnogenera of FA2, and are summarised in Table 4. Detailed descriptions for Facies 5 and Facies 6 are given below.

3.61 FACIES 5: Unburrowed to Moderately Burrowed Interbedded Sandstone, Siltstone and Shale

Lithology and Sedimentary Features: Due to the variable amounts of burrowing in this facies, the rocks commonly have a pinstriped appearance (Fig. 3.6A). Portions may be commonly burrowed, although the burrowing intensity overall is lower (*i.e.* rare to moderate) than in FA1. The sandstone beds are one to fifteen centimetres thick, are characterised by wavy parallel, low angle undulatory and low angle inclined stratification and grade upwards into smaller scale wavy parallel laminated sandstones (Fig. 3.6B) and then gradationally up into dark, organic-rich shales. The sandstones locally appear lens shaped and, in some cases, may represent sediment starved ripples. The "pinstriped" appearance of this facies is largely imparted by the nature of the bedding and the lack of biogenic reworking. Almost all of the sandstone beds are sharp based and fine upwards into black, organic-rich, essentially unburrowed shales (Fig. 3.6C). Rarely, the sandstone beds are erosively based cut and fill structures (Fig. 3.6D). As with many of the sandstone beds in other facies, the sandstone bed laminae are commonly accentuated by finely comminuted organic detritus, coaly and/or woody fragments. The basal part of this facies is generally more burrowed, transitionally passing upwards into lesser burrowed Facies 5.

Overall, the sandstone beds get thicker, and locally coarser, upwards. Commonly, the sandstone beds will become thicker upwards and subsequently be overlain by a succession that is dominantly shaly again, with thinner sandstone beds. The shale portion of this facies is organic-rich and normally quite friable. Ubiquitous dull brown organic detritus and vegetative detritus is found in the shales; this organic material is essentially identical to the organic detritus that accentuates the laminations in the sandstone beds. The shales commonly contain thin, sand-filled, ptygmatically folded synaeresis cracks (Figs. 3.9A,D), and are locally cemented with a very fine grained siderite. On core parting planes, the synaeresis cracks are spindle shaped and on the order of 3-5cm long (Fig. 3.9E). The shale beds are dominantly 1-5cm thick but are locally up to 15-

20cm thick. Facies 5 is interbedded with Facies 6 to make Facies Association Two (*i.e.* FA2).

Ichnology: This facies has a markedly reduced burrowing intensity, abundance and diversity compared to Facies 3. The ichnofossil assemblage that characterises this facies includes the following thirteen ichnogenera: *Anconichnus* (Figs. 3.5C; 3.8B), *Asterosoma* (Figs. 3.8C,D), *Bergaueria* (Fig. 3.9B), *Chondrites* (Figs. 3.5B; 3.8B,D,F,H), *Helminthopsis* (Figs. 3.8A,D), (?)*Lockeia* (Fig. 3.9A), *Palaeophycus* (Figs. 3.8B; 3.9B), *Planolites*, *Rhizocorallium* (Figs. 3.5B,D; 3.8A,C,D), *Teichichnus* (Fig. 3.9A), *Terebellina* (Figs. 3.8D; 3.9C), *Thalassinoides* (Figs. 3.8A,D) and *Zoophycos* (Figs. 3.5C; 3.8E,F,G). *Chondrites*, *Planolites* (Figs. 3.8A,D,F), *Rhizocorallium* and *Terebellina* are the most abundant traces; in contrast, *Bergaueria*, (?)*Lockeia* and *Teichichnus* are extremely rare. Of the thirteen ichnogenera represented, *Bergaueria*, *Chondrites*, (?)*Lockeia*, *Planolites*, *Rhizocorallium* and *Terebellina* are restricted to this facies, with the other seven ichnogenera being common to both this facies and Facies 6. The dark organic-rich shales of FA2 are ordinarily burrowed by only one or two ichnogenera. The *Chondrites*-*Planolites* association is most common in the dark shales, whereas single occurrences of *Asterosoma* and *Rhizocorallium* are less common.

Interpretation and Discussion: The wavy parallel and low angle undulatory stratification are interpreted as combined flow to oscillation ripples which are locally aggradational in nature. The sand was deposited by a combination of fairweather and storm-generated waves. Some thinner sandstone beds locally appear lens shaped and, in some cases, may represent sediment starved ripples. The low angle inclined stratification found in some of the thicker bedded sandstones is interpreted as small scale hummocky cross stratification (*i.e.* HCS). The HCS sandstone beds were deposited by storm-generated oscillatory currents. The HCS beds commonly grade upwards into smaller scale wavy parallel laminated sandstones, which in turn pass gradationally upwards into dark, organic-rich shales. The smaller scale wavy parallel laminated sandstones that cap the HCS beds are interpreted as combined flow and asymmetrical oscillation ripples that represent the reworking of the tops of the HCS beds by either waning stage storm-generated oscillatory/combined flow currents or fairweather waves.

The erosionally based cut and fill structures are interpreted as guttercasts. These structures are significant because they imply that seaward oriented unidirectional currents were active. The underlying shale was likely hydroplastic and possibly semi-cohesive. The cohesiveness is supported by the fact that the shale actually has a slightly overhangs the overlying sandstone (Fig. 3.6D). The shale was likely cut by seaward oriented rip currents and subsequently filled with very fine-grained sand. Rip currents develop in response to the convergence of two longshore drift currents flowing in opposite directions (Walker and Plint, 1992).

The organic-rich shales that gradationally cap the small scale oscillation and combined flow ripples may be related to observations on seasonal fluctuations of concentrations of organic material (*i.e.* phytodetritus) that have been made for the deep-sea by Rice *et al.* (1986). It is postulated that the dark, organic-rich shales that cap the sand beds may represent suspension fallout deposition associated with the waning flow portions of sandy storm beds (as oppoced to a return to "true" fairweather deposition by suspension fallout), as well as the lower shoreface expression of seasonal phytodetritus concentrations in the deep-sea/shelf. Another line of support for possible seasonal variations is the stacking patterns within this facies. Commonly, the sandstone beds thicken upwards only to gradationally return to much more thinly interbedded sandstone and shale of the same facies. This may represent a record of seasonal variations controlling such factors as frequency and/or strength of storms, as well as sediment supply. In core, the sandstone versus shale dominance in this facies is quite subtle and may locally appear to be a flooding surface. Obviously, seasonal change is only one possibility to explain variation in this facies, and other factors such as relative sea-level and autocyclic events (*e.g.* delta lobe switching or channel avulsion) should also be considered.

The sideritisation of the organic-rich shales most likely resulted from incipient diagenesis, catalysed by *in situ* breakdown of organic material (Berner, 1980). Organic detritus is visible in these muds and is omnipresent on a microscopic scale in samples processed for the purpose of biostratigraphic analysis. Moreover, the sampled muds are essentially barren of microfossils (J.A. MacEachern, pers. comm., 1993), which supports the interpretation of rapid deposition during storm events. The synaeresis cracks probably formed in response to shrinkage of clay minerals, which can be caused by salinity fluctuations associated with the introduction of freshwater into open marine environments (Burst, 1965; Plummer and Gostin, 1981). The ubiquitous synaeresis cracks indicate that there was a significant salinity stress during the deposition of this facies; this accounts for part of the reduced burrowing abundance and diversity noted in Facies 5. It is suggested that periodic introduction of freshwater locally reduced salinity, thus preventing all marine organisms from exploiting the less saline conditions. This environmental stress ultimately manifest itself in the rock record as a reduction in the overall ichnofossil assemblage observed in FA2.

The ichnofossils represent a slightly impoverished *Cruziana* assemblage, owing to the dominance of deposit feeding structures (Frey and Pemberton, 1984). The assemblage is depleted relative to FA1, mostly with regard to the abundance of individual burrows and the overall intensity of burrowing. The dark organic-rich shales of FA2 are ordinarily burrowed by only one or two ichnogenera. The *Chondrites-Planolites* association (Figs. 3.5B; 3.8A,D,F) is most common in the dark shales, whereas *Asterosoma* (Fig. 3.8C) and *Rhizocorallium* (Fig. 3.8D) are rare. Regardless of the suite, the burrowing is relatively sparse compared to similar dark shales associated with FA1. It is postulated that the dark shales were exploited by opportunistic, (?)deep tier burrowing organisms that were able to feed on the bacteria degrading the abundant organic material available. Such modes of feeding from storm buried organic material were discussed by Vossler and Pemberton (1988). The occurrence of *Chondrites* in the FA2 organic-rich shales is similar to that observed in the Jurassic Posidonienschiefer Formation of Germany (Bromley and Ekdale, 1984). In that unit, it was noted that *Chondrites* occurred in dark carbonaceous sediment deposited under chemically reducing, depleted oxygen conditions. Such an association also appears to exist for *Chondrites* in the dark, organic-rich shales of this facies; this implies that much of FA2 may have been deposited under reduced oxygen conditions. The *Asterosoma* and *Rhizocorallium* that are also found in these dark shales represent similar opportunistic feeding behaviour.

3.62 FACIES 6: Thickly Bedded, Low Angle Laminated Sandstones

Lithology and Sedimentary Features: Facies 6 has an average grain size between upper very fine and lower fine, but the grain size ranges anywhere from lower very fine to upper fine. In general, these sandstone beds are coarser than sandstone beds within Facies 5. In addition, the grain size increases upwards within Facies 6, resulting in an overall subtle coarsening upwards succession. The sandstone beds range in thickness between 0.15m and 4.0m. These sandstone beds commonly have low angle inclined to undulatory laminations (Fig. 3.7A) at their base that pass upwards into small scale wavy parallel and convex upwards laminae (Figs. 3.7C; 3.10C). Sandstone beds that are 1.0m or greater in thickness are generally made up of several smaller stacked sandstone beds separated by low angle truncation surfaces; in these instances, the small scale convex upwards laminae are only rarely preserved. The low angle (~5-15°) truncation surfaces are ubiquitous and commonly obliterate all trace of convex upward laminae (Fig. 3.10A). The low angle inclined laminae are commonly accentuated by finely comminuted organic detritus (Figs. 3.7A,D; 3.9A,F,G,H,I,J; 3.10G,I), and glauconite is also a constituent of the sandstone beds. The organic detritus is especially visible on laminar or bedding planes of the core; the glauconite is most easily seen under the binocular microscope as very fine grains interstitial to the sand grains. Rare occurrences of small (*i.e.* millimetre scale) coaly and/or intraformational shale rip-up clasts also locally accentuate the low angle inclined laminations. In one core location (14-22-22-24W4), a bedding plane in the amalgamated portion of this facies revealed a small bivalve shell (Fig. 3.7E). The sharp bases of the sandstone beds are locally marked by a few scattered pebbles and/or granules. The pebbles/granules are generally well rounded and ≤1cm in diameter. Locally, the granules/pebbles actually accentuate the laminations (Fig. 3.7B).

Ichnology: Burrowing of the thickly bedded sandstones is essentially restricted to the top 10-15cm of the beds and include escape traces (*i.e.* fugichnia) (Fig. 3.9F), *Ophiomorpha nodosa* (Fig. 3.9H) and *Ophiomorpha irregulaire* (Fig. 3.9G). *Ophiomorpha irregulaire* was found in only one well (7-7-25-20W4), where the thickly bedded lower to upper very fine-grained sands coarsen up into lower to upper fine-grained mottled sand. The escape traces, *O. nodosa* and *O. irregulaire* are restricted to the sandstone beds within FA2 (see Table 4). Other observed trace fossils include *Anconichnus horizontalis* (Fig. 3.9J), *Asterosoma, Helminthopsis* (Fig. 3.9H), *Palaeophycus* (Figs. 3.9I,J), *Teichichnus* (Fig. 3.9J), *Thalassinoides* and *Zoophycos* (Fig. 3.7D). *Ophiomorpha nodosa* and *Palaeophycus* are the most common ichnofossils within the tops of these thick sandstones. All the burrows, save *Helminthopsis*, reflect first stage opportunistic colonisation of sandy storm deposited substrates, similar to the colonisation of the thinner storm-generated sandstone beds of FA1 (*i.e.* in Facies 4). *Helminthopsis* represents a second stage reburrowing of the original pioneer trace suite, comparable to the role of *Helminthopsis* and *Anconichnus horizontalis* makers in reburrowing larger burrows in the sandstone beds of FA1. Overall, the burrowing intensity is rare to nil; locally, the trace fossils themselves have been truncated by the low angle truncation surfaces.

Interpretation and Discussion: This facies was deposited in a wave-dominated delta front or lower to middle shoreface environment. As previously mentioned, the low angle inclined to undulatory laminations at the base of the sandstone beds pass upwards into small scale wavy parallel and convex upwards laminae (Fig. 3.9J). The low angle inclined to undulatory laminations are interpreted as hummocky and swaly cross stratification (*i.e.* HCS and SCS). Low angle (~5-15°) truncation surfaces are ubiquitous in the thick sandstone beds; where they obliterate all trace of convex upward laminae, the sands are interpreted as swaly cross stratified (*i.e.* SCS) (Fig. 3.10A). Morphologically, Duke (1980; *fide* Duke, 1985) distinguished SCS as a variant of HCS in which swales are preferentially preserved, and hummocks are rarely preserved to absent. Where slightly convex upwards laminae are preserved, the sandstone beds are interpreted as hummocky cross stratified (*i.e.* HCS) (Fig. 3.9J). The HCS and SCS sandstone beds were most likely formed by storm-generated oscillatory currents. The small scale wavy parallel and convex upwards laminae, which commonly cap the thick sandstone beds, are interpreted as small scale oscillation to combined flow ripples (Figs. 3.7C; 3.10C) that likely represent reworking of the tops of the HCS/SCS sandstone beds by the waning stage effects of storm-generated currents or by fairweather waves. It is more probable, however, that the smaller scale ripples resulted from smaller and smaller wave orbital velocities associated with the abatement of storm induced waves. Duke (1990) suggested that the low angle inclined laminations in HCS beds resulted from oscillatory currents whereas the wavy parallel and convex upwards laminae resulted from combined flow currents (*i.e.* a current in which a unidirectional current is superimposed and "enhances" an oscillatory current). Much like the rarely to moderately burrowed portion of FA2, the dark shales that cap the sandstones are sporadically burrowed with *Planolites, Chondrites, Asterosoma* or *Rhizocorallium*, commonly have synaeresis cracks, and are locally sideritised (Fig. 3.10C). Burrowing in these muds is predominantly by a single ichnogenera, and the ichnologic interpretation of these organic-rich/carbonaceous shales is identical to that of the organic-rich shales of the burrowed portion of FA2 (*i.e.* Facies 5). The variable thickness of the sandstone beds can be attributed to the amalgamation of storm beds, with each successive storm sufficiently erosive so as to remove any interim fairweather deposits. The main parameters regarding the relative role of storm energy on shoreface ichnology and sedimentology are discussed in detail by MacEachern and Pemberton (1992), but in general, the dominance of SCS over HCS may reflect the higher energy and shallower water conditions of the middle shoreface as opposed to those of lower shoreface environments (Rosenthal and Walker, 1987). Duke (1985) also suggested that the dominance of amalgamated HCS beds (*i.e.* SCS) represents, "more energetic and/or frequent storm events, possibly indicating shallower depth and/or closer proximity to source". In general, storms and their deposits on shorelines are controlled by such factors as storm frequency, storm strength, seasonal effects (*e.g.* hurricanes and winter storms), shoreline configuration, water depth and shoreface gradients. Periodically, either pebbles were supplied from the source area, or the storm-generated currents were energetic enough to move small pebbles and granules into the delta front/lower to middle shoreface. In fact, the author observed small pebbles and granules in outcrops of HCS beds of the partially equivalent Bootlegger Member of the Blackleaf Formation in Montana, as well as in the subsurface SCS/HCS beds of the Albian Falher Member of the Spirit River Formation (*i.e.* the Falher A, B and D). Similarly, pebbles were seen accentuating swaly cross stratified sandstone beds in the Nomad Member of the Wapiabi Formation (Rosenthal and Walker, 1987). The rare coaly and intraformational rip-up clasts found in this facies also attest to the initial high energy, erosive nature of the storm-generated currents, which were followed by emplacement of the sandstone beds.

Hummocky cross stratification is thought to be generated by storm induced oscillatory currents. There is some debate surrounding this, but the most recent experimental flume studies in fine grained sand indicate that HCS arises as a result of bidirectional, purely oscillatory currents (Southard *et al.*, 1990). Similarly, Arnott (1993) suggested a purely oscillatory origin for HCS, specifically, long-period, high-speed oscillations. Duke *et al.* (1991) stated that HCS can be formed by combined flows, but they stressed that the flows are, "*very* strongly oscillatory-dominant flow.". Conceptually, it is reasonable to assume that HCS could also be produced by combined flows, although experimental work thus far has not substantiated this. Ongoing flume investigations hope to shed more light on the relative roles of oscillatory and combined flows on the formation of HCS (R.W.C. Arnott, pers. comm., 1993).

The recognition and identification of HCS and SCS in subsurface drill core has been a source of debate for a number of years. Strictly speaking, the wavelength of hummocks and swales (*i.e.* tens to hundreds of centimetres) that are characteristic of HCS and SCS are too large to be seen in a 3"-4" diameter core. Therefore, it is stressed that in core, HCS and SCS are interpretive. Their interpretation is based on experience, their context in the overall vertical succession of facies, the grain size of the thick sandstone beds, the observed lamination types, as well as observations made from outcrop. The author has seen HCS in partially correlative rocks of the Bootlegger Member of the Blackleaf Formation in Montana, as well as several other Cretaceous sandstone units throughout the Western Interior Seaway. In addition, HCS has been interpreted from core and outcrop in the Turonian Cardium Formation (*e.g.* Plint *et al.*, 1986, 1988), and from core in the Viking Formation by numerous authors (*e.g.* Hadley, 1992). Perhaps some of the most compelling evidence for the interpretation of HCS and SCS from core stems from the outcrop and core work of Pemberton *et al.* (1992d) on the Upper Cretaceous Spring Canyon Member (Blackhawk Formation) of the Book Cliffs, Utah. The outcrop of the Spring Canyon Member near Helper, Utah represents a shelf to shoreface to backshore succession of facies. The distal and proximal lower and middle shoreface deposits of the Spring Canyon Member outcrop contain beautiful examples of hummocky cross stratified and amalgamated hummocky cross stratified (*i.e.* SCS) sandstone beds (J.C. Van Wagoner, pers. comm., 1993). In April of 1982, Exxon Production Research Company stepped back approximately one mile from the main outcrop face at Helper, Utah and cored and logged a well (*i.e.* E.P.R. Co. Price River "C" core/well) in order to compare known outcrop observations with their core counterparts. The depositional context and physical manifestation of the HCS and amalgamated HCS beds in the Price River "C" core is, for all intents and purposes, identical to those interpreted as HCS and SCS sandstone beds in this study. Therefore, it is with confidence that the low angle inclined and low angle undulatory laminations in cores of the Bow Island Formation are interpreted here as HCS and SCS sandstone beds. Furthermore, the low angle truncations seen in core are likely representative of amalgamated, strongly erosive storm-generated features amenable to SCS.

The burrowing in the sandstone beds is representative of opportunistic colonisation of the top 10-15cm of storm-generated HCS beds. The presence of the bivalve shell in some of the SCS beds (see Fig. 3.7E) suggests that conditions were sufficiently energetic as to allow bivalves to survive via filter feeding. Furthermore, the shell suggests that some of the escape traces that are found in this facies were likely created by the action of bivalves, particularly where the escape traces had very sharp "V" structures (Kranz, 1974). The overall interpretation of the burrowing trends is identical to that given for the burrowed storm-generated sandstone beds of Facies 4.

3.7 Subfacies 6A, 6B, 6C and 6D

Facies 6 has four subfacies which have been designated Subfacies 6A through 6D. The subfacies are not commonly found within the study area but are important enough to be included here with Facies 6. Moreover, the subfacies have a significant effect on the overall interpretation of the lithologic successions noted in this study. The reason they are subfacies of Facies 6 is simply that they are most commonly associated with Facies 6 rocks and tend to be variants on Facies 6. As a result of their overall affinity for Facies 6, all the subfacies can be considered to be components, albeit minor components, of FA2. The subfacies descriptions are given below, from most commonly found to least commonly found. Subfacies 6A through 6D are colloquially referred to by the author as the "anomalous facies".

3.71 Subfacies 6A: Soft Sediment Deformed to Apparently Structureless Sandstone

Lithology and Sedimentary Features: Subfacies 6A is dominantly lower to upper very fine in grain size and does not have any visible burrowing. This subfacies is dominated by soft sediment deformational features including oversteepened/convolute laminations (Figs. 3.10E; 3.11A,B), ball and pillow structures (Fig. 3.10F) and microfaulting (Figs. 3.10G,H; 3.11C). The oversteepened/convolute laminations are generally visible due to minor grain size variations, the ball and pillow structures are made obvious by shaly laminae which have also been deformed; the microfaulting is most evident when the minor laminar offsets are clearly visible due to colour contrast supplied by either shaly laminae or finely comminuted organic detritus. Locally, the sandstone beds are apparently structureless (Figs. 3.10D; 3.11D). In these rare cases, no physical or ichnologic features are observed, the fabric of the rock is uniformly massive and the grain size is extremely consistent (most commonly lower very fine to siltstone). A second inspection of the apparently structureless sandstone revealed the local presence of vague low angle inclined laminations, but the identification is tenuous at best. Making X-radiographs of a slabbed piece of the apparently structureless sandstone might be a viable way to check for lamination types, but this was not done as a part of this study. X-radiographs were taken of similar, but thicker, apparently structureless sandstones in the Belly River Formation by Power (1993); his X-radiographs revealed that the sandstones were, in fact, structureless. In addition, large siderite cemented clasts and intraformational rip-up clasts are associated with this subfacies (Fig. 3.10I).

Ichnology: There were no trace fossils observed in this subfacies.

Interpretation and Discussion: The apparently structureless sandstones are interpreted as beds formed by sediment liquefaction generated by the release of elevated intergranular pore-fluid pressures. Associated oversteepened laminations and ball and pillow structures support synsedimentary deformation in response to extremely rapid deposition of some of the thick sandstones. Being intimately associated with Facies 6, Subfacies 6A was also deposited in a storm dominated delta front/lower to middle shoreface setting. It is envisaged that an "original" storm resulted in the deposition of hummocky cross stratified beds which contained high amounts of intergranular water. Instantaneous dewatering of the recently deposited HCS bed was then triggered by incipient slumping/sliding or other mass movement phenomena. Alternatively, a subsequent strong storm event may have occurred shortly after the "original" storm which resulted in the rapid emplacement of even more sand (*i.e.* sediment loading) on top of the "original" bed. This resulted in the instantaneous dewatering of all of the sand, which left its trace in the geologic record as a set of sandstone beds with oversteepened/convolute laminations and ball and pillow structures. As the dewatering occurred penecontemporaneously with deposition of the sandstone, it locally resulted in the total homogenization of the sandstone, with no trace of any type of lamination whatsoever. This penecontemporaneous sediment liquefaction is the best explanation for the apparently structureless sandstone beds, especially in light of their association with Facies 6 and the beds with oversteepened/convolute laminations and ball and pillow structures. The merits of other mechanisms that can account for the observed sedimentary features (or lack thereof) of Subfacies 6A are discussed in some detail below.

A possible explanation for the apparently structureless sandstones is that they were totally biogenically reworked, perhaps by small makers of the trace *Macaronichnus*. There is, however, no positive evidence to support this notion, even though there are *Macaronichnus* zones in more proximal facies within the overall depositional succession. Diagenetic alteration could also cause the sandstones to appear massive; so this must also be considered a possibility. When viewed through a binocular microscope under high power, the structureless sandstones appear to have a high amount of interstitial clay minerals between the sand grains, but this is also true for much of Facies 6 and the sandstones with oversteepened laminations. Furthermore, the apparently structureless sandstones are commonly associated with Facies 6 and sandstone beds with oversteepened/convolute laminations; this makes it difficult to envisage a scenario in which diagenesis preferentially selected a portion of the depositional cycle to render structureless. The context of the apparently structureless sandstone beds, then, makes diagenetic effects an unlikely candidate to explain the absence of visible structures.

Power (1993) suggested that structureless sandstones in the Belly River Formation were deposited rapidly with much of the sediment travelling in suspension rather than as bedload; that the structureless sandstones were deposited by shallow water turbidity currents [with the structureless sandstone presumably representing the "A" portion of the classical Bouma sequence (Walker, 1984)]. Shallow water turbidity currents are a possible mechanism for the generation of the apparently structureless sandstones of Subfacies 6A; it is suggested that the turbidity currents may have arisen as delta front entities. Possible deltaic influences will be discussed later in the thesis. Some main differences between the apparently structureless sandstones of Subfacies 6A and the structureless sandstones of Power (1993) include the thickness of the beds (Power's (1993) are much thicker) and the overall succession of associated sedimentary structures. Regardless, it is certainly within the realm of possibility that the apparently structureless sandstone beds were deposited extremely rapidly out of suspension as the result of decelerating shallow water turbidity currents.

The idea of turbidity currents in the Viking (and Bow Island) Formation is not new (see Chapter 2, Section 2.2). The notion of turbidity currents acting in the Alberta Foreland Basin has been a source of great controversy. Among several problems with the turbidity current model are: 1) How are the turbidity currents generated?; and 2) How are the turbidity currents maintained?. Within an overall shoreline setting, there are only three plausible ways of generating highly sand laden turbidity/density currents: 1) The currents were somehow initiated by storm wave activity; 2) The currents initiated as a result of seasonal floodstage fluvial debouchment into the marine domain; or 3) The currents may have been created by some synsedimentary mass movement process such as slumping. The first option is unlikely, as current knowledge suggests that storms are unlikely to cause sand laden currents. As previously mentioned, however, the context of the apparently structureless sandstone beds suggests that closely spaced storm events in time could account for rapid sand deposition and dewatering via loading.

The second possibility involves heavy fluvial discharge into a marine environment. During floodstage, rivers carry large amounts of sediment both as bedload and as suspended load. If the rivers were carrying a large amount of sand as suspended load, the sand laden freshwater that entered a marine body of water would be denser than the basinal, marine water. In the case of deltaic settings, this density contrast is termed hyperpycnal inflow (Bates, 1953; Bhattacharya, 1992). In this scenario, the apparently structureless sandstone beds and the sandstone beds with oversteepened/contorted laminations would have been deposited by hyperpycnal density flows that debouched from river mouths. As these density currents decelerated quickly, the sand in suspension would literally be dumped (*i.e.* "frozen") and deposited as an apparently structureless sandstone bed. This is a plausible explanation, but there are several problems with it also. One line of evidence to support this hypothesis is the overall patchy distribution of Subfacies 6A. Generally, Subfacies 6A is seen in cores that are quite closely spaced (≤ 2 miles), suggesting that their deposition was possibly point sourced (*i.e.* close to a source of fluvial input from where the hyperpycnal flow could have originated). Unfortunately, no evidence of fluvial or distributary channels have been found in the study area, although this may largely be a function of well and core spacing. This interpretation requires the hyperpycnal flow to have travelled a minimum of 24km from the nearest coeval emergent shoreline (~T24; R22W4), to the location of some of the apparently structureless sandstone beds (~T27; R20W4). The maintenance of a hyperpycnal density underflow for such a long distance is unlikely, especially given the essentially flat depositional slopes calculated for the sandstone wedges (~0.03°). Furthermore, the author knows of no documented cases of such sediment transport and deposition reported from the modern. This does not dismiss fluvial floodstage derived hyperpycnal flows as a possibility, but it is perhaps not the most reasonable explanation.

Finally, consideration must be given to shallow water turbidity currents initiated by mass movement/slumping of previously deposited material. Slumping is common in deltaic settings largely because of the rapid and fluctuating nature of sediment deposition, high sedimentation rates, and the high amount of interstitial water in the sediment itself. Slumping has been documented from the modern Mississippi River delta by Coleman and Prior (1982). Slumping is most common in the delta front where depositional rates are high and the depositional slope is relatively steep and unstable. Given these conditions, density currents could be generated, particularly at times of high fluvial discharge of dense mixtures of water and sediment. Lindsay *et al.* (1984) reported that close to half of the distributary mouth bar deposits from the Mississippi River delta were later slumped into more basinal settings; so obviously, slumping also occurs in proximal areas of modern deltas. Ubiquitous slumping in deltas is due to high rates of aggradation and/or progradation. The key point is that wherever one is on a delta profile, sedimentation rates are high and the sediment is inherently prone to be unstable due to high pore water content. In this study, there is strong evidence to support synsedimentary slumping as an explanation for the apparently structureless sandstone beds. Firstly, there is the association with ball and pillow structures, oversteepened/convolute laminated sandstone beds and small scale microfaulting, all of which can be accounted for by slumping. In fact, the slumping may be the only process required to explain the observed features in Subfacies 6A, as turbidity currents are not even required. Pore-water rich, unstable sand was deposited at distributary mouth bars (dominantly at river floodstage). It is postulated that this sand periodically slumped and was dumped into a delta front setting. The initial impetus for the slumping of the mouth bar sand could be sediment or wave loading at the delta mouth by major storms (and its resultant seaward pressure gradient), or some tectonically induced event. There are bentonites associated with the Bow Island Formation sediments in the study area, indicating that nearby areas were tectonically active (see Chapter 2, Section 2.4.1). The slumped sediment would have been dumped on pre-existing delta front sediments, which in turn were deformed [both soft sediment deformed (*e.g.* oversteepened/convolute laminated sandstone beds and ball and pillow structures), and brittly deformed (*e.g.* the microfaulting)]. The slumping and dumping of sediment may have subsequently triggered shallow water turbidity currents in the delta front; therefore, what is preserved in the rocks of interest may record a combination of slumping and shallow water turbidity currents. Moreover, the "point source" argument made in the preceding paragraph is also amenable to this explanation. Also, the slumping model does not require sustained flows over great distances, but rather provides a mechanism by which sediment could have been incrementally transported and deposited.

Overall, the favoured interpretation for Subfacies 6A involves slumping and dewatering in a delta front environment. The slumping, in turn, may have initiated sediment gravity flows. The slumping may have been triggered by wave loading, sediment loading or seismic activity; although seismic activity is the most likely cause. Schwab and Lee (1988) attributed slumping on the upper continental slope of Alaska to earthquake activity. Schwab and Lee (1988) also attributed the development of sediment gravity flows on the shoreface to storm wave loading. Although the Alaskan upper continental slope is not a good analogy for the Alberta Foreland Basin (*i.e.* depositional gradients, rate of sedimentation *etc.*), it is encouraging that at least the processes and mechanisms being interpreted for the uppermost Bow Island Formation are observable in the modern.

The high energy affinity of these modes of rapid deposition is manifest by the incorporation of intraformational sandstone, shale, and sideritised shale rip-up clasts (Fig. 3.10A). As previously alluded to, microfaulting is also evident (Figs. 3.10H; 3.11D). The most important conclusion to be made is that occurrences of Subfacies 6A, where found, were essentially deposited/created instantaneously as a result of very energetic events.

3.72 Subfacies 6B: Rippled Pebbly/Granular Sandstone

Lithology and Sedimentary Features: Morphologically, Subfacies 6B is very similar to the pebbly/granular portion of Facies 6. The subfacies is dominantly lower to upper very fine-grained, but the very fine-grained sandstone beds also contain ≤1cm diameter, rounded chert pebbles and smaller granules/coarse-grained to very coarse-grained sand. The coarser-grained fraction of this subfacies is commonly incorporated into the sandy bedform, indicating simultaneous deposition and modification of the lower to upper very fine-grained sand and the pebbles/granules. The beds themselves show wavy parallel and wavy inclined laminations (Fig. 3.12A). This subfacies is only associated with Facies 6 and the other subfacies of Facies 6.

Ichnology: No trace fossils were visible in this subfacies.

Interpretation and Discussion: The wavy parallel and wavy inclined laminations in this subfacies are interpreted as oscillation to combined flow ripples. Subfacies 6B was deposited as a result of storm-generated, dominantly oscillatory currents. This interpretation is supported by the work of Leckie (1988) who suggested that storm waves that formed coarse-grained ripples were not particularly strong, and likely had wavelengths of 2-5m and periods of 8-14 seconds. Furthermore, Leckie (1988) noted the association of coarse-grained ripples with HCS beds, postulating that oscillatory/oscillatory-dominant flows moulded medium to very coarse-grained sand, or pebbly sand into 2-dimensional coarse-grained ripples. These same flows moulded very fine and fine-grained sand into 3-dimensional HCS, and this is borne out in an outcrop example from the Gates Formation in which a coarse-grained ripple bed passes laterally into an HCS bed (Leckie, 1988). Essentially identical associations and grain sizes were observed in Subfacies 6B as for those modern and ancient examples of Leckie (1988). These rippled pebbly sandstone beds probably remained inactive after their formation and were subsequently buried by finer-grained shifting sands (Leckie, 1988). Gillie (1979 *fide* Leckie, 1988) suggested that the coarse-grained ripples formed during the waning stages of larger storm events, as opposed to during the height of a large storm. Occurrences of this subfacies have been reported from storm influenced shoreface environments in other Cretaceous units in the Western Canada Sedimentary Basin (*e.g.* Wright and Walker, 1981 in the Cardium Formation; Leckie and Walker, 1982 in the Gates Formation; Rosenthal and Walker, 1987 in the Nomad Member of the Wapiabi Formation).

Transportation of ≤2cm diameter pebbles into lower shoreface environments requires storm waves on the order of 1-9m high and 6-16 second periods; can be found in water depths from 3-160m (Leckie, 1988). The most important implication of this is that waves are capable of moving fairly large pebbles, and therefore every thin pebbly horizon seen in the rock record does not necessarily require major allocyclic processes such as lowering of sea level. Furthermore, the overall context (*i.e.* commonly associated with HCS sandstone beds) and abundance of Subfacies 6B favours its interpretation as a storm-generated phenomena.

3.73 Subfacies 6C: Structureless/Soft Sediment Deformed Grey Siltstone

Lithology and Sedimentary Features: This subfacies comprises siltstone with minor lower very fine-grained sandstone (Fig. 3.12B). No physical sedimentary structures are readily apparent, although what appear to be dish structures are visible. Rare small scale soft sediment deformational features are also seen in this subfacies (Fig. 3.12C). Overall, the fabric of Subfacies 6C is massive. Subfacies 6C is only found in one or two of the studied cores and was found in bed thicknesses ≤15cm.

Ichnology: No trace fossils were visible.

Interpretation and Discussion: This subfacies was deposited in a wave-dominated delta front environment. Subfacies 6C was most probably deposited very rapidly by similar processes to those responsible for the deposition of the apparently structureless sandstone beds and soft sediment deformed sandstone beds of Subfacies 6A. For a detailed account of these processes, please refer to the discussion of Subfacies 6A. The dish structures and soft sediment deformation features are indicative of rapid deposition and dewatering of the siltstone beds. Subfacies 6C has many similarities with the apparently structureless sandstone beds of Subfacies 6A, but have an even finer grain size.

3.74 Subfacies 6D: Fining upwards pebbly sandstone

Lithology and Sedimentary Features: This subfacies has a variable lithology and grain size. Subfacies 6D is only represented in one core in the study area (*i.e.* 6-2-24-17W4). The bed in question has a sharp base and is overlain by a thin zone of conglomerate with rounded chert pebbles in excess of 4cm diameter (Figs. 3.12C,E). This passes gradationally upwards into a pebbly sandstone (lower to upper very fine-grained) with smaller pebbles (average 1-2cm rounded diameter) dispersed throughout ([illegible]. few pebbles were observed touching each other, and this became even less so upwards within the bed). This gradationally passes up into a deformed silty very fine-grained sandstone similar to Subfacies 6A, but with the persistence of a few scattered <8mm diameter rounded pebbles dispersed throughout (Figs. 3.12C,D). This succession is then sharply overlain by a low angle inclined laminated sandstone bed with a few scattered 1cm diameter scale rounded pebbles.

Ichnology: No trace fossils were visible in this subfacies.

Interpretation and Discussion: This subfacies was produced by a singular, high-energy event. It is suggested that the bed was deposited as a combined result of a major slumping event and a possible shallow water density current that it triggered. The mechanisms for major slumping and the generation of sediment gravity flows is discussed in detail in the interpretation of Subfacies 6A. This bed resembles what have been called seismites. Figure 3.12C also illustrates coarse-tail grading. Coarse-tail grading simply means that there is an upwards normal grading of the coarsest fraction of this event bed.

3.75 Brief Summary of the "Anomalous Facies", Subfacies 6A through 6D

Subfacies 6A through 6D were deposited in close association with storm-generated HCS and SCS sandstone beds of Facies 6. As such, Subfacies 6A through 6D generally represent extremely rapidly emplaced beds in an overall wave dominated succession. The "anomalous facies" likely represent beds generated by delta front slumps which may have been initiated by any one of a number of processes. There also appears to be evidence to suggest deposition by rare sediment gravity flows; these flows were likely triggered by the slumps. It is stressed that one or more of Subfacies 6A through 6D occur in only ~10% of the examined cores.

3.8 FACIES 7: Clast And Matrix Supported Conglomerate

Lithology and Sedimentary Features: This facies is composed of well rounded pebbles in a matrix of lower to upper very fine-grained sandstone (Figs. 3.13A,B), and is most commonly associated with FA2. In some localities, Facies 7 is found near the contact between FA1 and FA2. Although, the rounded sides of the core commonly do not show the pebbles touching one another, bedding planes reveal that most of the pebbles are in contact; hence the designation of this facies as dominantly clast supported. However, examples of matrix supported conglomerate do exist (Fig. 3.13B). The beds of unimodal conglomerate range in thickness from 1-75cm, with the average bed thickness being 1-15cm. The pebbles are dominantly sub- to well rounded, and range in grain size from 0.5-6cm in diameter. The average pebble diameters range from 0.75-2.5cm. In most of these beds, the maximum pebble diameter observed was on the order of 3-4cm, with instances of pebble diameters in excess of 4.5cm being relatively rare. The pebbles are dominantly varicoloured and composed of chert. Dominant pebble colours included black, white, green and red. A minor component of the pebbles appeared to be of lithic origin. Subangular to well rounded siderite and intraformational shale rip-up clasts, as well as rare woody or slightly coalified wood fragments also comprise a minor component of this facies. The siderite/ripped-up shale clasts range from 3-8cm in diameter and tend to be larger than the pebbles they are associated with. Although Facies 7 is dominantly clast supported, there is still a significant amount of matrix that occupies the interstices between the pebbles. Most commonly, the matrix comprises very well sorted lower to upper very fine-grained sandstone that appears both macro- and microscopically to be identical to the sandstone surrounding Facies 7 (*i.e.* normally Facies 5, 6 or the Subfacies 6A-D). The grain size of the matrix does vary somewhat from a maximum of 1-3mm diameter granules, through to shale, but the lower to upper very fine-grained sand is by far the prevailing matrix grain size. The lower to upper very fine-grained matrix is not totally featureless. Locally, the pebbles appear to distort very fine scale laminations in the very fine-grained sandstone and siltstone that comprise the matrix (Figs. 3.13A,C; Figs. 3.14A,B). In the 16-8-26-19W4 and 6-18-27-20W4 cores, the matrix actually appears to be bedded on a fine scale. Furthermore, the 6-18-27-20W4 core shows a unique example of pebbles apparently "floating" in a shaly matrix which is burrowed by the ichnogenus *Chondrites*. Locally, this facies fines upwards (*e.g.* in Unit 4, 16-8-26-19W4; Unit 2, 9-14-28-21W4; Fig. 3.13C), although few other sedimentary fabrics were determinable. No obvious examples of preferential pebble imbrication were noted anywhere in the study area. Some of these unimodal clast supported conglomerates pass upwards into upper medium-grained to lower coarse-grained sandstones, which pass upwards into oscillation rippled very fine-grained sandstones, which in turn pass gradationally upwards into unburrowed black shale (*e.g.* Unit 4, 6-6-26-18W4). In many of the cores where this facies is visible, there are actually two thin (*i.e.* <10cm thick) but distinct beds of Facies 7 which are separated by zones of shale or interbedded very fine-grained sandstone and shale. This relationship is a real one, as in several instances, the pieces of core in question were reliably fit back together (Fig. 3.14B).

The nature of the contact between Facies 7 and whatever facies underlies it is variable. The contact is always lithologically sharp because it normally juxtaposes 2-5cm diameter pebbles on top of very fine-grained sandstone. However, this contact only appears erosive in a few localities. Evidence for erosion includes an undulatory contact on the scale of the core, as well as demonstrable truncation of underlying features such as physical sedimentary laminations or burrow forms. Also present, are locations where the basal contact of Facies 7 does not appear any more erosive than any other sharp bedding contact (*e.g.* the Unit 7/Unit 8 contact in core location 6-9-29-22W4). In some cores the contact appears very "gentle", with some of the pebbles delicately overlying and distorting (but not truncating) fine scale laminations in the underlying sandstone beds (Fig. 3.13A; Fig. 3.14B). Also, a few of the pebbles are actually detached from the true well sorted clast supported conglomerate bed and are found "floating" in the underlying substrate, with laminations in the underlying sediment actually wrapping all around the pebbles (Fig. 3.13A). Other occurrences of the basal Facies 7 contact show vertically oriented (*i.e.* pebble C- or long axis) pebbles subtending into the underlying bed (*e.g.* Unit 3/Unit 4 contact in core location 6-6-26-18W4).

Facies 7 is commonly overlain by thinly interbedded Facies 5 or Facies 3. The Facies 5 interval has a pinstriped appearance to it, with common to moderate burrowing intensity, whereas the Facies 3 interval is thoroughly mottled by a diverse marine assemblage of trace fossils. The superposition of Facies 3 on Facies 7 is somewhat subtle, but is seen in many cores. It should also be noted, that Facies 7 is normally quite thin; so recognition of this facies on well logs is essentially impossible.

Ichnology: No trace fossils were obviously visible in this facies. In the rare instance that the pebbles were in a shale matrix, some *Chondrites* were seen in the shale. In addition, the sandstones and shales that comprise the fining upwards portion of some of these beds are burrowed with traces similar to those found in Facies 4 (Fig. 3.14D).

Interpretation and Discussion: There are two main possible interpretations for Facies 7: a) The facies was deposited by storm-generated currents; b) The facies represents transgressively reworked lowstand derived deposits. A critical discussion of these interpretations is given below.

Storm-generated density currents may have deposited this facies. The depositional context and processes associated with a storm-derived origin are very similar to those proposed for Subfacies 6A, 6B and 6D. When assessing this particular interpretation, it is important to note that in many localities, the facies that both underlie and overly Facies 7 are the same (*i.e.* Facies 6 or one of its subfacies). The main differences between Facies 7 and Subfacies 6B are that Facies 7 contains larger pebbles and lacks the ripple forms characteristic of Subfacies 6B. Otherwise, they are quite similar, especially in their association with HCS and SCS beds. It is suggested that storm-generated density currents were responsible for deposition of this facies; this was followed by a period of storm-wave reworking of the deposited material. The fact that the sandstone matrix locally retains some unaltered fine scale lamination suggests that the conglomerate beds may have been deposited by decelerating density currents that caused the pebbles to "freeze" and be emplaced very quickly, with open frameworks. Then, as the very fine-grained sand associated with the density current began to settle out of suspension, it filled in the open interstitial pore spaces between the pebbles. The fining upwards of many of these pebble beds supports the interpretation of rapid deposition by single decelerating flows (similar to Subfacies 6D). It is envisaged that major storms were able to "pile up" water at the shoreline, thus creating a hydrostatic pressure gradient capable of driving seaward oriented bottom currents (Walker and Plint, 1992). This seaward pressure gradient is augmented by storm-driven oscillatory currents capable of producing the shear stresses required to move sediment offshore (Walker and Plint, 1992). An alternate method of moving sediment offshore is related to waves breaking at the shoreline and setting up a system of longshore current cells. Where opposing longshore currents converge, they can combine to create a seaward oriented rip current capable of moving sediment offshore (*cf.* Figure 3 of Walker and Plint, 1992). As Wright and Walker (1981) pointed out, however, maintaining energetic offshore oriented currents capable of moving up to 5cm diameter chert pebbles as bedload over 5-25km distances is highly improbable. Therefore, it is suggested for this facies that transport and deposition occurred as the result of density currents or turbidity currents associated with rapid and fluctuating deltaic deposition (*e.g.* floodstage discharge of lots of sediment in suspension). Factors affecting possible turbidity current deposition is given in more detail with the discussion of Subfacies 6A through 6D. Although Facies 7 is common in the study area, its occurrences are patchy, its thicknesses are variable and the individual beds do not necessarily occur at consistent stratigraphic levels. Some of the beds can be traced over small distances where core control is very good, but individual beds are difficult to correlate over large distances. This suggests that their location may be controlled, at least partially, by proximity to coeval shorelines and possibly, the location of fluvial systems/delta distributaries on the corresponding shoreline. Several previous studies of Cretaceous rocks of the Western Canada Sedimentary Basin have proposed sediment dispersal of pebbly beds by storms and storm-induced currents. Density currents have previously been invoked as a mode of rapid deposition of gravel up to 7cm in diameter in Cardium Formation outcrops near Seebe, Alberta (Wright and Walker, 1981). Similarly, Leckie and Walker (1982) suggested that sharp based, fining upwards conglomeratic beds of the Gates Formation were actually emplaced by storms, and noted that the conglomeratic beds were rippled at their tops and were associated with SCS beds. Rosenthal and Walker (1987) observed pebbly layers and beds in the Nomad Member of the Wapiabi Formation which they interpreted as storm-wave reworked storm rip current deposits. Moreover, Rosenthal and Walker (1987) suggested that the sand in the HCS beds may have been initially deposited by storm-generated turbidity currents. This implies that the processes depositing sand could have included storm-generated density and turbidity currents; that the presence or absence of pebbly material could simply be related to availability of pebble-sized material. Facies 7 was found in the identical depositional context in the Harmattan area (Viking Formation) by Hadley (1992). Facies 7 of this study is the same as Facies 6 of Hadley (1992). Furthermore, cores logged in this study are in the same depositional cycle as those logged in Allomember D by Hadley (1992). In other words, the two studies are based on similar rocks at the same stratigraphic level. Hadley's (1992) conglomerate beds ranged in thickness from 1-90cm (average 20-25cm thick), and his chert pebble diameters ranged from 0.6-15cm in diameter (average

2.5cm diameter). Hadley (1992) suggested that the pebbles and cobbles of his Facies 6 were transported onto the shelf by geostrophic flows during very large storms, and were subsequently winnowed by waves. Hadley (1992) goes on to suggest that HCS and SCS beds associated with his Facies 6 reflect waning effects of the same flows. Hadley (1992) ultimately interpreted the presence of pebble beds with SCS beds as reflecting periodic gravel supply to a shallow shoreface environment. The pebbles and cobbles were supplied to the beach by fluvial channels and subsequently transported offshore via intense storms (Hadley, 1992). A similar interpretation is suggested as an explanation for the pebble beds of Facies 7 in this study. The best evidence for this lies in the observed rocks. Figure 3.14C beautifully illustrates a storm generated sandstone bed that passes from pebbles at the base, through hummocky cross stratified very fine-grained sandstone and continues gradationally upwards into massive grey siltstone and organic rich shale. It is suggested that modifications to this type of deposition and storm reworking may also be partially applicable to the origins of Subfacies 6A, B, C and D. Furthermore, Figure 3.14D illustrates a similar type of storm generated deposit to Figure 3.14C, with the exception of an opportunistic marine trace fossil suite colonising the sandy substrate.

The second possible interpretation of Facies 7 involves fluctuations in relative sea level. As mentioned, this facies is commonly found near the FA1/FA2 contact. This contact is normally very sharp and is easily seen in core due to an increase in sandstone content and bed thickness, and the dramatically reduced burrowing intensity of FA2 compared to FA1. This abrupt change represents one of two things: a) a sharp transition from distal delta front/lower shoreface (*i.e.* FA1) to proximal, storm-dominated delta front/lower shoreface (*i.e.* FA2) within a single, overall shoaling upwards succession, or b) a basinward shift in facies, with proximal facies (*i.e.* FA2) overlying genetically unrelated distal deposits (*i.e.* FA1), with a discontinuity surface separating the two. Firstly, if there are two shorelines separated by a surface of some allostratigraphic significance, then Hadley's (1992) allostratigraphy (see Figure 2.4 on page 27) would have to be modified such that a discontinuity surface would be present within allomember D, between his VE3 and VE4 surfaces. The basinward shift in facies manifest by the FA1/FA2 transition would suggest that the two facies associations were separated by a relative lowstand surface. Locally, erosively based Facies 7 does occur close to or at the FA1/FA2 contact. In this interpretation, the pebbles would not have to be transported offshore because the relative lowstand would facilitate the supply of pebbles and other coarse detritus into previously offshore environments. If Facies 7 is the byproduct of a relative lowstand event, then one would expect to find age correlative/ stratigraphically equivalent incised channels and/or valleys and possible updip evidence of subaerial exposure, but no evidence of these types of deposits were discerned in the study area. A relative lowstand event, then, solves the problem of transporting the pebbly material, but does not explain how many of the conglomerates were moulded into fining upwards beds. In this interpretation, the relative lowstand was followed by a transgressive phase and it was in the transgressive phase that the conglomerates were reworked by storm waves. Similar interpretations of transgressively reworked, rippled conglomerates have been suggested for other units in the Cretaceous of Western Canada (*e.g.* Cheel and Leckie, 1992 in the Chungo Member of the Wapiabi Formation). The common occurrence of Facies 3 overlying Facies 7 is also evidence of a deepening event. Therefore, it is possible that a relative lowstand facilitated deposition of the pebbly material; this was followed by a transgressive phase which is manifest in the rocks by a return to essentially fully marine conditions as indicated by Facies 3 (and its associated wide diversity/heavily burrowed nature). Storm and fairweather waves could then have winnowed and modified the conglomerate beds.

Facies 7 may represent storm-wave modified density or turbidity current deposits, but overall, the favoured interpretation is that the majority of the occurrences of Facies 7 represent deposits of large waves that resulted from major storms, perhaps coupled with a supply of pebbles to the shoreline during times of high runoff/discharge from coeval fluvial or delta distributary channels. The reasons for this include the placement of Facies 7 within the overall depositional sequence, its occurrence at several different stratigraphic levels, its lack of widespread correlatability, its association with facies of similar origin, the literature concerning these types of beds, the nature of the basal bed contacts and matrix, and the common fining upwards of the conglomeratic beds. An amalgamated lowstand/transgressive interpretation [or "Flooding Surface-Sequence Boundary" (*i.e.* FS/SB) in the terminology of Van Wagoner *et al.* (1990)]

cannot be ruled out, as their is some evidence to support it, but it is not the favoured interpretation. There is the possibility that both interpretations contribute to the observed characteristics of this facies. It is possible that there are in fact two stacked deltaic/shoreface cycles separated by an FS/SB and that each of the two cycles within what correlates to Hadley's (1992) Allomember D have density current or storm-induced conglomeratic beds associated with them. Perhaps this combination of the two discussed interpretations is the best way to explain all the characteristics of Facies 7.

3.9 FACIES 8 through FACIES 11

Facies 8 through Facies 11 are only present in one core in the study area (*i.e.* the 14-11-22-24W4 core); so their descriptions and interpretations will be brief.

3.10 FACIES 8: Rippled fine to medium grained sandstone

Lithology and Sedimentary Features: Facies 8 comprises upper fine-grained to upper medium-grained sandstone. Small scale angle of repose foreset laminae were observed (Figs. 3.15A,B). Maximum ripple heights were on the order of 3-4cm and the small scale foreset laminae were accentuated by finely comminuted organic detritus. This facies grades out of SCS beds of Facies 6 as part of an overall coarsening upwards succession.

Ichnology: No trace fossils were visible in this facies.

Interpretation and Discussion: This facies was deposited in an upper shoreface environment. The small scale angle of repose foreset laminae are interpreted as current ripples. The current ripples were small, migrating bedforms in the upper shoreface which suggest that unidirectional currents were prevalent.

3.11 FACIES 9: Planar parallel to very low angle laminated medium-grained sandstone

Lithology and Sedimentary Features: Facies 9 comprises planar parallel to low angle laminated, lower to upper medium-grained, greyish coloured sandstone (Figs. 3.15B,C). Facies 9 grades and coarsens slightly out of Facies 8. The sandstone comprised dominantly black and white quartz sand grains.

Ichnology: Facies 9 has a monospecific trace fossil assemblage. The only ichnofossil found in this facies is *Macaronichnus segregatis* (Figs. 3.15B,C). The *M. segregatis* are 1-2mm in diameter and some burrows show significant vertical components, although the burrows are dominantly horizontal in nature. Generally, the individual burrows do not cross cut one another. Where the *M. segregatis* occur, they were found in dense concentrations, particularly right above the Facies 8/Facies 9 contact, and in a zone 15cm above the Facies 8/Facies 9 contact. Where the burrows are found in association with primary physical sedimentary structures, they do not appear to disrupt the stratification. As such, the burrows appear to be in equilibrium with the bedforms. The *M. segregatis* are difficult to see and their visibility was enhanced when water was sprayed on the rocks. Upon inspection under a binocular microscope, it became clear that the *M. segregatis* were unlined, but their fills were entirely made up of white quartz grains. The lack of dark, mafic grains in the burrow fills made it look like the burrows had a distinctive lining, but in reality, no true lining was observed.

Interpretation and Discussion: Facies 9 is interpreted as representative of foreshore/beach deposits (*i.e.* the intertidal portion of a shoreline dominated by the zone of wave swash). The planar parallel to low angle laminations observed are interpreted as swash zone laminations characteristic of foreshore and beach environments. As classic beach and foreshore wedge sets are too big to be seen in core, it is stressed that these features are purely interpretive, and based on the nature of the stratification, grain size, overall depositional context and trace fossils. Laminations in this facies are distinct from those of Facies 6 because of larger grain sizes, fewer truncation surfaces and lower angles. The presence of dense zones of *Macaronichnus segregatis* in this facies had a profound effect on the interpretation. *M. segregatis* was named by Clifton and Thompson (1978); as they pointed out, dense concentrations of the trace in intertidal to shallow subtidal nearshore environments constitutes an important exception to the commonly held notion of decreasing burrowing intensity with proximality to the beach. Both ancient *M. segregatis* and modern *Macaronichnus* generating worms are commonly found at the contact between the upper shoreface and the foreshore (T.D.A. Saunders, pers. comm., 1993). Such a relationship appears true for this study also.

Dense zones of *M. segregatis* are typically associated with the foreshore; as such, dense *M. segregatis* zones seem to be facies controlled. Normally, deposit feeding strategies are more characteristic of low energy conditions (*i.e. Cruziana* ichnofacies) whereas vertically oriented, suspension feeding organisms are more characteristic of shifting sandy substrate, high energy environments (*i.e. Skolithos* ichnofacies). *M. segregatis* represents a very specialised and unique deposit feeding strategy that is atypical of high energy, shifting substrate conditions that characterise the foreshore/beach (Pemberton and Saunders, 1990). Modern studies on the west coast of Washington State by Clifton and Thompson (1978), and on the west coast of Canada by Saunders (1989) and Pemberton and Saunders (1990) showed that opheliid worms that made *M. segregatis*-like burrows fed preferentially on microorganisms (*i.e.* epigranular bacteria) that lived on the surface of selectively ingested sand grains. It follows, then, that dense concentrations of *M. segregatis* are and were related to zones with abundant bacteria. Saunders and Pemberton (1990) suggested that within high energy foreshores, wave swash waters rich in dissolved oxygen and nutrients infiltrate up to several metres below the sediment-water interface. This in turn allows epigranular bacteria to flourish to appreciable depths, and may be related to where the dense zones of *M. segregatis* are found (Saunders and Pemberton, 1990). Ancient examples of *M. segregatis* found in the Appaloosa sandstone (Campanian-Maastrichtian aged Bearpaw-Horseshoe Canyon Formations) were studied by Saunders (1989) and Saunders and Pemberton (1990). Detailed observations of burrow configurations, morphologies and spatial relationships conducted in these works suggested the following conclusions: 1) prior to ingestion, the tracemaker selectively removed grains unlikely to host much food; 2) the tracemakers maximised their "food consumed/energy expended looking for food" ratios by employing phobotaxic and thigmotaxic behaviours (Saunders, 1989; Saunders and Pemberton, 1990). Bedding plane observations of *M. segregatis* revealed that where one burrow converged on another, the "approaching" burrow either veered away sharply (*i.e.* phobotaxic behaviour) or ran parallel with the "encroached upon" burrow for a short distance before diverging off (*i.e.* thigmotaxic behaviour) (Saunders and

Pemberton, 1990). Hints of these types of burrow relationships were indicated on core bedding planes, although true analysis of such behavioural modes are not conducive to small diameter subsurface drill cores.

The observed sedimentary features, together with the strictly facies controlled occurrences of dense zones of *Macaronichnus segregatis* in Facies 9, strongly support its interpretation as representative of foreshore/beach deposits.

3.12 FACIES 10: Mottled and rooted shaly medium-grained sandstone

Lithology and Sedimentary Features: Facies 10 comprises mottled and rooted shaly lower to upper medium-grained sandstone (Fig. 3.15D). The mottled fabric of this facies obliterates any trace of original sedimentary structures. Abundant organic/plant detritus and coal and coalified wood fragments are common. Facies 10 was actually separated from Facies 11 by a very thin zone of organic-rich shale (Fig. 3.16B) that is included as part of Facies 10. The organic-rich shale was made up entirely of finely comminuted organic/plant detritus and coaly fragments.

Ichnology: Vertical, wispy root traces characterise this facies (Fig. 3.15D). On average, the roots are between 5 and 10cm long and are millimetres wide. They are made up of fine organic/carbonaceous detritus. The roots were sinuous in nature and commonly thickened and thinned along their lengths. Rare, very thin bifurcations at the terminations of the roots were visible under the binocular microscope. No other trace fossils were observed in this facies.

Interpretation and Discussion: Facies 10 is interpreted as representative of beach and/or backshore deposits. The sediments were likely initially deposited as part of a beach complex. As the shoreline prograded, original beach deposits eventually came to lay in the supratidal zone. This allowed the establishment of vegetation on these deposits, which manifest itself in the geologic record as rooted sandstones. The overall mottled fabric of Facies 10 was imparted by the establishment of root systems which disrupted the original traces of stratification. The organic-rich shale is specifically interpreted as a backshore deposit. Strong wave swash (likely during times of storms) carried organic-rich material into lows that lay behind beach ridge highs (*i.e.* berms); this is represented by the organic-rich shale. The organic-rich shale may also represent backshore environments that were heavily vegetated, possibly marshes or areas adjacent to shallow lakes (see interpretation for Facies 11).

3.13 FACIES 11: Unburrowed dark blocky mudstone

Lithology and Sedimentary Features: Facies 11 comprises blocky dark mudstone with millimetre scale siltstone/lower very fine-grained sandstone "stringers" that are discontinuous on the scale of the core (Fig. 3.16C). The facies passes from dark grey/black at the base, into grey, and finally into a greenish grey. This progressive colour change is gradational, and goes upwards into Facies 12. The greenish grey coloured portion has a higher sandstone proportion, is cemented and represents the transition from Facies 11 into Facies 12 above. No physical sedimentary structures were visible, although the siltstone/lower very fine-grained sandstone "stringers" were very sharp based. Facies 11 is characterised by abundant organic detritus, coal fragments, wood fragments and abundant, blotchy patches of pyrite (see Fig. 3.16C).

Ichnology: Root traces are the dominant ichnological feature of Facies 11. Other than the rootlets, the only other trace fossil observed was a rather large ?*Planolites* near the top of the facies.

Interpretation and Discussion: Firstly, this facies is called a mudstone because of its blocky nature and lack of good fissility. The mudstones are interpreted as representative of backshore pond or ephemeral shallow lake deposits. Alternatively, Facies 11 could be representative of lagoonal deposits, however, the lack of core in this area does not allow the definition of barrier island/lagoonal environments. The abundant organic detritus and coaly and woody fragments were likely transported short distances into the ponds. The lack of burrowing as well as the plentiful pyrite suggest harsh environmental conditions which were possibly reducing at times (although the pyrite could also have formed much later). Lack of burrows with marine or marine influenced affinities also support a non-marine, possibly stressed, environment of deposition. If the environment was actually a lagoon associated with a barrier island system, one might expect to find a more marine trace fossil signature to this facies. Regardless, it is impossible to say from a single core. The thin sandstone beds could have been supplied from either the marine or non-marine realm. The colour changes are likely related to the level of subaerial exposure experienced by the sediments, as Facies 11 passes gradationally upwards into subaerially exposed rocks of Facies 12 (see Section 3.15). The depositional context and sedimentary and ichnological features strongly support interpretation of Facies 11 as deposits of backshore ponds or shallow lakes that were rarely, if ever, inundated with significant amounts of saline marine water.

3.14 Summary of Facies 8 through Facies 11

Basically, Facies 8 through Facies 11 represent a continuous shoaling upwards succession that overlies Facies 6. The shoaling goes from the marine upper shoreface, foreshore and beach environments (*i.e.* Facies 8 and 9), into the essentially non-marine realm of the backshore (*i.e.* Facies 10) and backshore ponds or shallow lakes (*i.e.* Facies 11). Where found, Facies 12 grades out of one of the interpreted non-marine facies and is greenish-grey to greenish-yellow in colour.

3.15 FACIES 12: Friable silty shale/shaly siltstone and siltstone

Lithology and Sedimentary Features: Facies 12 comprises friable silty shale of somewhat variable colour. The facies is light green/greenish-yellow to greenish-grey in colour, and commonly grades out of Facies 11. The amount of silt sized material is variable such that portions could, in the strictest sense, be considered to be shaly siltstone or siltstone (Fig. 3.16D). The finer grained the material comprising the facies, the more crumbly and friable the rock. The facies is very commonly found as pieces of rubble in the core boxes that easily fall apart even with minimal handling. The facies is characterised by a waxy texture that appears to be imparted largely by the abundant shiny slickenside surfaces (Fig. 3.16E). Disseminated "wispy" organic detritus, coal and wood fragments are also common.

Ichnology: Wispy, vertical rootlets were the only ichnofossil visible in this facies. What appeared to be leached rootlets were visible in Unit 3 in the 11-9-22-25W4 core. The roots were very thin and characteristically had large length to width ratios. When viewed carefully under a binocular microscope, thin vertical bifurcations were also visible at the terminations of several root structures.

Interpretation and Discussion: Facies 12 is interpreted as a palaeosol deposit. Palaeosols develop due to extended periods of subaerial exposure. The colouring of the palaeosol deposits is extremely variable due to the varying degrees of exposure, wetting/drying, drainage patterns and oxidation. The palaeosols may represent deposits developed as part of the exposed coastal plain of a prograding delta. In this autocyclic scenario, the palaeosol simply represents non-marine deposits associated with a coeval prograding delta. Alternatively, the subaerial exposure that caused the podsolisation of preexisting sediments may have been facilitated by a lowering of (relative) sea level. In this allocyclic case, the palaeosol becomes very important because it suggests the lowering of sea level and all its accompanying lowstand deposits. Moreover, the sea level facilitated exposure surface would be considered a sequence boundary (*i.e.* SB) in the terminology of Van Wagoner *et al.* (1990). Aspects of these possibilities are discussed later in the thesis.

3.16 FACIES 13: Polymodal conglomerate/Pebbly and shaly mottled sandstones

Lithology and Sedimentary Features: This facies comprises both clast and matrix supported conglomerate; with common locations of clast supported conglomerate gradationally passing upwards into matrix supported conglomerates which in turn pass gradationally upwards into pebbly and shaly mottled sandstones. Where the proportion of pebbles becomes even lower, the facies is referred to as pebbly and shaly mottled sandstone (Figs. 3.17C,D). The conglomeratic portion of Facies 13 is different from Facies 7 by virtue of its being polymodal, having extremely variable matrix composition and being mottled/burrowed (Figs. 3.17A,B). Generally, this facies sharply overlies FA2 (*i.e.* Facies 5 or 6) rocks except in well locations where the non-marine facies were preserved, in which case Facies 13 sharply overlies one of the non-marine facies. The basal contact is commonly undulatory and sharp, indicating an erosive relationship between Facies 13 and the underlying rocks. Furthermore, the facies underlying Facies 13 is locally cemented with a fine grained siderite cement. Pebbly and shaly mottled sandstones of Facies 13 were also commonly found in thin 1-15cm thick beds, interbedded with Facies 14 and Subfacies 14a; in this context, Facies 13 is mottled pebbly medium-grained "salt and pepper" sandstone. The largest pebble observed in Facies 13 was 6cm in diameter, but more commonly, the largest pebble associated with this facies was on the order of 1.7-2.2cm in diameter. The average grain size of the pebbles is 0.8-1.3cm in diameter. Varicoloured chert pebbles dominate, but locally, rare lithic pebbles were observed. The pebbles were mostly subrounded to well rounded, with only rare subangular pebbles. The matrix of the conglomerate ranges from friable dark shale to very coarse-grained sandstone, but the dominant matrix is a distinctive looking "salt and pepper" medium-grained sandstone (Figs. 3.17A,B). The "salt and pepper" colouration is imparted by approximately equal proportions of medium-grained black and white quartz grains. Where thick accumulations of this facies occur (*e.g.* 15-16-28-22W4), the matrix gradationally became finer and finer grained upwards, and the abundance of pebbles became lower and lower. Other features of this facies include ripped up angular to subrounded shale clasts, sandstone clasts, sideritic clasts (up to 6.5cm in diameter), coal fragments and coalified wood fragments. In rare locations, siderite clasts appeared to be larger than the core diameter. In one location (*i.e.* 15-16-28-22W4), the pebbly sandstone showed hints of wavy parallel laminations.

Ichnology: The truly conglomeratic portion of this facies appears somewhat mottled, but no individual burrow forms were observed. The pebbly and shaly sandstone portion of Facies 13 has a moderate to abundant burrowing intensity. The visibility of individual burrows within Facies 13 seems to be enhanced by increased sandstone content in concert with a decrease in the abundance of pebbles. The scattered nature of pebbly material was likely caused by the actions of burrowing organisms. Observed trace fossils in the pebbly and shaly sandstone were generally quite robust, and include the following twelve ichnogenera: *Arenicolites, Asterosoma, Diplocraterion, ?Ophiomorpha, Palaeophycus, Planolites, Skolithos, ?Subphyllachorda, Teichichnus, Terebellina, Thalassinoides* and *Zoophycos*. Of these, *Arenicolites, Planolites, Skolithos* and *Thalassinoides* were the most common. The contact between this facies and underlying facies is locally demarcated by the *Glossifungites* ichnofacies (see discussion of discontinuity surfaces in Chapter 4).

Interpretation and Discussion: Facies 13 is equivalent to Facies A and B of MacEachern *et al.* (1992b), and is interpreted as transgressive or transgressively modified lowstand deposits brought about by a relative rise in sea level. The conglomeratic portion passes upwards into sandy mottled shales with scattered pebbles and this is interpreted as the result of progressive transgression by marine waters. Evidence for inundation of marine waters lies in the relatively diverse marine influenced ichnofossil assemblage as well as from marine suites of arenaceous foraminifera collected from shales associated with this facies [the basal part of the *Verneuilina canadensis* Subzone (C.R. Stelck, pers. comm., 1993)]. The trace fossil suite represents a relatively high energy, mixed *Cruziana*/*Skolithos* ichnofacies. The overall interpretation of this facies, the associated discontinuity surfaces and sediments they envelope is given in greater detail in the next chapter. Similarly, the significance of the surfaces demarcated by the *Glossifungites* ichnofacies are addressed in Chapter 4.

3.17 FACIES 14: Dark shale with millimetre to centimetre scale siltstone to very fine-grained sandstone beds

Lithology and Sedimentary Features: This facies comprises black shale and/or black mudstone. Although no physical sedimentary structures are visible in the dark shale, locally there are patchy, diffuse zones where the shale has been sideritised with a very fine grained siderite cement. Small fish scales are observable on shale parting planes (*e.g.* Unit 8; 7-1-29-19W4). Rare millimetre to centimetre scale siltstone to lower very fine grained sandstone beds also comprise a minor component (~10-20%) of this facies. These siltstone/lower very fine-grained sandstone beds range in average thickness from 2mm-2cm. Also, the siltstone/lower very fine-grained sandstone beds generally have sharp and/or loaded bases (Figs. 3.18A,B), exhibit normal grading/fining upwards, and individual beds can be discontinuous on the scale of the core, and are therefore apt to appear "lensoidal" in nature. The thin siltstone/lower very fine-grained sandstone beds are dominantly oscillation rippled (Fig. 3.18B), but also show evidence of wavy parallel laminations and rare combined flow ripple laminations

(Fig. 3.18A). The lamination types are difficult to observe as most of the siltstone/lower very fine-grained sandstone beds are extremely thin. Facies 14 commonly grades upwards into what is termed Subfacies 14a, which is essentially identical to Facies 14, but contains thicker lower to upper very fine-grained wavy parallel laminated, sharp based sandstone beds on the order of 1-5cm thick.

Ichnology: The burrowing intensity is rare to nil in this facies, although the discontinuity of the siltstone/lower very fine-grained sandstone beds appears to be at least partially attributable to burrowing activity. *Planolites* is the only discernible trace fossil, although unnamed, small grazing and ?resting traces were rarely seen on the shale parting planes. Similar grazing and surface trails are postulated in transgressive Facies E of MacEachern *et al.* (1992b).

Interpretation and Discussion: This facies is found overlying Facies 13, is commonly interbedded with Facies 1, 13, 15, and 16, and normally passes gradationally upwards into Subfacies 14a. Facies 14 and Subfacies 14a are equivalent to the transgressive Facies E and D respectively, of MacEachern *et al.* (1992b), and are found almost exclusively in transgressive deposits of the Lower Colorado shales that overlie the Bow Island and Viking Formations. The black shale was deposited in quiet, relatively deep water reflecting marine offshore shelfal conditions. The thin siltstone/lower very fine-grained sandstone beds were transported and deposited by the last vestiges of storm-generated currents that were presumably acting on a correlative palaeoshoreline. The shale was deposited out of suspension in an environment below fairweather wave base. The thin siltstone/lower very fine-grained sandstone beds indicate that the environment was periodically within storm weather wave base, and consequently, subjected to storm-generated waves which transported the silt/lower very fine-grained sand into the shelfal setting. These same currents imparted the remnant wavy parallel to oscillation/combined flow ripple laminations found in the siltstone/lower very fine-grained sandstone beds. The siltstone/lower very fine-grained sandstone beds with loaded bases suggest that the "background" shale was likely a soupy substrate that was eroded slightly with the introduction of each storm-generated bed. The local sideritisation of the shale is poorly understood, but may be related to breakdown of organic material deposited from suspension along with the clay particles.

The poor burrowing intensity and paucity of observable burrow structures in the shale may simply be an artifact of this facies' lack of lithologic contrast with which to highlight individual burrows. In general, burrowing is more obvious where there is sufficient lithologic contrast, such as near the storm-generated beds. Not surprisingly, this is where the *Planolites* are most obvious, as the burrow fill (grey sandstone) contrasts with the surrounding black shale. Another possibility for the lack of observable burrowing in the shale is linked to the preservational nature of shales in general. The original trace fossil assemblage may have been obscured, or even obliterated by the high degree of burial compaction that shales undergo. A third possibility is that the muddy shelf in question was not amenable to biogenic activity due to some stress (or combination of stresses) such as anoxia, salinity, unsuitable substrates, or lack of foodstuffs. Fairly diverse marine foraminiferal assemblages of the *Miliammina manitobensis* biostratigraphic zone were garnered from this facies, and these suites tend to support the notion of relatively unrestricted (or "normal") shelfal marine conditions (J.A. MacEachern, pers. comm., 1993). Furthermore, the microfossil suite indicates that this facies does, in fact, have a demonstrable affinity for the uppermost Albian stage and likely represents the basal portion of the Lower Colorado shales [*Verneuilina canadensis* Subzone (C.R. Stelck, pers. comm., 1993)]. A thorough discussion of this type of facies can be found in MacEachern *et al.* (1992b, pp.271-272).

3.18 FACIES 15: Medium to coarse grained cross bedded and apparently structureless sandstone and pebbly sandstone

Lithology and Sedimentary Features: This facies comprises pebbly cross bedded sandstone beds (Fig. 3.19A,B) and massive to cross bedded medium-grained to very coarse-grained "salt and pepper" sandstone beds (Figs. 3.19C,D). Facies 15 is most commonly found as 1-15cm thick beds interbedded with Facies 14, 1 and Subfacies 14a. Less commonly, Facies 15 lies directly on "VE4" of Hadley (1992). The pebbly cross bedded medium-grained to coarse-grained sandstone beds average 7cm in thickness and the pebbles and granules commonly accentuate the cross laminations (Fig. 3.19A). In rare localities (*e.g.* 8-20-26-18W4), the beds are sufficiently pebbly as to be considered cross bedded conglomerate beds. The pebbles and granules average 0.4-0.8cm in diameter, with measured maximum pebble diameters between 1.2 and 1.7cm. The pebbles and granules are dominantly cherty, with minor amounts of lithic pebbles and granules; the grains tend to be subangular to subrounded. The dominant sand grain size for these beds is lower to upper medium. Cross bed set thicknesses reached a maximum of 7-10cm, with hints of steepening-upwards angles of cross lamination within a given bed. Cross bedding angles ranged from ~25-30°. The bed boundaries were unclear, but did not appear to be planar horizontal in nature. Very rare occurrences of wavy parallel laminations were also observed. The massive to cross bedded medium-grained to very coarse-grained sandstone beds were dominantly composed of lower to upper medium-grained "salt and pepper" sand, with only rare occurrences of coarse or very coarse grain sizes. The "salt and pepper" nature of the sand is imparted by the presence and homogeneous mixture of black and white, subangular to subrounded sand grains (Fig. 3.19C). These beds tend to be very sharp based, with rare scattered granules and pebbles at their bases (average 0.6cm diameter). Rare beds are calcite cemented and have a bluish tinge to them.

Ichnology: No trace fossils were observed within the sandstone beds themselves, but the bases of some of the beds were demarcated by the *Glossifungites* ichnofacies. The trace fossils found at the bases of some of these beds include *Arenicolites, Diplocraterion, Skolithos* and *Thalassinoides*. The *Diplocraterion* are likely the *habichi* species, as revealed by the closely paired tubes visible on bedding planes of core (*e.g.* in 14-11-22-24W4). The burrows are not particularly robust or deeply penetrative, but they do have very sharp margins and are typically filled with medium-grained to coarse-grained "salt and pepper" sand and small pebbles that contrast markedly with the shalier facies that normally underlie Facies 15.

Interpretation and Discussion: Firstly, the cross bedding is interpreted as trough cross bedding. The interpretation is based on the observed steepening-upwards of cross laminations that is characteristic of vertical sections taken through trough cross bedded bedforms. The cross bedded units represent migrating megaripples formed by unidirectional currents. Alternatively, the cross beds may have been formed by tidal currents. Facies 15 generally occurs in thin beds within Facies 14, 1 or Subfacies 14a, all of which represent deposition in offshore marine conditions. In such scenarios, it is feasible that tidal currents moulded the cross bedded portions of Facies 15. In offshore to shelfal environments, tidal currents are essentially rotary, that is, unidirectional in a rotary path. These tidal currents could also account for the cross bedding observed in this facies. Similar interpretations in essentially the same depositional context have been suggested by numerous previous workers (*e.g.* Leckie, 1986; Davies, 1990; Hadley, 1992). Unlike other studies, evidence supportive of a tidal interpretation does not exist for Facies 15 in this study area, largely due to the overall thin nature of the beds and hence, their inherent lack of regional correlatability. Whatever the source of the currents, the currents were certainly unidirectional and sufficiently powerful to move granules and small pebbles. The granules and pebbles likely concentrated in the troughs of the megaripples, accounting for their accentuation of the cross bedding. The local presence of elements of the *Glossifungites* ichnofacies at the bases of beds of Facies 15 suggests that the underlying substrate was firm and later colonised dominantly by suspension feeding animals which, upon burrow vacation, facilitated a passive infilling of the open burrows with material (in this instance, mostly medium-grained sand and pebbly sand) from later deposition. Occurrences of the *Glossifungites* ichofacies at the bases of beds of Facies 15 within Facies 14, mark potentially key stratal surfaces which may represent a record of an extremely complex relative sea level history during the deposition of Facies 14 (*i.e.* within the overall rise in relative sea level largely represented by Facies 14). This issue will be dealt with in more detail in Chapter 4. The *Glossifungites* ichnofacies and its stratigraphic implications and applications are discussed in detail by MacEachern *et al.* (1992a) and Pemberton *et al.* (1992a).

3.19 FACIES 16: Light grey bentonite

***Lithology and Sedimentary Features*:** This facies comprises light grey coloured bentonitic claystone and silty claystone (Figs. 3.18C,D,E). It is normally found in 1-5cm thick beds, with very rare occurrences of beds from 10-20cm in thickness. Most occurrences of Facies 16 have no visible sedimentary structures. In the 7-35-26-20W4 core (in Unit 10), however, there is a 12cm thick silty bentonitic claystone bed that has small scale wavy parallel and foreset laminations (Figs. 3.18C,D). The bentonitic nature of this facies is most evident when the rock is wetted and becomes very slippery; upon drying, cracks and breaks off in small friable pieces. Bentonite beds have been well documented as thin beds throughout the Cretaceous, including the Bow Island and Viking Formations (*e.g.* Amajor and Lerbekmo, 1980). Facies 16 is most commonly associated with Facies 3, 14 and 15. These associated facies are commonly bentonitic (*i.e.* have abundant interstitial swelling clay material) for 10-30cm zones above and below some of the thicker beds of Facies 16.

Ichnology: All occurrences of this facies, except one, contain no observable trace fossils. The bentonite bed in Unit 10 in the 7-35-26-20W4 core contained thin *Diplocraterion* (*?habichi*) burrows (Figs. 3.18C,D). The burrows are sharp walled and filled with black shale material from above, and may represent another occurrence of the *Glossifungites* ichnofacies. The *Diplocraterion* burrows had very well defined rims around the shafts when viewed in bedding plane orientations (Fig. 3.18E).

Interpretation and Discussion: The claystone and silty claystone beds are interpreted as bentonite beds that were deposited from suspension fallout in quiescent marine environments, where their preservation potential was the greatest. The bentonites comprise volcanic ash that was periodically ejaculated from active volcanoes along the western margin of the Western Interior Seaway throughout deposition of the Bow Island/Viking Formation (see Chapter 2). The wavy parallel and small scale foreset laminations are interpreted as representative of combined flow ripples. Waves locally impinged on the bentonitic substrate and, where sufficiently silty/sandy, allowed the formation of rare combined flow ripples. The interpretation of the possible occurrence of the *Glossifungites* ichnofacies has the identical interpretation for its genesis as outlined in the discussion of discontinuity surfaces in Chapter 4.

Figure 3.1 **Facies 1: Black shale with minor dispersed silt.** **(A)** Unnamed Colorado Group shale with very minor siltstone lenses, 14-11-22-24W4, depth 1342.8m; **(B)** Black shale with sharp based, fining upwards siltstone beds that are discontinuous on the scale of the core, 6-9-27-18W4, depth 1118.6m. **Facies 2: Burrowed shaly sandstone.** **(C)** Characteristic mottled appearance with no evidence of primary physical sedimentary structures. Note the compacted *Terebellina* (Te) and the robust *Thalassinoides* (Th). Some of the unlabelled upwards convex shaly laminae may represent *Zoophycos* burrows, 6-15-24-20W4, depth 1220.8m.

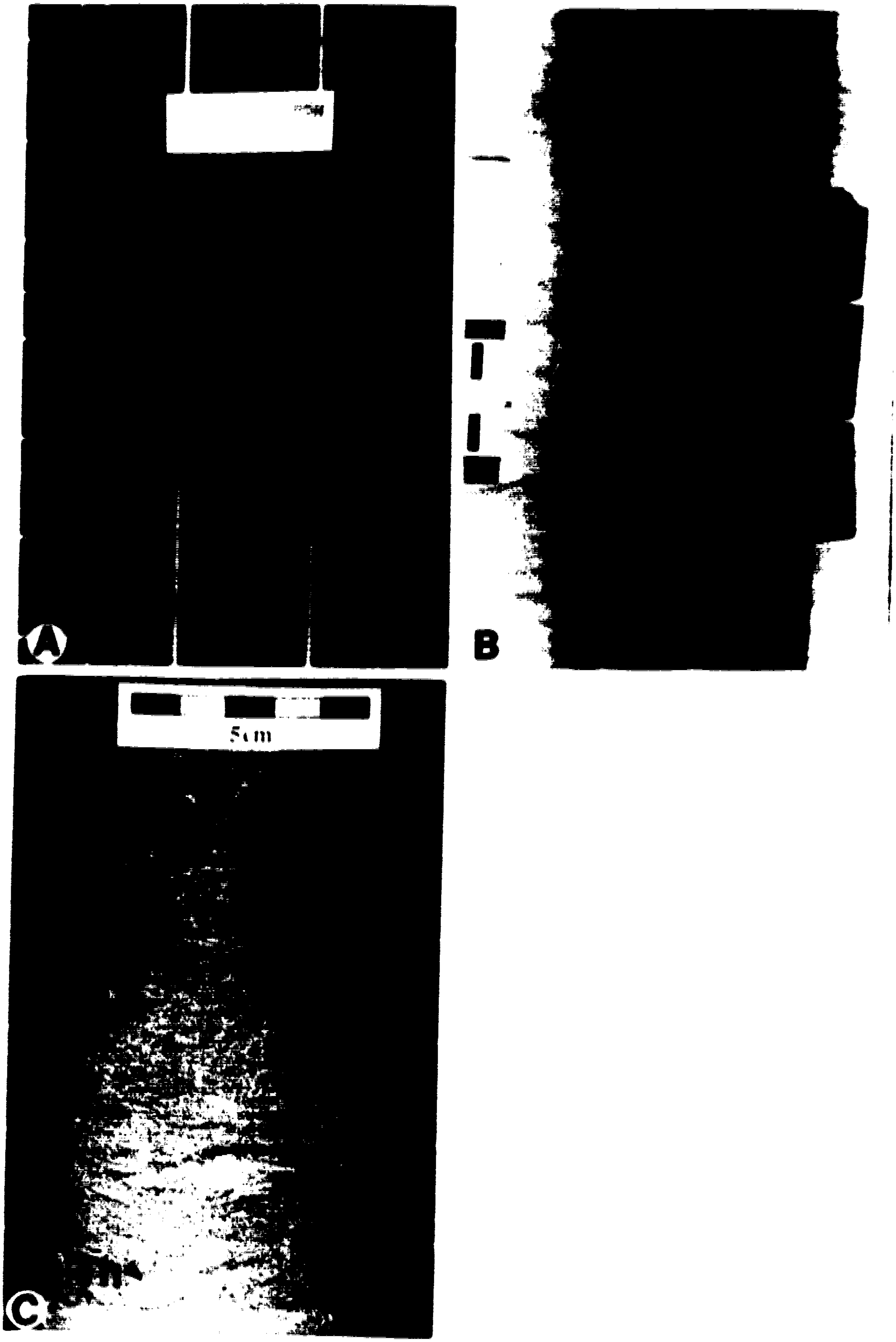

A
B
5cm
C

Figure 3.2 **Facies 3: Thoroughly burrowed sandstone, siltstone and shale.** **(A)** Typical silty and sandy "regional Viking" shale facies with total sediment homogenisation by ubiquitous *Helminthopsis* (H) burrows, 6-9-29-22W4, depth 1273.1m; **(B)** Slightly sandier manifestation of Facies 3 with abundant burrows including: *Terebellina* (Te), *Rhizocorallium* (R), *Zoophycos* (Z), *Helminthopsis* (H) and *Chondrites* (C), 6-9-27-18W4, depth 1122.25m. **Facies 4: One to fifteen centimetres thick very fine grained sandstone.** **(C)** *Ophiomorpha irregulaire* (O) in a thin storm generated rippled sandstone bed, 7-4-29-22W4, depth 1268.21m; **(D)** *Gyrolithes* (G) in a thin storm generated sandstone bed. Note the low angle undulatory/wavy laminations interpreted as small scale HCS. The laminations are accentuated by dark comminuted carbonaceous detritus, 11-19-26-20W4, depth 1259.9m.

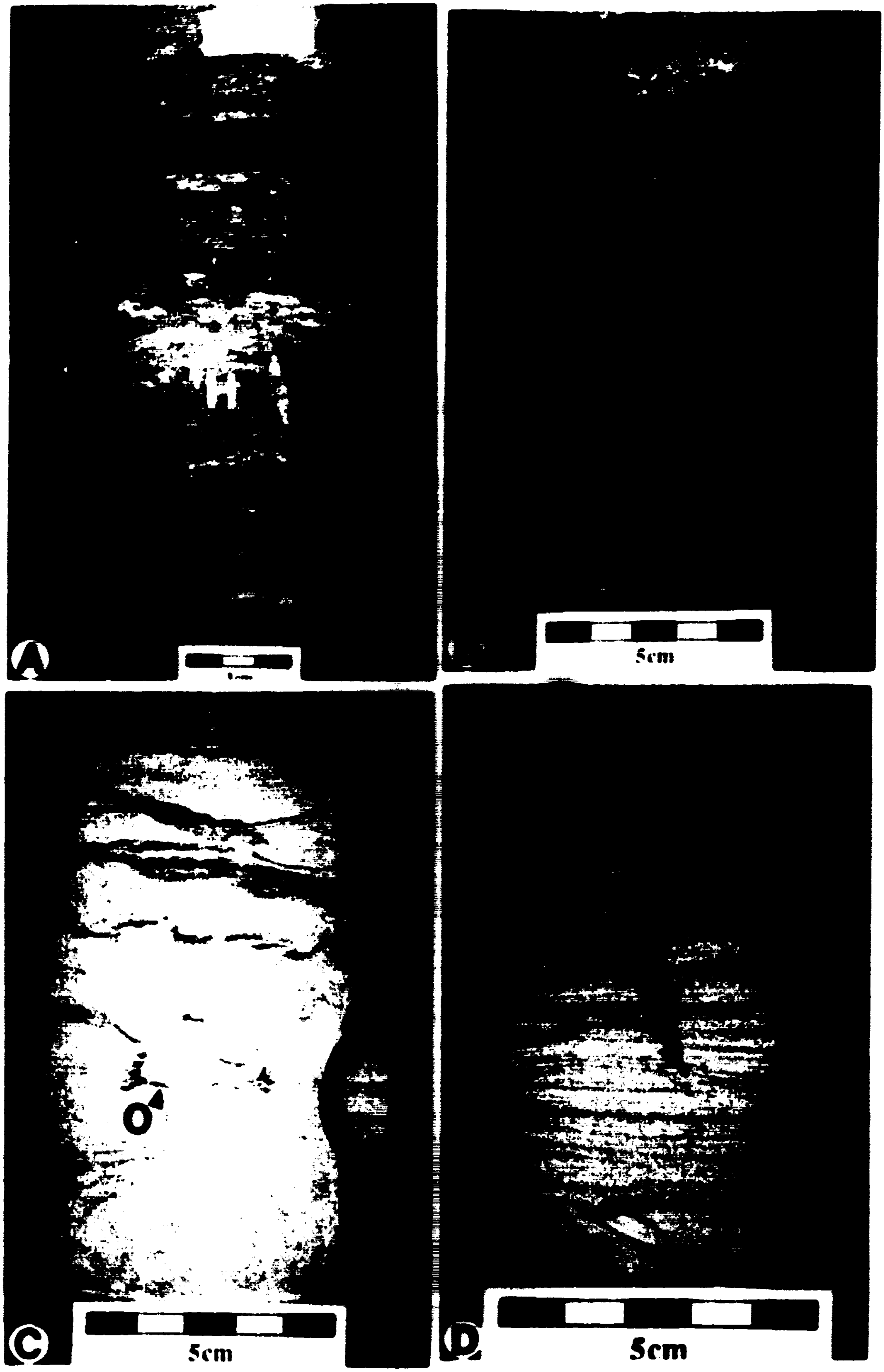
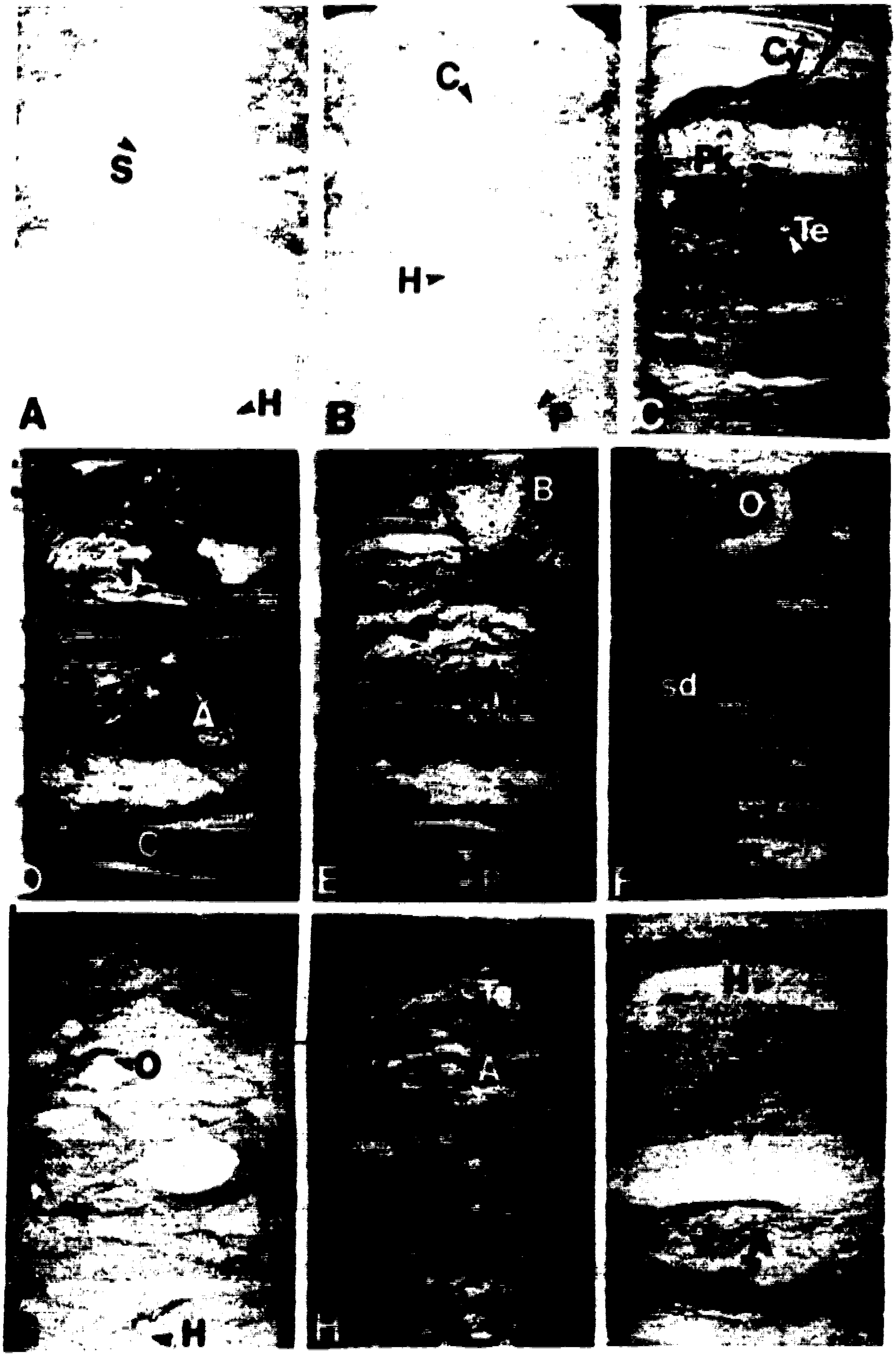

A
H
5cm
C
O
5cm
D
5cm

Figure 3.3 **FA1 trace fossils**; all core photographs are approximately 9cm in diameter. **(A)** muddy *Skolithos* (S), *Helminthopsis* (H), 10-34-24-20W4, depth 1193.75 m; **(B)** *Chondrites* (C), *Helminthopsis* (H), *Planolites* (P), 11-15-27-19W4, depth 1177.3 m; **(C)** *Cylindrichnus* (Cy), *Polykladichnus* (Pk), *Terebellina* (Te), 16-25-26-20W4; **(D)** *Teichichnus* (T), *Asterosoma* (A), *Chondrites* (C), 10-5-24-18W4, depth 1109.4 m; **(E)** *Bergaueria* (B), *Planolites* (P), 10-5-24-18W4, depth 1109.4 m; **(F)** *Ophiomorpha* (O), siderite cemented bed (sd), 8-22-26-19W4, depth 1280.8 m; **(G)** *Zoophycos* (Z) and *Ophiomorpha* (O) in thin storm generated bed, *Thalassinoides* (Th), *Helminthopsis* (H), 16-25-26-20W4, depth 1223.0 m; **(H)** *Terebellina* (Te), *Asterosoma* (A), 6-9-26-18W4, depth 1190.25m; **(I)** *Helminthopsis* (H), *Asterosoma* (A), 10-34-24-20W4, depth 1193.6 m. Also note the thin storm beds.


S
A
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Te
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H
A

Figure 3.4 **FA1 trace fossils**; for all core photographs without a scale, the photographs are approximately 9cm in diameter. **(A)** *Arenicolites* (Ar), *Skolithos* (S), *Teichichnus* (T), 16-25-26-20W4, depth 1217.15m; **(B)** *Rhizocorallium* (R), *Ophiomorpha* (O), and *Palaeophycus* (Pa) colonising a thin storm bed, *Terebellina* (Te), *Chondrites* (C), 8-20-26-18W4, depth 1220.7 m; **(C)** *Ophiomorpha* (O) colonising a thin storm bed, *Rosselia* (Ro), *Helminthopsis* (H), 8-20-26-18W4, depth 1220.7 m; **(D)** abundant *Chondrites* (C) as essentially the only trace fossil in a thin organic-rich shale bed, *Rhizocorallium* (R) exhibiting opportunistic colonisation of a sandy storm bed, 7-27-29-22W4, depth 1255.3 m; Note that the spreite point in different directions in the *Rhizocorallium* (R); **(E)** robust *Macaronichnus simplicatus* (M) colonising a storm bed, 7-1-27-20W4, depth 1203.9 m; **(F)** *Macaronichnus* (M) in a thin storm bed, *Anconichnus horizontalis* (An) colonising a storm bed, (?)*Phycodes* (Ph) in a dark organic-rich shale bed. Note the "C" and "U"-shaped hooks with the thin silty halos characteristic of *Anconichnus horizontalis* (An). Also note *Helminthopsis* reburrowing *Thalassinoides* (r), 6-18-27-20W4, depth 1179.65 m; **(G)** (?)*Phycodes*, 11-15-27-19W4, depth 1178.13 m; **(H)** *Planolites* (P) in a sharp based, normally graded sand bed. Note that the *Planolites* (P) has been reburrowed by *Helminthopsis* (r), 8-20-26-18W4, depth 1221.17 m.

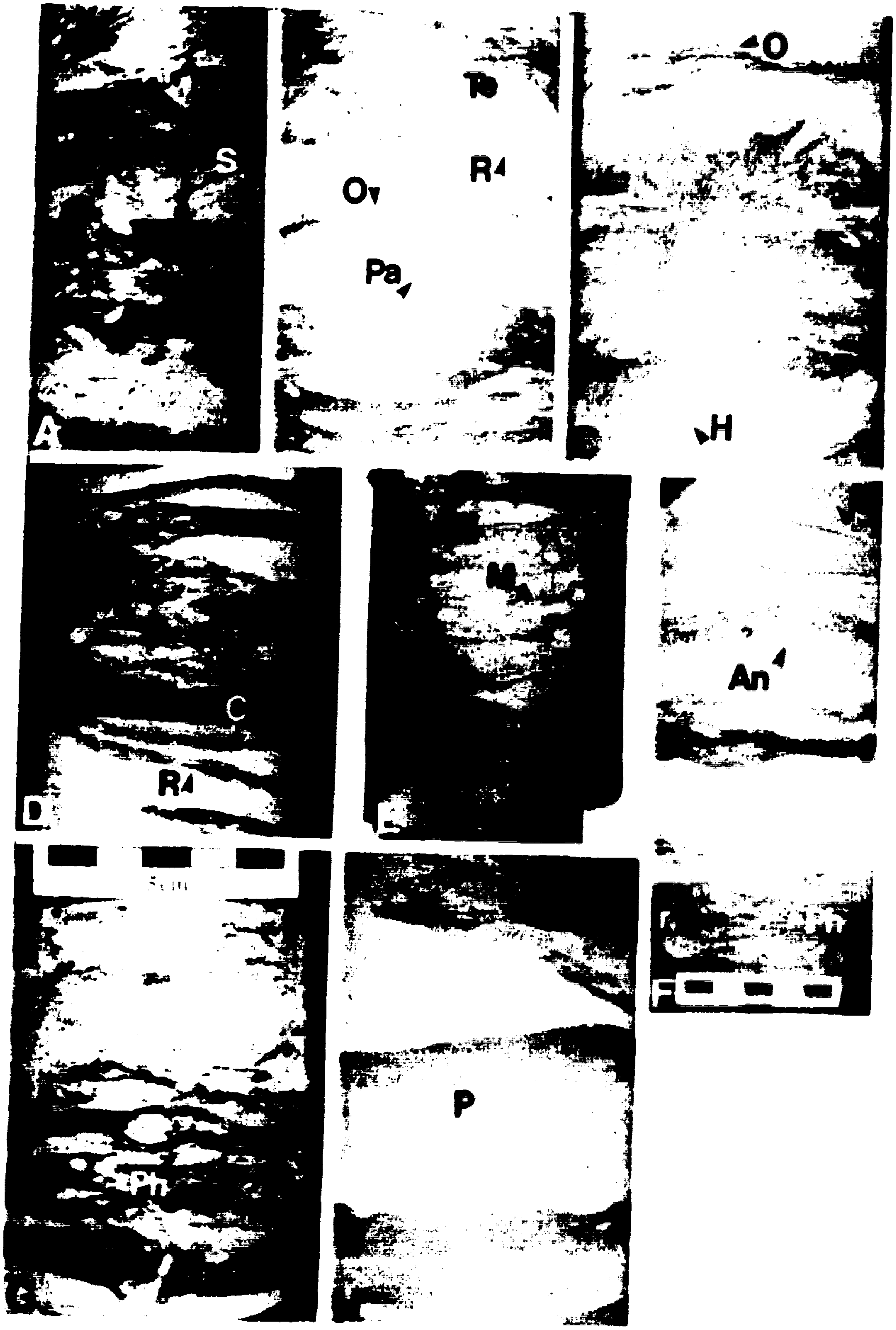

A
S
Te
R
O
Pa
O
H
D
C
R
M
E
An
F
5 cm
Ph
P

Figure 3.5 **FA1-FA2 contact, and typical examples of thinly interbedded Facies 5.** All cores are approximately 9cm in diameter. **(A)** FA1-FA2 contact, with thoroughly burrowed muddy sandstone with *Rhizocorallium* (R), *Zoophycos* (Z), *Ophiomorpha*, *Planolites*, Helminthopsis and Chondrites below, sharply overlain by low angle laminated sandstone (HCS). White arrow demarcates the contact, 6-9-27-18W4, depth 1124.25 m; **(B)** Thinly interbedded Facies 5 with *Chondrites* (C)-*Planolites* (P) association, and *Rhizocorallium* (R)-*Chondrites* (C) association in the dark organic-rich shales. Note the thin pebbly stringer, the interbedding of thin sand and shale beds, and the sporadic burrowing, 6-9-29-22W4, depth 1259.45 m; (C) Thinly interbedded Facies 5 with *Zoophycos* (Z) and *Anconichnus horizontalis* (An), 7-1-27-19W4, depth 1152.1 m; (D) Sandy, thinly interbedded Facies 5 with *Rhizocorallium* (R) and sideritised shale (sd), 6-9-27-18W4, depth 1122.1 m.

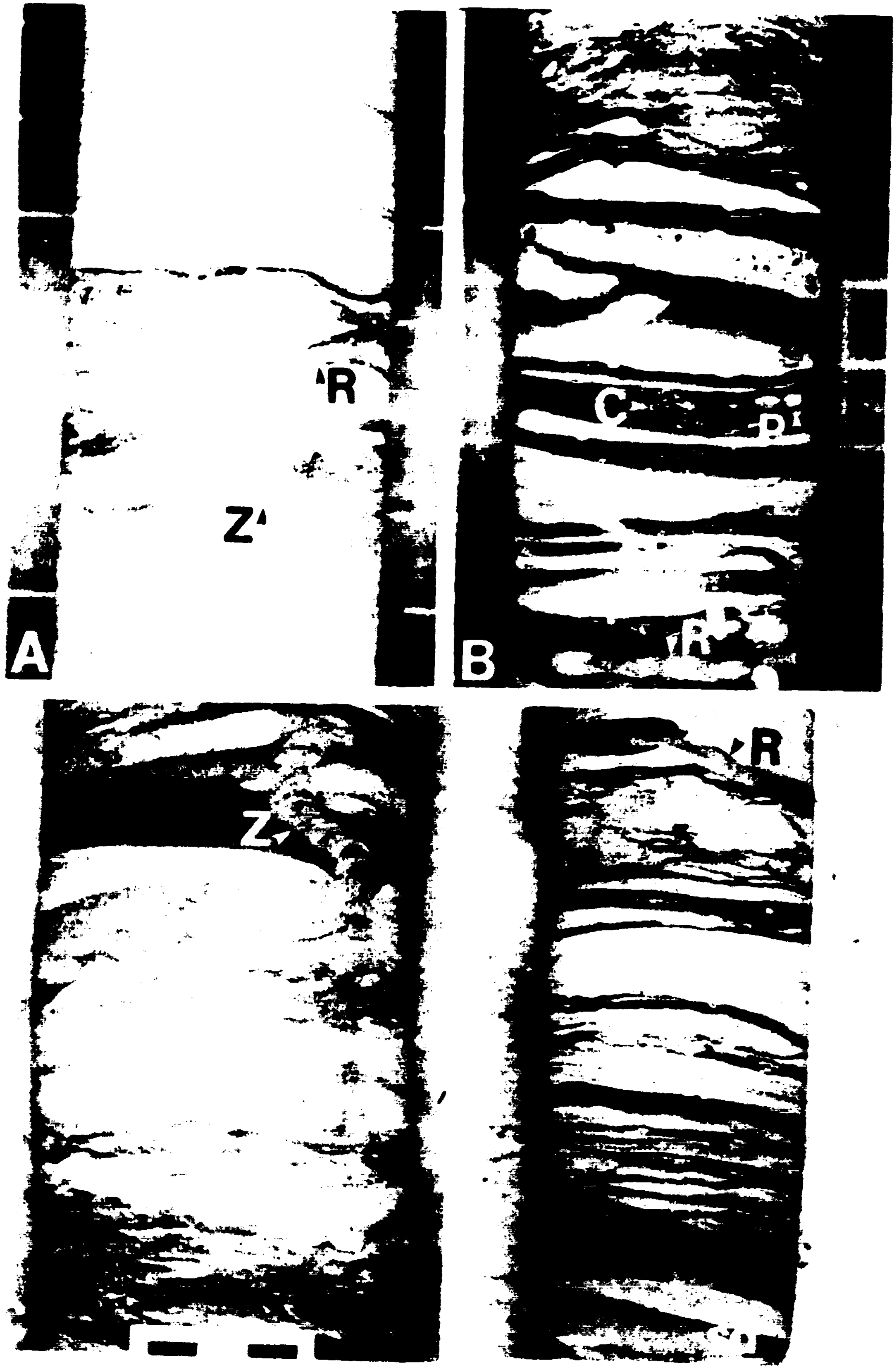

R
Z
A
C
B
R
B
Z
R

Figure 3.6 **Facies 5: Rarely to moderately burrowed interbedded sandstone, siltstone and shale. (A)** Thinly interbedded sandstone and shale giving an overall "pinstripe" appearance. Note the pinching and swelling of the oscillation rippled sandstone beds, suggesting that the ripples may be sediment starved, 6-15-27-23W4, depth 1302.6m. **(B)** Low angle inclined/undulatory laminations passing upwards into smaller scale ripple laminations. This is interpreted as a hummocky cross stratified sandstone that gradationally passes upwards into a combined flow/oscillation rippled sandstone representative of waning flow competency facilitated by storm abatement, 7-1-29-25W4, depth 1472.35m. **(C)** Sharp based oscillation/combined flow rippled sandstone beds that fine upwards into rarely burrowed, organic rich shales. Note the dark carbonaceous laminae accentuating the rippling, the small *Planolites* (P) burrows, and the local very fine grained siderite (reddish-brown colouration) cement (sd), 6-25-29-23W4, depth 1300.6m. **(D)** Unburrowed organic rich shale being cut into and eroded by a small sand filled cut and fill (?guttercast) feature, 10-14-29-24W4, depth ~1321m.

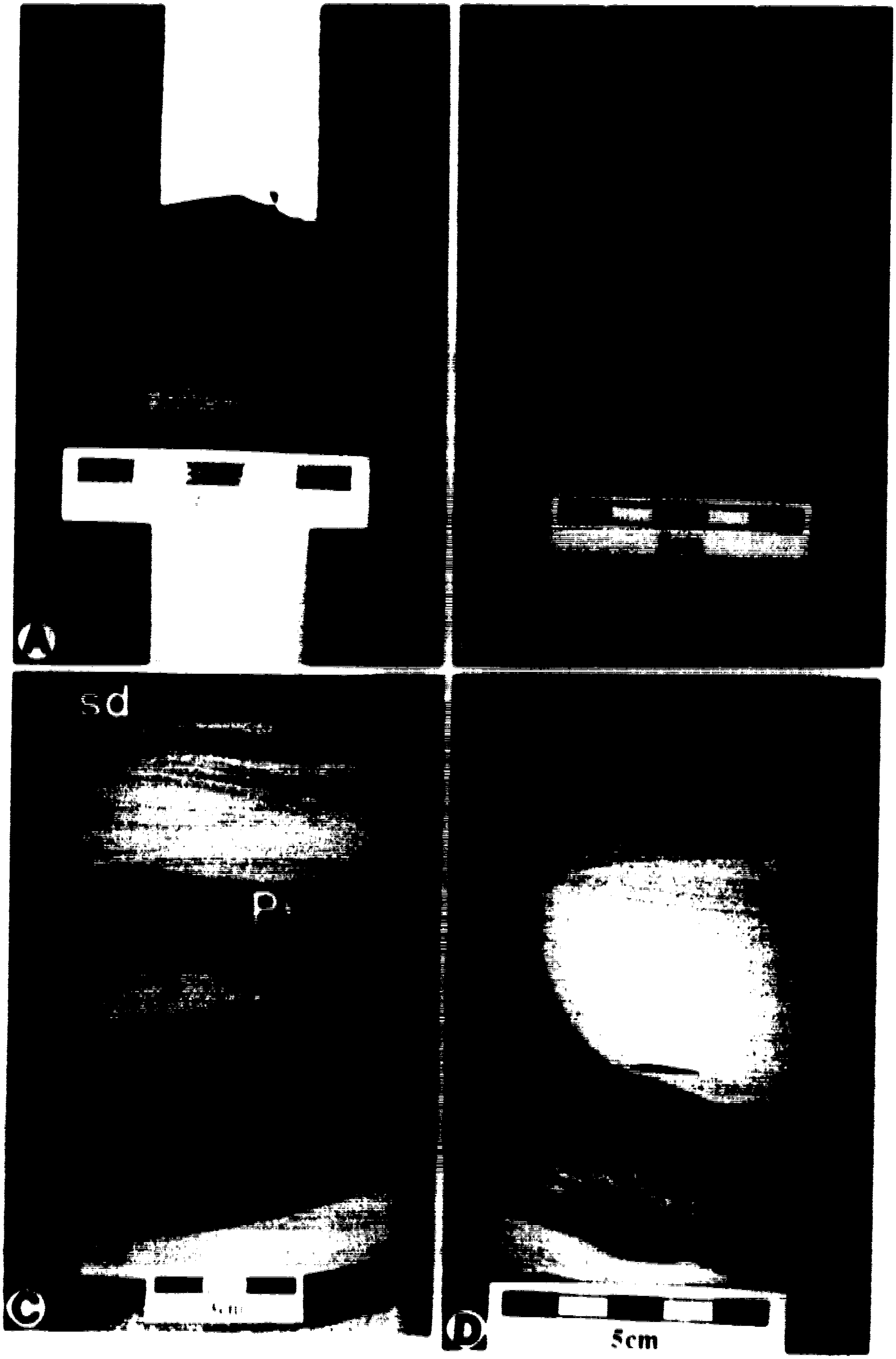

A
sd
p
C
D
5cm

Figure 3.7 **Facies 6: Thickly bedded, low angle laminated sandstone. (A)** Low angle inclined stratification at the base of what is interpreted as HCS. Note the dense accumulations of finely comminuted dark organic detritus accentuating the low angle parallel laminations, 7-35-26-20W4, depth ~1231m. (B) Small pebbles and granules accentuating the low angle inclined stratification interpreted as HCS, 6-36-26-20W4, depth 1217.8m. (C) Low angle to planar parallel laminated HCS sandstone passing gradationally upwards into smaller scale oscillation to combined flow ripples representative of the reworked tops of sandy storm beds as the storm energy waned. The small scale ripples are commonly overlain by 2-5cm thick carbonaceous, unburrowed shales interpreted as relatively rapid suspension fallout of organics associated with the waning storm flows, 6-19-29-22W4, ~1279.7m.(D) *Zoophycos* (Z) representative of opportunistic colonisation of an HCS bed. Note the carbonaceous detritus accentuating the laminae, 7-1-27-19W4, depth ~1154.5m. (E) Core bedding plane of amalgamated HCS beds (*i.e.* SCS) revealing a small bivalve shell. Similar bivalves likely created the sharply "V"-shaped escape burrows observed elsewhere in Facies 6 (see Fig. 3.9F), 14-11-22-24W4, depth 1356.48m.

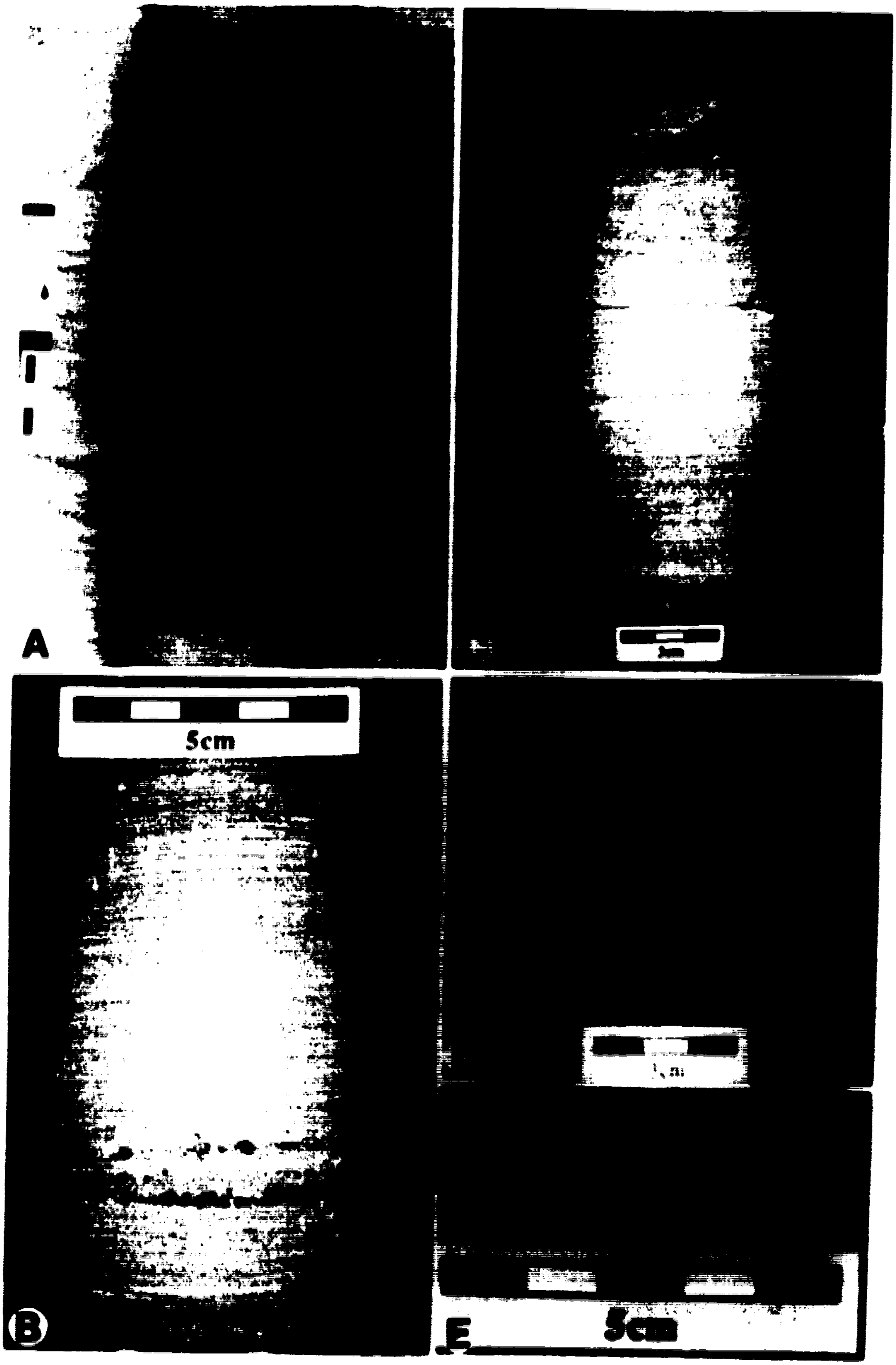
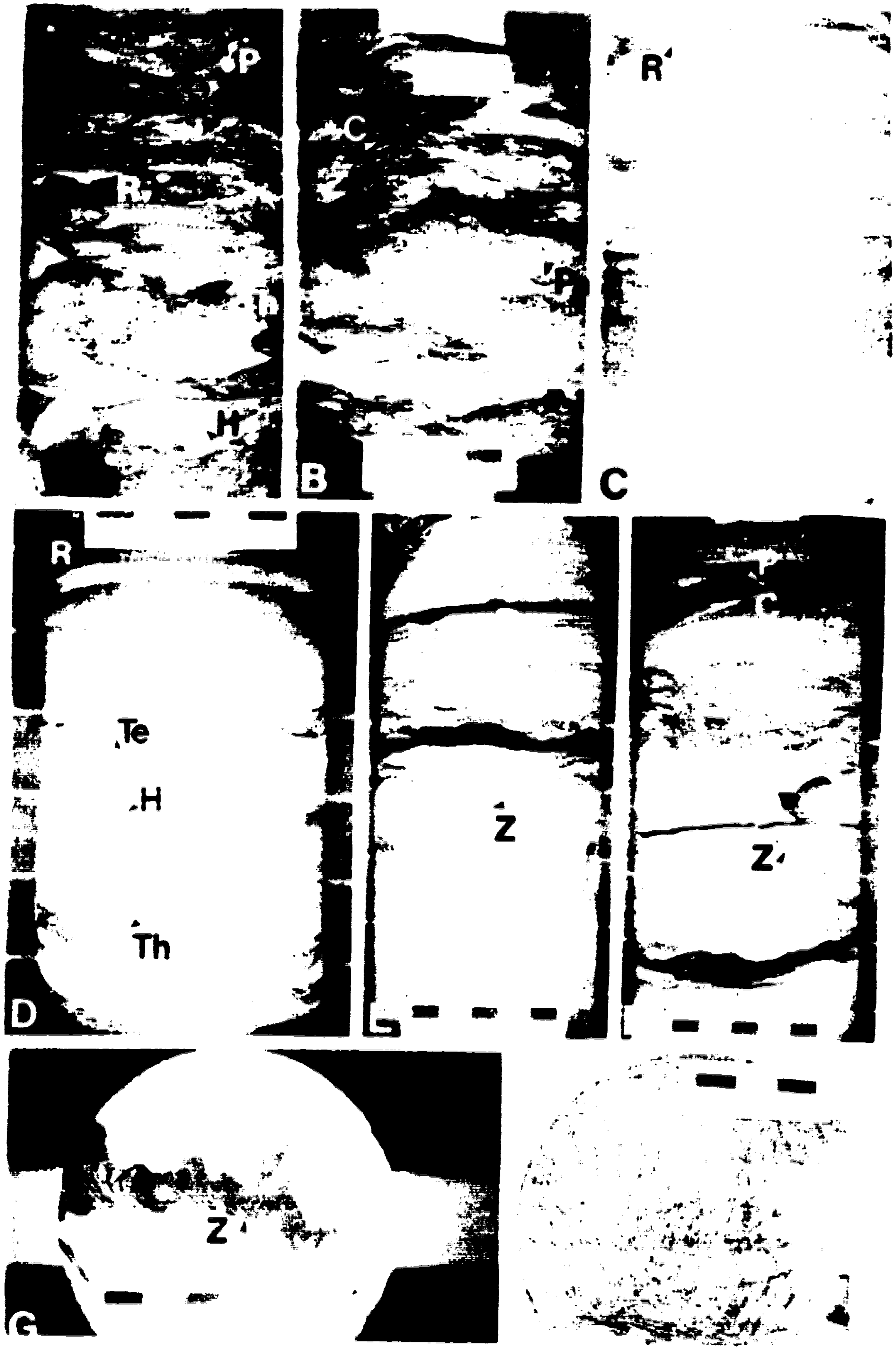

A
5cm
B
E
5cm

Figure 3.8 **FA2 trace fossils**; core photographs without scales are all approximately 9cm in diameter. **(A)** *Planolites* (P), *Rhizocorallium* (R), reburrowed *Thalassinoides* (Th), *Helminthopsis* (H) in moderately burrowed portion. Note the *Chondrites-Planolites* association, 8-22-26-19W4, depth 1274.4m; **(B)** *Chondrites* (C) reburrowing an unidentified trace fossil, *Anconichnus horizontalis* (An) and *Palaeophycus* (Pa) colonising a thin storm bed, 14-35-26-20W4, depth 1202.3m; **(C)** *Rhizocorallium* (R), and *Asterosoma* (A) in an organic-rich dark shale, 7-20-23-18W4, depth 1043.0m; **(D)** *Rhizocorallium* (R) as the lone trace fossil in a dark organic-rich shale bed, *Asterosoma* (A), *Terebellina* (Te), *Helminthopsis* (H), reburrowed *Thalassinoides* (Th), *Chondrites* (C), *Planolites* (P). Note the *Chondrites-Planolites* association, 7-1-27-19W4, depth 1155.25m; **(E)** *Zoophycos* (Z), 6-9-27-18W4, depth 1123.95 m; **(F)** *Planolites* (P)-*Chondrites* (C) association in dark organic-rich shale, *Zoophycos* (Z), 6-9-27-18W4, depth 1123.95m; **(G)** Bedding plane view of *Zoophycos* (Z), 8-20-26-18W4, depth 1219.4m; **(H)** Bedding plane view of *Chondrites* (C), 6-29-27-19W4, depth 1147.3m.


P
C
R
Th
H
B
R'
P
C
R
Te
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D
Z
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Z
G

Figure 3.9 **Trace fossils and other features of FA2**; all core photographs without scales are approximately 9cm in diameter. **(A)** (?)*Lockeia*, *Teichichnus* (T), synaeresis cracks (sy), siderite cemented band (sd), 6-18-27-20W4, depth 1168.25m; **(B)** *Bergaueria* (B), *Palaeophycus* (Pa), 6-17-25-20W4, depth 1213.3m; **(C)** *Terebellina* (Te) with "jagged" wall linings, starved ripple (sr), 6-18-27-20W4, depth 1175.35m; **(D)** small *Planolites* (P) in dark, organic-rich shale, ptygmatically folded synaeresis cracks (sy), 10-1-27-22W4, depth 1217.1m; **(E)** oblique view showing both bedding plane and transverse to bedding views of synaeresis cracks (sy), 8-5-24-20W4, depth 1153.2m; **(F)** escape trace (E) in low angle laminated sandstone bed. Note the sharp "V" morphology, 7-27-29-22W4, depth 1248.6m; **(G)** *Ophiomorpha irregulaire* (O) in fg sandstone. Note the "spiky" wall lining compared to Figure 3.8H, 7-7-25-20W4, depth 1205.7m; **(H)** *Helminthopsis* (H) reburrowing a pre-existing trace fossil, *Ophiomorpha nodosa* (O). Note the single pellet, bulbous wall lining as compared to Figure 3.8G, 8-20-26-18W4, depth 1228.7m; **(I)** *Palaeophycus* colonising a storm bed, 8-20-26-18W4, depth 1219.5m; **(J)** *Teichichnus* (T), *Anconichnus horizontalis* (An), and *Palaeophycus* (Pa) colonising the top of a thick storm bed. Note the black arrow illustrating the slightly upwards convex laminae amenable to waning flow stages of storm-generated hummocky cross stratification, 6-18-27-20W4, depth 1172.2m.


sy
L
sd
A
Pa'
B
Te
C
E
sy
E
F
P
sy
D
O
G
H
O
H
Pa
I
J

Figure 3.10 **Sedimentary features common to the thick FA2 sandstones (*i.e.* Facies 6 and its Subfacies)**; all cores are approximately 9cm in diameter. **(A)** Swaly cross stratification with low angle truncation surfaces and no preserved convex upwards laminae, 7-7-25-20W4, depth 1211m; **(B)** Aggradational combined flow ripple. These commonly cap the thick low angle laminated sandstones and are interpreted as waning storm flow features. Note the small *Planolites* (P) and synaeresis crack (sy) in the thin shales, 8-22-26-19W4, depth 1272.7m; **(C)** Low angle laminated thick sandstone passing upwards into small scale oscillation ripples, capped with dark, organic-rich shale that is siderite cemented (sd), 11-15-27-19W4, depth 1172.0m; **(D)** Apparently structureless (massive) sandstone interpreted as being deposited as a result of sediment liquefaction, 10-14-27-20W4, depth 1168.9m; **(E)** Oversteepened lamination/contorted bedding interpreted as being deposited as a result of sediment liquefaction, 10-14-27-20W4, depth 1170.1m; **(F)** Ball and pillow structure, 6-17-25-20W4, depth 1208.75m; **(G)** synsedimentary microfaulting. Note the dark laminae consisting of finely comminuted organic detritus, 14-35-26-20W4, depth 1200.5m; **(H)** Micro-faulting and soft sediment deformation features, 6-17-25-20W4, depth 1209.0m; **(I)** Intraformational sandstone, shale, and siderite cemented shale rip-up clasts within the thickly bedded low angle laminated sandstone. Note the dark laminae consisting of finely comminuted organic detritus, 6-22-27-20W4, depth 1152.15m.

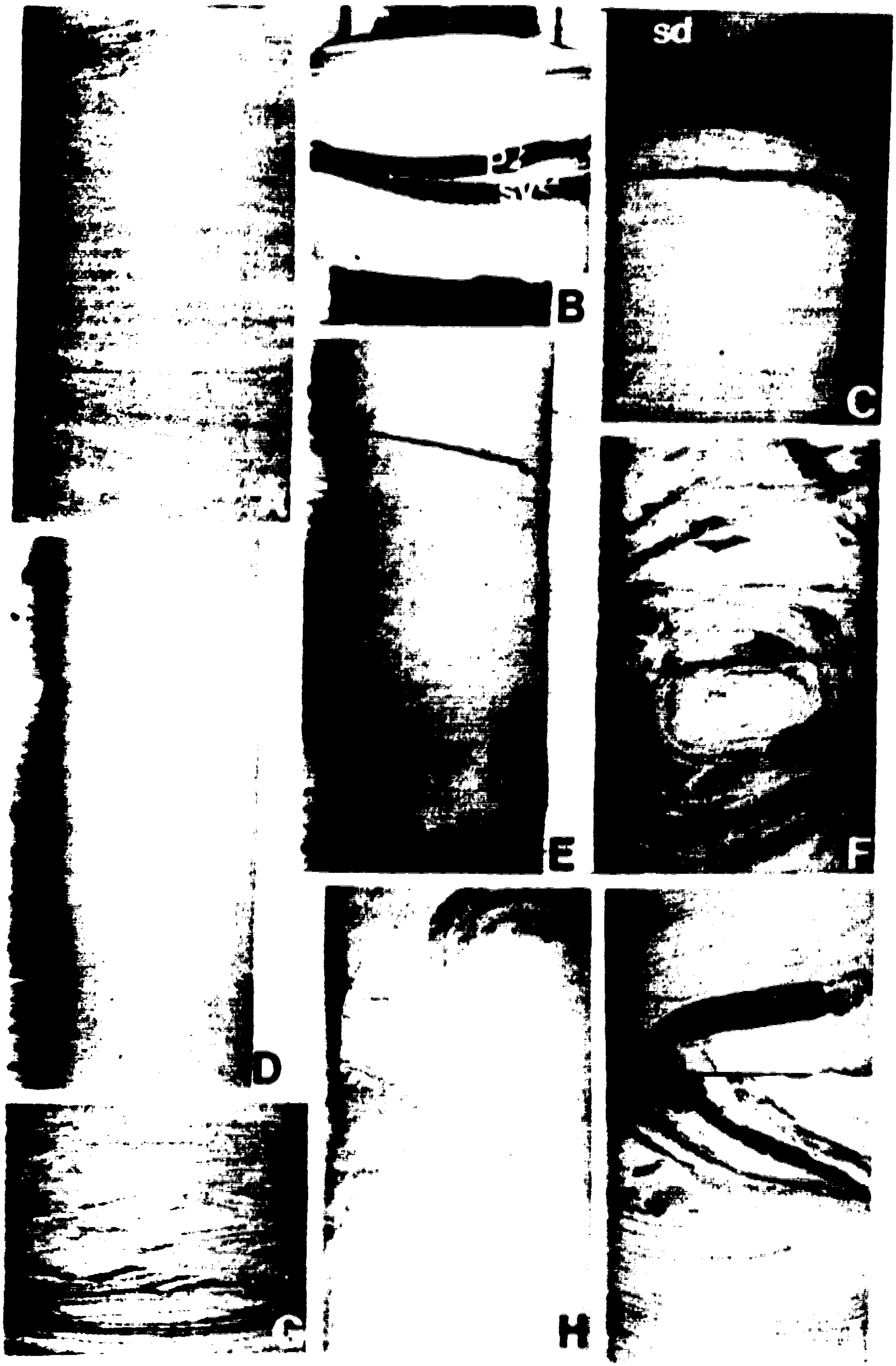

sd
B
C
D
E
F
G
H

Figure 3.11 **Features common in the "exotic" Subfacies 6A. All of the subfacies are associated with FA2.** (A) Note the oversteepened laminations that locally even wrap around themselves. The sandstone was rapidly deposited and penecontemporaneously dewatered, 10-14-29-24W4, depth ~1321.4m; (B) Convolute laminations at the base of a storm generated sandstone bed (interpreted as HCS). The association of the oversteepened laminations with the HCS beds is crucial to the interpretation of the "exotic" Subfacies. Also note that the convolute laminations resemble the trace fossil *Zoophycos*, 6-21-29-22W4, depth ~1260.8m. (C) Small scale microfaulting and convolute laminations, 6-23-27-21W4, depth ~1155.5m. (D) An example of the apparently structureless, massive vfL sandstone beds. Note the subtle erosive surface (arrow) in this example, as well as its proximity in depth to Fig. 3.11C, 6-23-27-21W4, depth ~1154.9m.

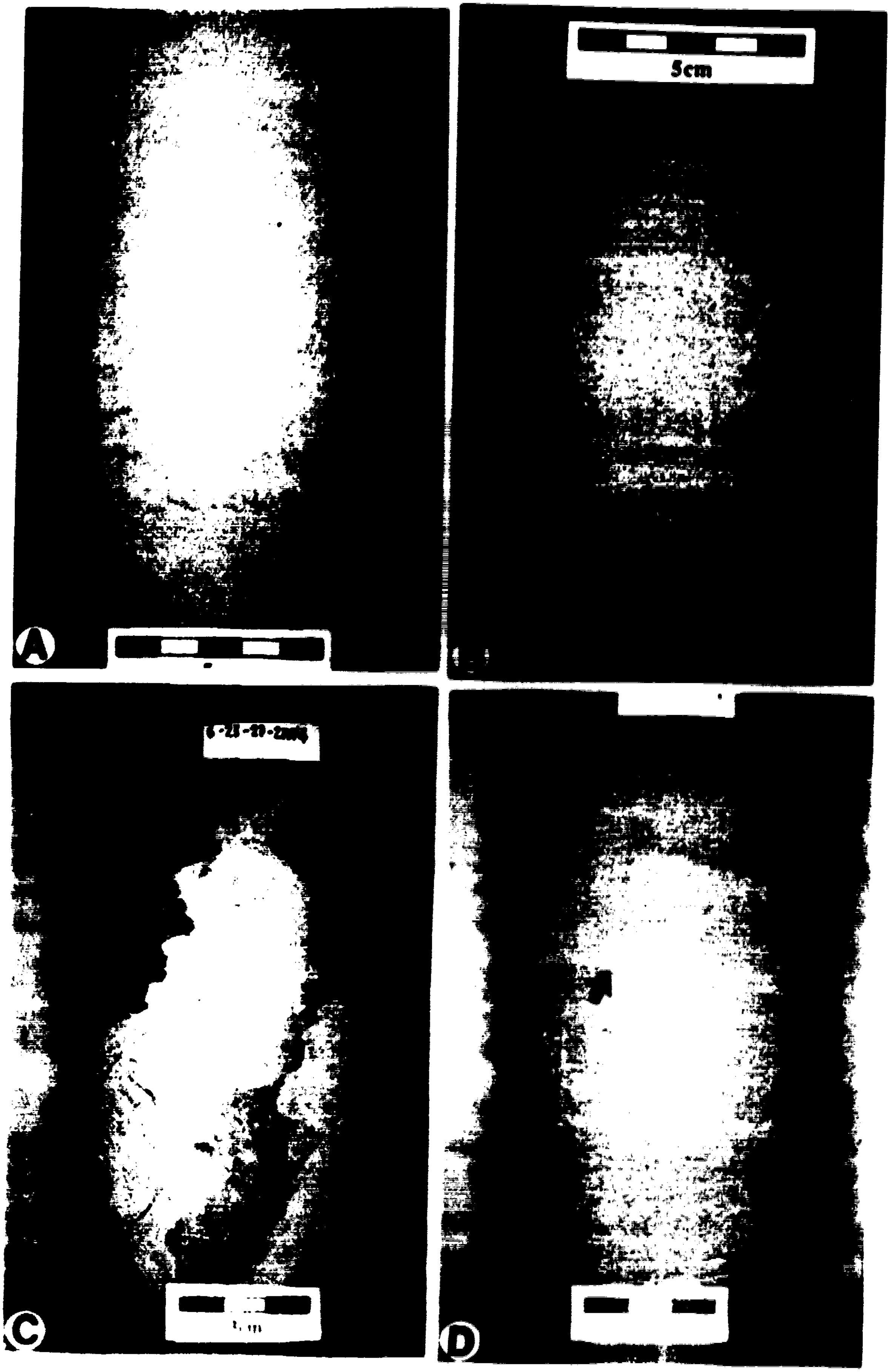

5cm
A
C
D

Figure 3.12 **Features of Subfacies 6B, 6C and 6D. Subfacies 6B: Rippled pebbly/granular sandstone. (A)** Granules and small pebbles at the base of an oscillation rippled vf sandstone bed (associated with the moderately burrowed portion of FA2). Note the granules incorporated into the rippleform (arrow), 8-22-26-19W4, depth ~1275.9m. **Subfacies 6C: Structureless/soft sediment deformed grey siltstone. (B)** Evidence of loading induced soft sediment deformation (arrow) of otherwise massive grey siltstone. These features are probably dish structures, characteristic of extremely rapid deposition and dewatering, 11-15-23-23W4, depth 1386.7m. **Subfacies 6D: Fining upwards pebbly sandstone. (C)** Conglomeratic bed passing upwards into soft sediment deformed sandy siltstone with scattered granules. This bed illustrates coarse-tail grading of the pebbly and granular fraction, 6-2-24-17W4, 976-976.25m. **(D)** Close-up of upper portion of bed illustrated in Fig. 3.12C. Note the soft sediment/slumped deformation and the entrained granular material, 6-2-24-17W4, depth 976.1m. **(E)** Close-up of basal portion of bed illustrated in Fig. 3.12C. Note the disorganised fabric of the pebbles/granules and the abundant vf sandstone matrix, 6-2-24-17W4, depth 976.25m.

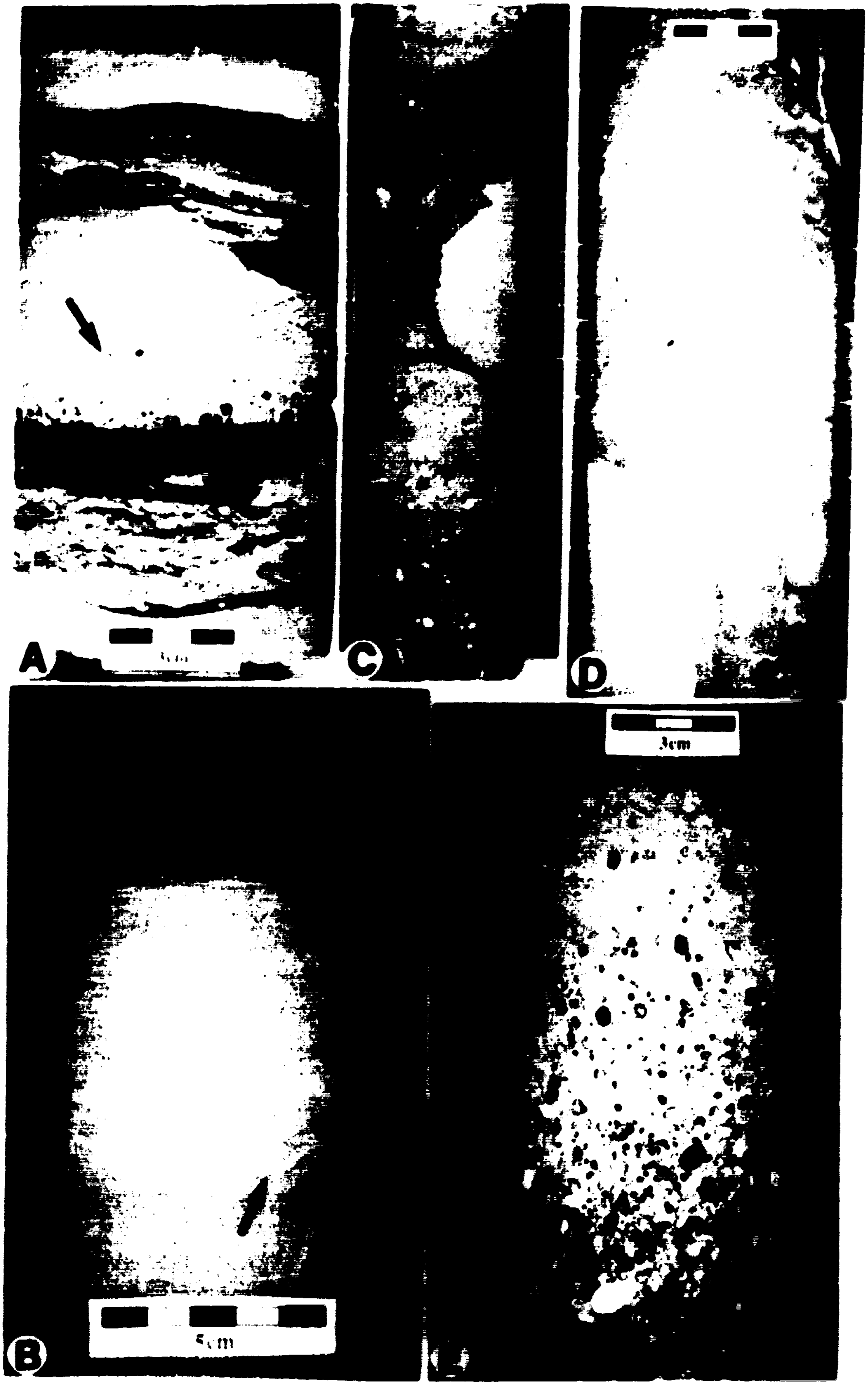

A
C
D
B
3cm
5cm

Figure 3.13 **Facies 7: Clast and matrix supported conglomerate. (A)** Unimodal clast supported conglomerate with vf sandstone matrix. Note the varicoloured pebbles/granules and the distorted, fine scale laminations near the base of the photo. The core photo was taken while the core was wet, 6-22-27-20W4, depth ~1158.4m. **(B)** Matrix supported conglomerate at base, moving upwards into clast supported conglomerate. Note the varicoloured pebbles and the abundant vf sandstone matrix. The core photo was taken while the core was wet, 6-22-27-20W4, depth ~1157.55m. **(C)** Example of fining upwards conglomerate. Note the pebbly stringer detached from the underlying, dominantly conglomeratic interval and the delicate laminations accentuated by comminuted organic detritus overlying the pebbles, 7-16-26-22W4, depth 1268.5m.

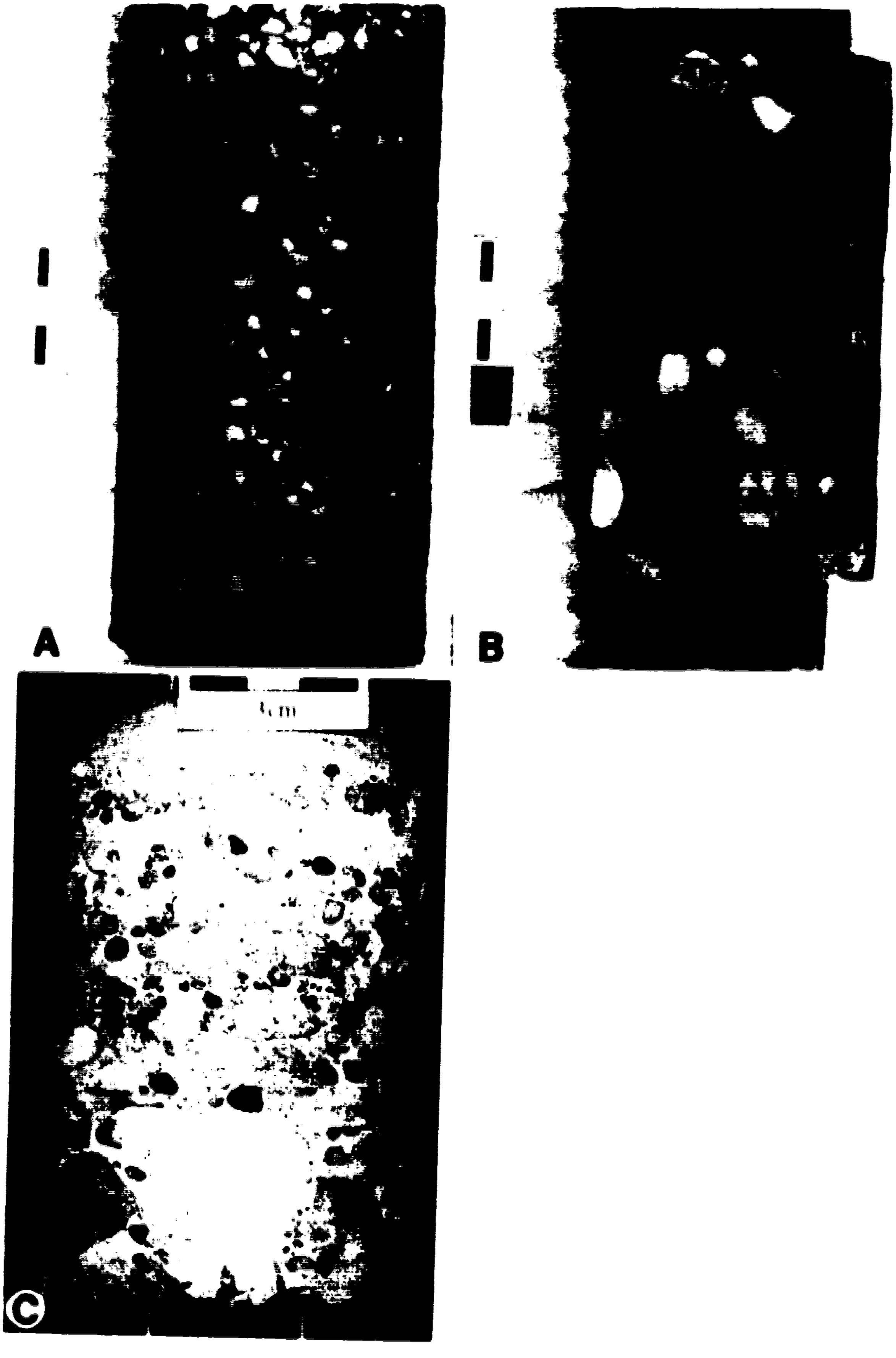
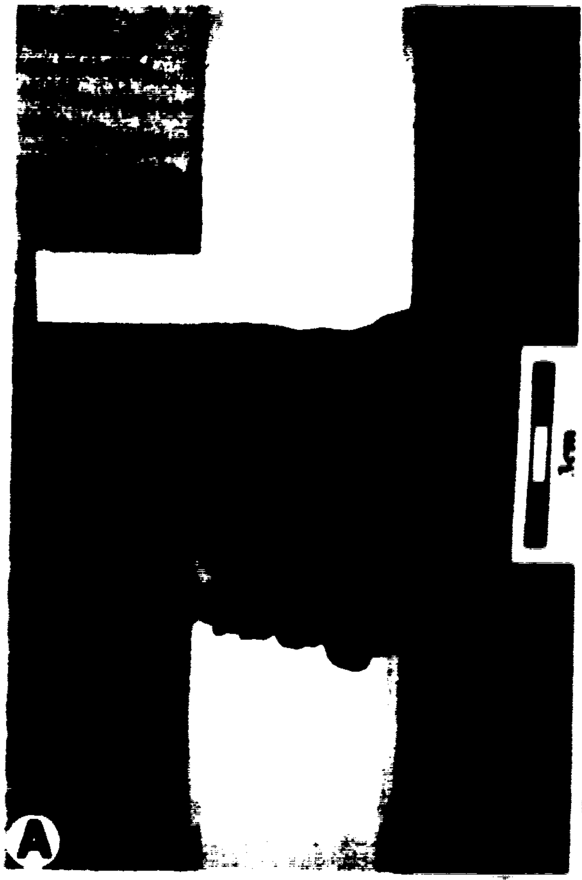

A
B
C
1cm

Figure 3.14 **Facies 7: Clast and matrix supported conglomerate.** **(A)** Pebbles at the base of an interpreted HCS bed, 16-18-26-19W4, depth ~1220.55m. **(B)** Three conglomeratic zones separated by low angle laminated vf sandstone and shale. Note that the basal portion appears vaguely inverse graded. Also note the finer grained material draping the pebbles and the lack of truncated laminae in the intervening sandy and shaly regions. Finally, note the uppermost bed which fines upwards into vf sandstone and unburrowed, organic rich friable shale, 7-1-29-22W4, depth 1240.85m. **(C)** Interpreted storm generated bed passing from pebbles at the base upwards into HCS vf sandstone, and gradationally upwards into massive grey siltstone, 7-7-29-22W4, depth 1286.85m. **(D)** Interpreted storm generated bed with pebbles and shaly rip-up clast at base, passing upwards into oscillation rippled vf sandstone that illustrates opportunistic colonisation of sandy substrate by marine trace fossils including *Zoophycos* (Z) and *Palaeophycus* (Pa). Also note the abundant *Chondrites* (C) in the dark, organic rich shale that caps the sandstone, 7-35-26-20W4, depth ~1234.15m.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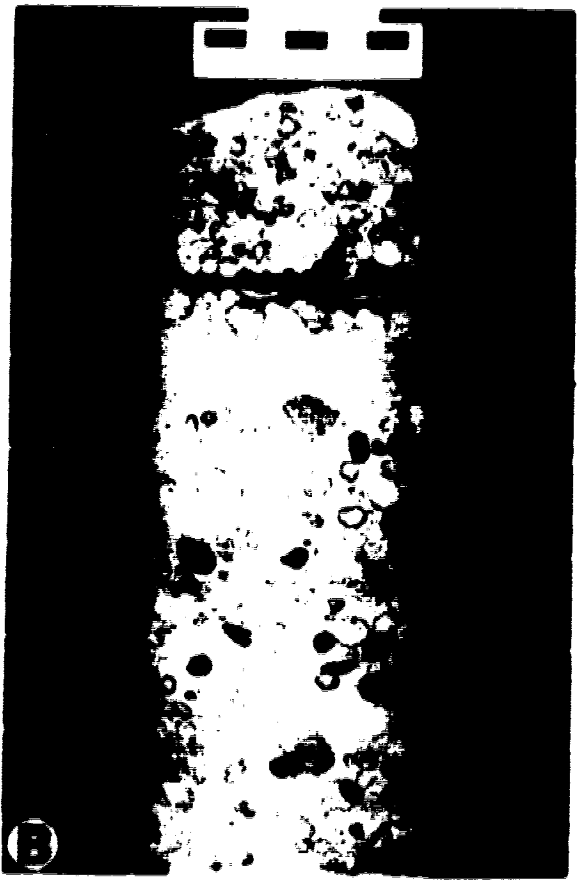
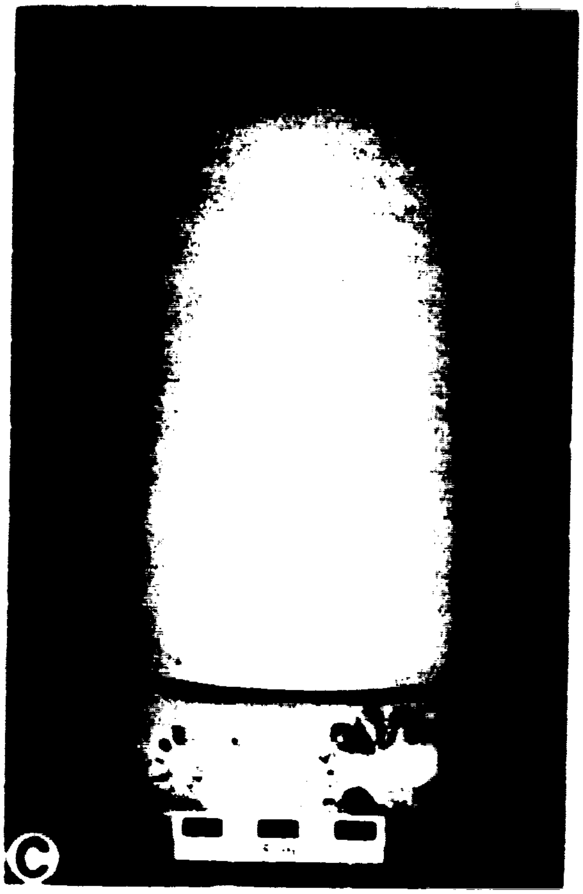

B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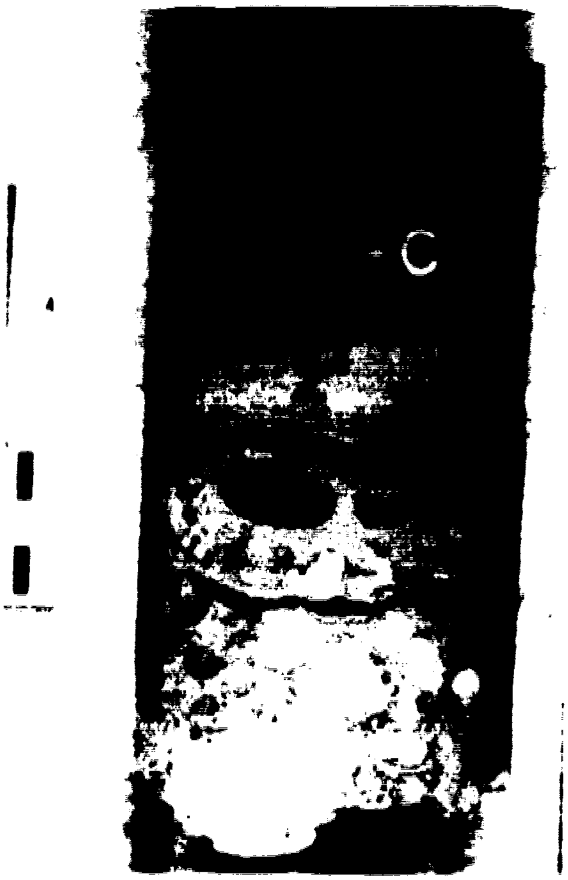
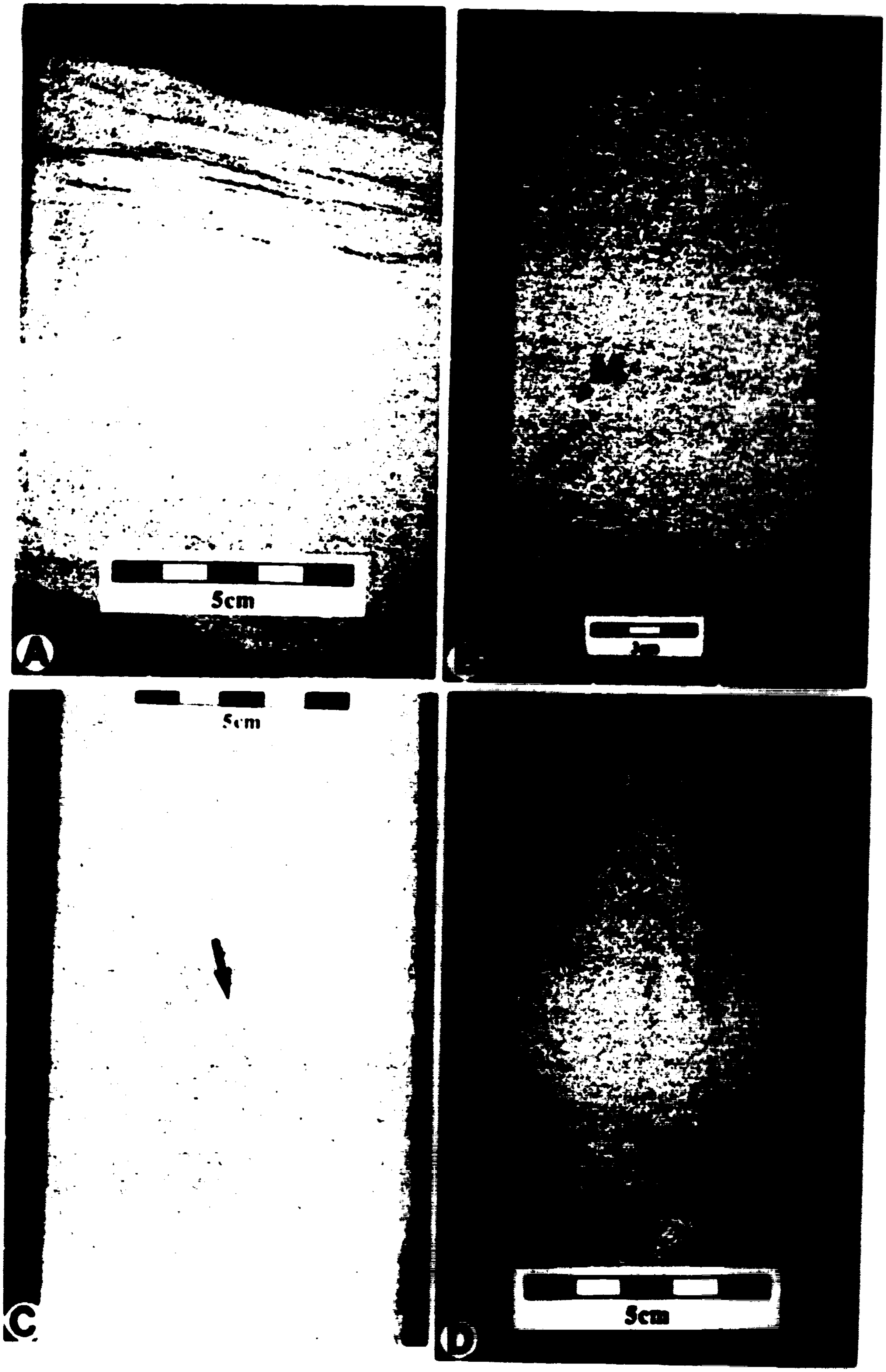

C

Figure 3.15 **Core photographs of Facies 8 through Facies 10.** All photographs are from 14-11-22-24W4. **Facies 8: Rippled fg-mg sandstone. (A)** Note the small scale current ripple foreset laminae being accentuated by carbonaceous detritus, depth 1352.58m. **(B)** Photograph illustrates the Facies 8/Facies 9 contact (arrow) from current rippled/small scale cross bedded mg upper shoreface/delta front sandstone (Facies 8) at the base, into very low angle/planar horizontal laminated mg beach/foreshore sandstone (Facies 9). Note the abundant *Macaronichnus segregatis* (M) just above the contact, depth 1352.3m. **Facies 9: Planar parallel to low angle laminated mg sandstone.** (C) Typical beach/foreshore mg sandstone with very low angle inclined laminations (arrow), depth 1351.37m. **Facies 10: Mottled and rooted shaly mg sandstone.** (D) Foreshore sandstone with low angle laminations disrupted by wispy root traces (arrows), depth 1351.08m.


5cm
A
5cm
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5cm
D

Figure 3.16 **Core photographs of Facies 10 through Facies 12.** All photographs are from 14-11-22-24W4. **(A)** Facies 9/Facies 10 contact. Note that the foreshore/backshore contact is gradational, depth 1350.87m. **Facies 10: Organic rich shale portion.** **(B)** Interpreted backshore shale is totally composed of finely comminuted carbonaceous/organic detritus and coaly fragments, depth 1350.43m. **Facies 11: Unburrowed dark blocky mudstone.** **(C)** Dark grey-black blocky non-marine mudstone with mm scale siltstone lenses. Also note the blotchy patches of pyrite (arrows), depth 1349.95m. **Facies 12: Friable silty shale/shaly siltstone and siltstone.** **(D)** Massive grey-green cemented siltstone that underlies a true palaeosol. Perhaps this represents a previously deposited facies that was in the initial stages of podsolisation, depth 1348.76m. **(E)** Bedding plane view of crumbly yellow palaeosol. Note the waxy looking appearance, depth 1348.42m.

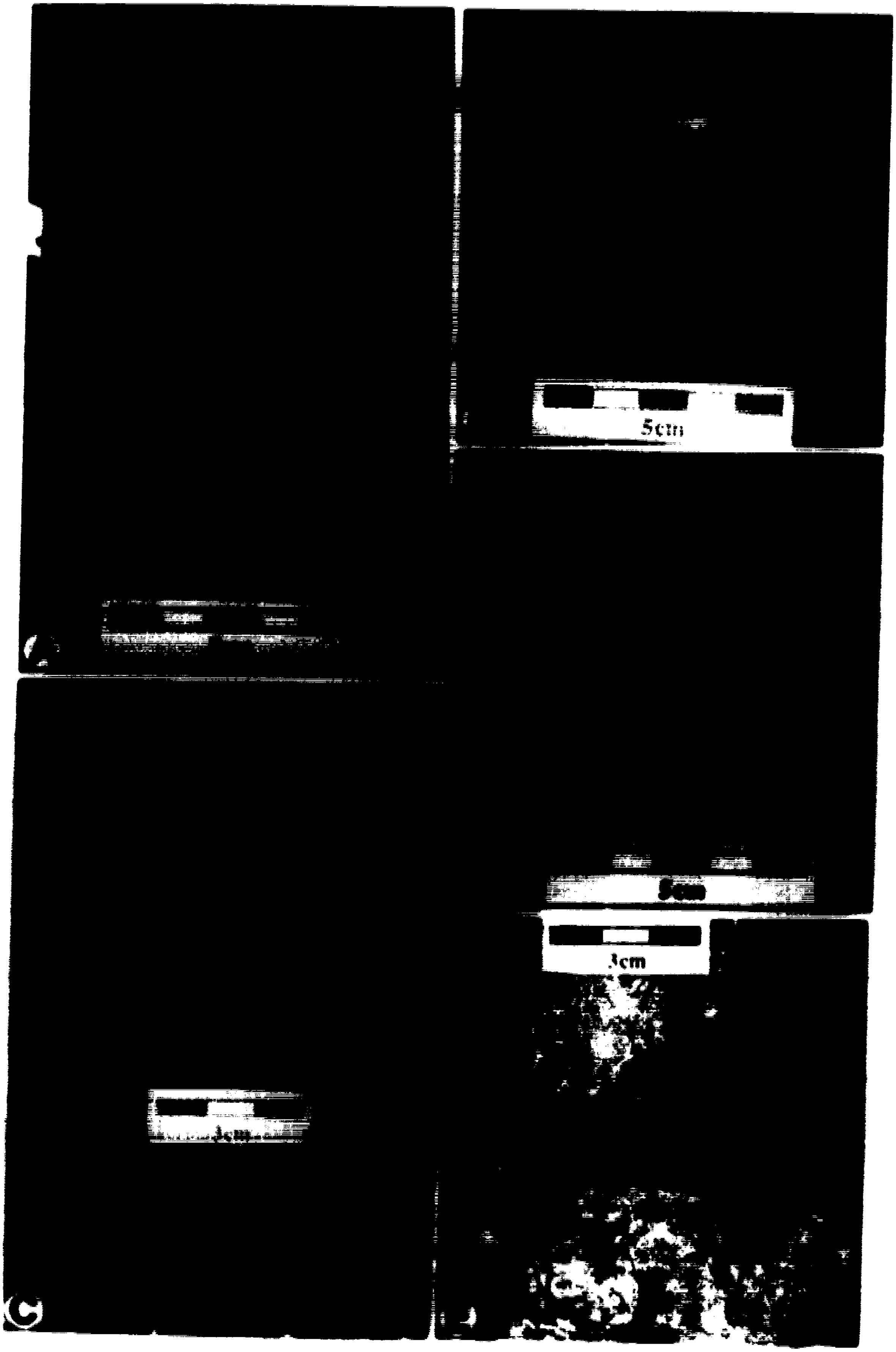
a
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Figure 3.17 **Core photographs of Facies 13: Polymodal conglomerate/Pebbly and shaly mottled sandstone.** This facies is colloquially referred to as the "Viking Grits" by oil industry geologists. **Polymodal matrix supported conglomerate.** **(A)** Note the highly variable pebble size, nature of the matrix, and overall chaotic bedding, 14-35-26-20W4, depth ~1198.8m. **(B)** Note the dominantly "salt and pepper" mg sandstone matrix, 15-16-28-22W4, depth ~1276.15m. **Mottled shaly mg sandstone.** **(C)** Note the robust *Teichichnus* (T) burrow. The bedding plane view of this particular core photograph reveals the presence of several cross-cutting *Teichichnus* burrows, 8-20-26-18W4, ~1213.7m. **(D)** Mottled sandy shale with rare scattered pebbles and granules (arrow). Note the churned/burrowed fabric but the absence of identifiable individual burrow forms. Also note the "salt and pepper" nature of the sandstone and the ripped up bentonite clast (b), 14-11-22-24W4, depth 1346.97m.

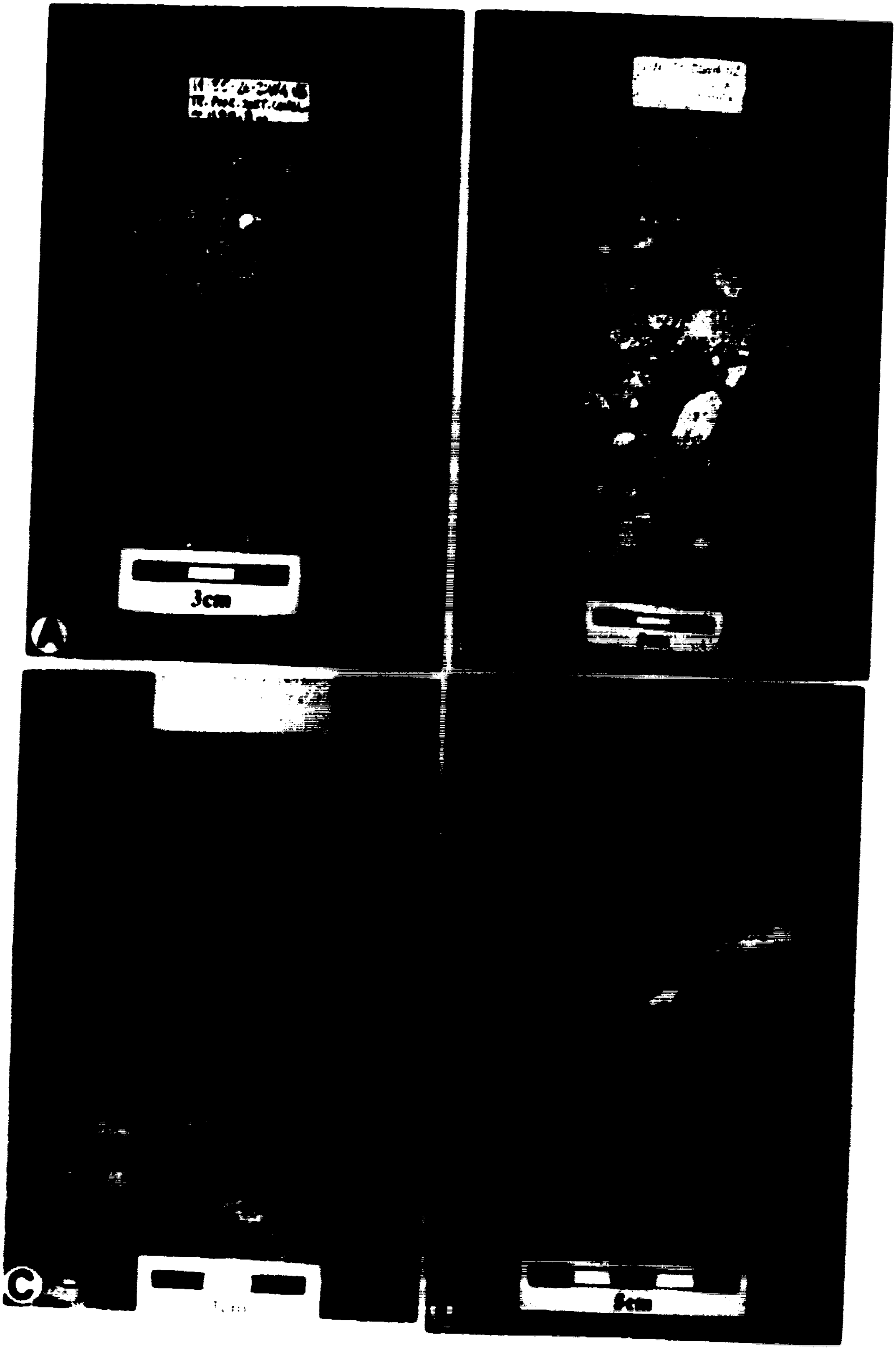
3cm
A
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Figure 3.18 **Facies 14: Dark shale with mm-cm scale siltstone to vf sandstone beds. (A)** Note the loaded base of the combined flow rippled vf sandstone bed (arrow), 14-35-26-20W4, depth ~1196.15m. **(B)** Typical facies photograph with sharp based oscillation ripple laminated vfL sandstone bed interbedded with dark shale, 14-11-22-24W4, depth ~1345.8m. **Facies 16: Light Grey bentonite. (C)** Silty bentonite bed with possible oscillation/combined flow rippling at base and U-shaped *Diplocraterion* shaft (D) that may reflect the *Glossifungites* ichnofacies, 7-35-26-20W4, depth ~1125.1m. **(D)** Silty bentonite with possible combined flow rippled base and dark shale filled, sharp walled *Diplocraterion* (D) shafts that may reflect the *Glossifungites* ichnofacies, 7-35-26-20W4, depth ~1125.1m. **(E)** Bedding plane view of dumbbell-shaped, dark shale filled *Diplocraterion habichi* (arrows) shafts in a bentonite bed. Note the distinctive alteration rim around the *Diplocraterion*, 7-35-26-20W4, depth ~1125.1m.

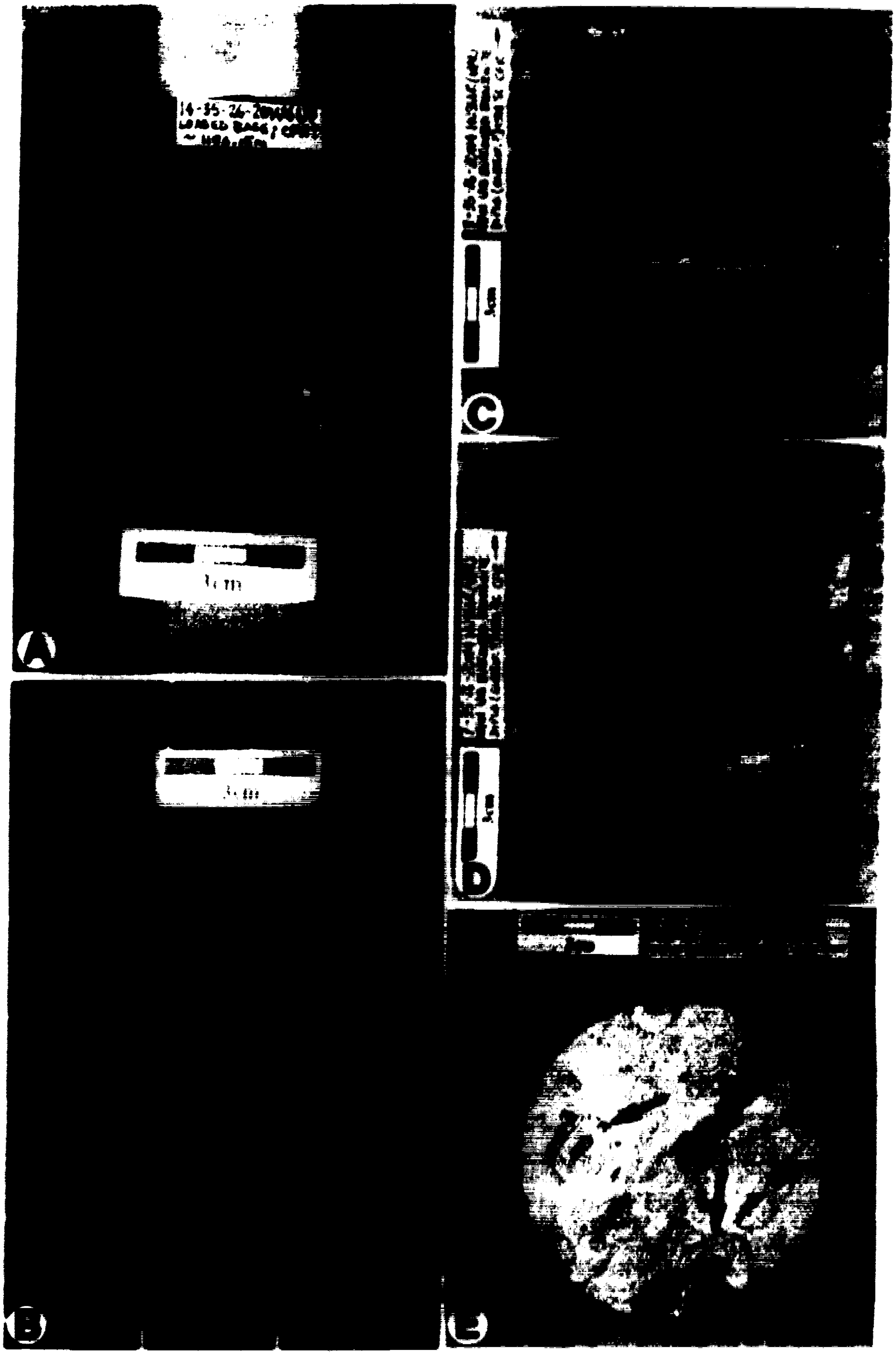
A
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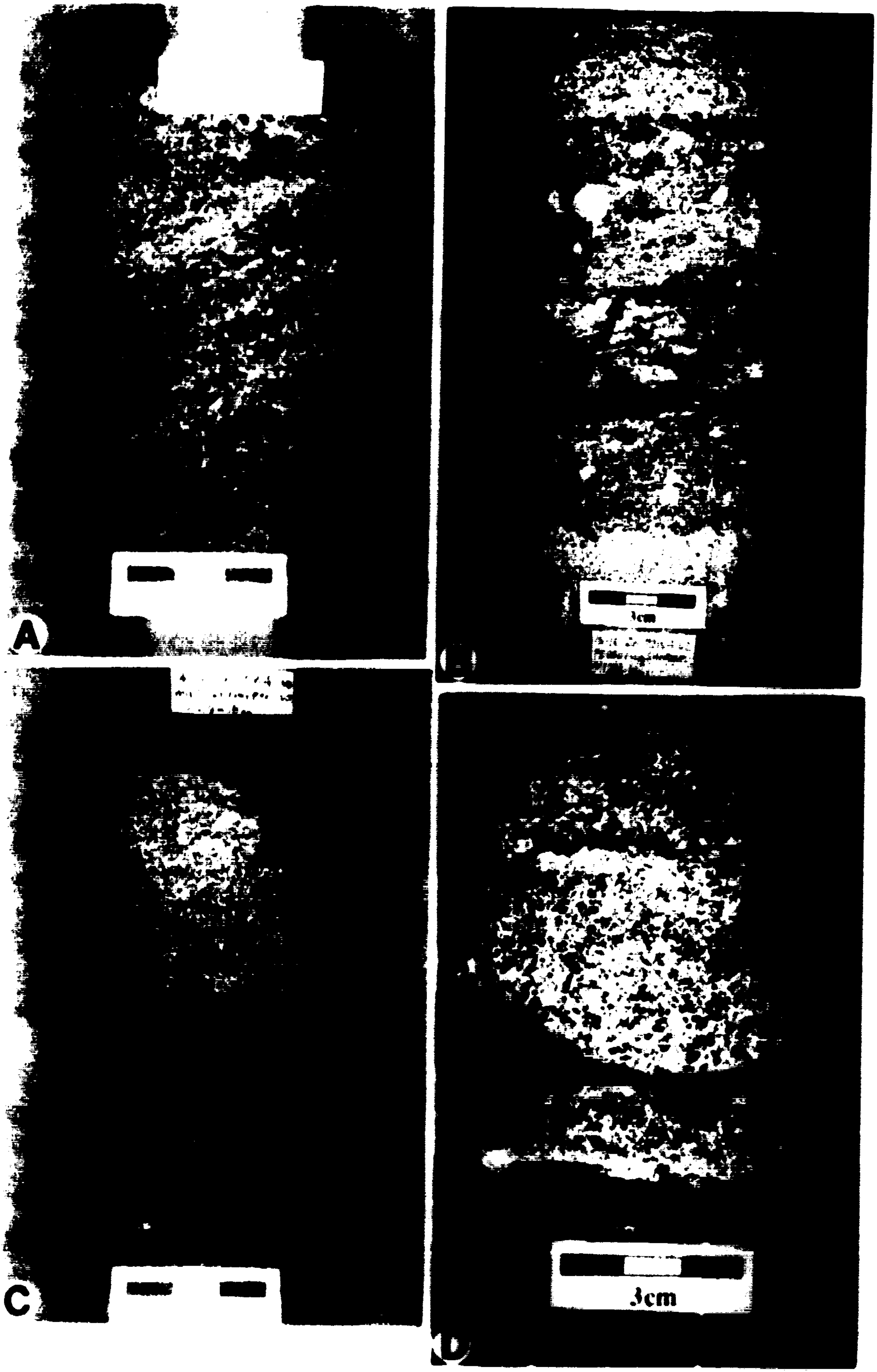
Figure 3.19 **Core photographs of Facies 15: Medium to coarse grained cross bedded sandstones and pebbly sandstones.** (A) Cross bedded mg-cg pebbly sandstone. Note the pebbles and granules accentuating the cross laminae, 7-1-27-19W4, depth ~1148.5m. (B) mg sandstone with dispersed pebbles and granules which are accentuating low angle laminations (possible toesets of large megaripples?). Note the interbedded mottled shaly sandstone being truncated by the sharp based pebbly sandstone (arrow), 15-16-28-22W4, depth ~1276.56m. (C) Apparently structureless/massive mg "salt and pepper" sandstone, 14-35-26-20W4, depth ~1196.8m. (D) Apparently structureless granular sandstone/conglomerate, 7-30-24-19W4, depth 1166.1m.


A
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3cm
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TABLE 2: Grain size designations used in this study

* U=upper; L=lower

Can-Strat Terminology	Diameter (µm)	Phi (ø) size
Very coarse-grained		
vcU	1410-2000	-0.5 to -1.0
vcL	1000-1410	0.0 to -0.5
Coarse-grained		
cU	710-1000	0.5 to 0.0
cL	500-710	1.0 to 0.5
Medium-grained		
mU	350-500	1.5 to 1.0
mL	250-350	2.0 to 1.5
Fine-grained		
fU	177-250	2.5 to 2.0
fL	125-177	3.0 to 2.5
Very fine-grained		
vfU	88-125	3.5 to 3.0
vfL	62-88	4.0 to 3.5

TABLE 3: TRACE FOSSILS ENCOUNTERED DURING STUDY AND THEIR ETHOLOGICAL CLASSIFICATION

ICHNOFOSSIL	ETHOLOGY	TROPHIC GROUP	POSSIBLE TRACEMAKER
Anconichnus	fodinichnia	deposit feeder	annelid or other worm-like phyla
Arenicolites	domichnia	suspension feeder	annelid or other worm-like phyla
Asterosoma	fodinichnia domichnia	deposit feeder grazing trace	annelid worm decapod crustacean
Bergaueria	cubichnia	passive carnivore	anemone
Chondrites	fodinichnia	deposit feeder	nematode; (?)sipunculid or polychaete worm
Cylindrichnus	domichnia	suspension feeder	polychaete or other worms
Diplocraterion	domichnia	suspension feeder	amphipod crustaceans; (?)polychaete worms
Escape trace	fugichnia	locomotion trace	bivalves; worms
Gyrolithes	domichnia	suspension feeder	polychaete worm (*Notomastus*)
Helminthopsis	pascichnia	grazing trace	annelid, polychaete or other worm-like phyla
(?)*Lockeia*	cubichnia	suspension feeder	bivalves
Macaronichnus	fodinichnia	deposit feeder	opheliid polychaetes (bloodworms)
Ophiomorpha	domichnia/ fodinichnia	suspension feeder	crustacean (thalassinid decapod)
Palaeophycus	domichnia	carnivore; (?)suspension feeder	annelid or polychaete worm
(?)*Phycodes*	fodinichnia	deposit feeder	annelid or other worm-like phyla
Planolites	fodinichnia	deposit feeder	annelid or other worm-like phyla
Polykladichnus	domichnia	suspension feeder	annelid or other worm-like phyla
Rhizocorallium	fodinichnia; domichnia	deposit feeder; suspension feeder	crustacean or annelid worm
Rosselia	fodinichnia	deposit feeder	annelid or other worm-like phyla
Siphonichnus	fodinichnia/ domichnia	suspension feeder/ deposit feeder	bivalves
Skolithos	domichnia	suspension/deposit feeder; carnivore	annelid, phoronid or other worm-like phyla
Trichichnus	fodinichnia	deposit feeder	annelid, phoronid or other worm-like phyla
Terebellina	domichnia	suspension feeder	annelid, phoronid or other worm-like phyla
Thalassinoides	domichnia/ fodinichnia	deposit feeder	crustacean (thalassinid decapod)
Zoophycos	fodinichnia	grazing trace/ deposit feeder	annelid or other worm-like phyla

TABLE 4: Summary of the ichnological characteristics of the two facies associations

FACIES ASSOCIATION 1	**TRACE FOSSILS FOUND ONLY IN THE THOROUGHLY BURROWED SHALY PORTION** *Arenicolites* *Bergaueria* *Chondrites* *Diplocraterion* *Helminthopsis* (?)*Phycodes* *Rosselia* *Skolithos*	**TRACES COMMON TO THE THOROUGHLY BURROWED SHALY PORTION AND THE 1-15CM THICK SANDSTONE BEDS** *Asterosoma* *Ophiomorpha* *Planolites* *Rhizocorallium* *Teichichnus* *Terebellina* *Thalassinoides* *Zoophycos*	**TRACE FOSSILS RESTRICTED TO THE 1-15CM THICK RIPPLED VERY FINE GRAINED SANDSTONE BEDS** *Anconichnus horizontalis* *Cylindrichnus* *Gyrolithes* *Macaronichnus simplicatus* *Palaeophycus* *Polykladichnus* *Siphonichnus*
FACIES ASSOCIATION 2	**TRACE FOSSILS FOUND ONLY IN THE RARELY TO MODERATELY BURROWED PORTION** *Bergaueria* *Chondrites* (?)*Lockeia* *Planolites* *Rhizocorallium* *Terebellina*	**TRACES COMMON TO THE RARELY TO MODERATELY BURROWED PORTIONS AND THE THICKLY BEDDED SANDSTONE BEDS** *Anconichnus horizontalis* *Asterosoma* *Helminthopsis* *Palaeophycus* *Teichichnus* *Thalassinoides* *Zoophycos*	**TRACE FOSSILS RESTRICTED TO THE THICKLY BEDDED, LOW ANGLE LAMINATED VERY FINE TO FINE GRAINED SANDSTONE BEDS** fugichnia (*i.e.* escape traces) *Ophiomorpha irregulaire* *Ophiomorpha nodosa*

CHAPTER 4: STACKING PATTERNS AND DISCONTINUITY SURFACES

4.1 INTRODUCTION

The previous chapter dealt with the interpretation of the observed ichnology and sedimentology of the designated facies (*i.e.* the "building blocks") and recurring facies associations (*i.e.* FA1 and FA2). This chapter deals briefly with the stacking patterns of the facies (*i.e.* stacking the "building blocks"). The stacked facies and facies associations form sanding upwards cycles referred to as parasequences in the terminology of Van Wagoner *et al.* (1990). Stacked parasequences are separated from one another by marine flooding surfaces. A discussion of the stratigraphically significant discontinuity surfaces that envelope the facies and facies associations is found in this chapter. The key surfaces will be referred to as discontinuity surfaces, simply because this study has not illustrated any concrete time breaks at the surfaces. Strictly speaking, in order for the surfaces to be referred to as unconformities, significant time breaks must be demonstrated. In addition, the ichnological signature of the discontinuity surfaces is discussed. A list of abbreviations used in this chapter and its accompanying figures is given in Table 5.

4.2 STACKING PATTERNS

The overall stacking patterns of the facies observed can be summarised quite briefly. It is emphasized that the stacking patterns discussed only apply to the uppermost Bow Island Formation, as this is where the core control allowed a reasonable investigation into their configurations. In general, most cores show a basal shoaling upwards succession of facies from offshore deposits at their base (*i.e.* Facies 1, FA1), upwards into shoreface or delta front deposits (*i.e.* FA2). This basal cycle shoals upwards into FA2, and is truncated sharply by a marine flooding surface, locally veneered with a pebble lag. This flooding/discontinuity surface is correlatable to VE3 of Hadley (1992) (see Figures 2.4 and 4.1) and may represent an erosional unconformity. The cycle above VE3 [(*i.e.* Allomember D of Hadley (1992)] also starts in offshore deposits, and shoals upwards into shoreface or delta front deposits (*i.e.* FA2, Subfacies 6A, B, C, D, Facies 7 through 10), and locally, up into non-marine deposits (*i.e.* Facies 11 and Facies 12). There is a major transgression on top of the Bow Island Formation which results in the deposition of the Lower Colorado shale. Through most of the study area, one of the transgressive facies (*i.e.* Facies 13, 14 and 15) erosionally overlies FA2 sediments; the major discontinuity separating the two is correlatable to VE4 of Hadley (1992) (see Figs. 2.4 and 4.1). In a few localities in the southwest of the study area, the VE4 unconformity separates transgressive deposits from underlying non-marine deposits. There is some evidence from the cores examined to suggest that a significant surface lies within the shoaling upwards cycle between VE3 and VE4 (*i.e.* Allomember D) (Figs. 2.4 and 4.1). This surface is herein informally referred to as VE3.5 (Fig. 4.1). A discussion of these three main surfaces is given below.

4.3 KEY SURFACES

4.31 VE3 and VE4 Surfaces of Hadley (1992)

The VE3 and VE4 surfaces are commonly overlain by some pebbly or conglomeratic material (Figs. 4.2A,B; 4.3A,B; 4.4; 4.5). VE3 and VE4 are fairly easily recognised in core (Figs. 4.4 and 4.5). Where Facies 13 or Facies 15 erosively overlies FA2 or non-marine deposits, three possibilities exist for the cause of the erosion: a) transgressive wave erosion; b) lowstand erosion; c) a combination of transgressive and lowstand erosion. Transgressive wave erosion (*i.e.* ravinement) supplies the simplest explanation for both the erosion surface as well as the transgressive deposits that directly overlie the VE3 and VE4 surfaces. The difficulty with this explanation is that it does not account for where the pebbles themselves originated from. An interpretation in favour of transgressive wave erosion necessitates the origin of the pebbles as reworked material derived from unrecognised pre-existing deposits. Purely lowstand conditions also seem unlikely as there is evidence of reworking of the lowstand derived deposits into some of the marine transgressive facies (*i.e.* Facies 13 and 15), and the local presence of the *Glossifungites* ichnofacies. Lowstand erosion followed by modification of the lowstand supplied pebbles by waves associated with subsequent transgression is the favoured interpretation. As such, the VE3 and VE4 surfaces are interpreted as amalgamated lowstand/transgressive surface of erosion (*i.e.* LSE/TSE), or a flooding surface/sequence boundary (*i.e.* FS/SB) in the terminology of Van Wagoner *et al.* (1990). The VE3 and VE4 surfaces are locally demarcated by elements of the *Glossifungites* ichnofacies. The characteristics and significance of the *Glossifungites* ichnofacies are given in Section 4.4.

4.32 The ?VE3.5 surface

The VE3.5 surface is somewhat problematic. As discussed at length in the discussion of Facies 7 in Chapter 3, some pebbly and conglomeratic deposits are interpreted as having been deposited by rapid slumps and flows likely initiated by tectonic activity or major storms. In most cores, the section between VE3 and VE4 appears to be one continuous sanding and shoaling upwards shoreline cycle, but there is some evidence that suggests that a VE3.5 discontinuity surface exists within the Allomember D defined by Hadley (1992).

The evidence for a VE3.5 surface lies in the rare localities where erosively based conglomeratic horizons are encountered within Allomember D (Fig. 4.6A). This in itself could be explained by processes similar to those proposed for Facies 7, except for the association of increased burrowing intensity and diversity commonly observed above the conglomeratic horizon. Where the conglomerate is not visible at the VE3.5 level, the FA1/FA2 contact is commonly at the same approximate level (Figs. 4.4; 4.5; 4.6B). The conglomerate (*i.e.* Facies 7) overlain by thoroughly homogenized Facies 3 or burrowed thinly interbedded Facies 5 (Figs. 4.6C,D) may represent an LSE sourced conglomerate that was subsequently transgressed by marine waters. Locally, these types of surfaces could be amalgamated, forming an LSE/TSE, or only manifest by the slight basinward shift in facies represented by the FA1/FA2 contact (see Fig. 4.1). Obviously, if two similar looking cycles are stacked on top of each other in an aggradational to progradational manner, the ability to discern a subtle surface between the two cycles is very difficult. As previously mentioned in the discussion of Facies 7, the favoured interpretation involves deposition by major storms, although the LSE/TSE interpretation cannot be completely ruled out. ?VE3.5, unlike VE3 and VE4, shows no evidence of the *Glossifungites* ichnofacies. For a more detailed review of the pros and cons in the interpretation of a possible VE3.5 surface, the reader is referred back to the detailed discussion of Facies 7 (Chapter 3, pp.70-74).

4.33 Surfaces at the bases of coarse to pebbly transgressive deposits

The occurrences of 1-15cm thick beds Facies 13 and Facies 15 (*i.e.* "onlap markers" in Fig. 4.1) interbedded with Facies 14 and Subfacies 14a may have similar interpretations to the main occurrence of Facies 13 (*i.e.* above VE4 and VE3). This, then, implies that VE4 was followed by several further LSE/TSE events. Evidence to support this is largely from the *Glossifungites* ichnofacies demarcated surfaces commonly found at the base of the beds (Fig. 4.7). Alternatively, the pebbly and mottled shaly sandstone beds interbedded with Facies 14 and Subfacies 14a may be the only preserved record of short-lived stillstand events within the overall, somewhat "step-wise" marine transgression of the Lower Colorado Seaway. Their true origin is very difficult to discern due to the overall thickness of the beds combined with their poor bedding characteristics and somewhat limited ichnofossil assemblages. As these units above VE4 are commonly the best in terms of reservoir quality, the ability to predict their occurrences would be useful, but is, unfortunately, extremely difficult.

4.4 General characteristics of the *Glossifungites* ichnofacies

Many of the key surfaces are marked by trace fossil assemblages amenable to the *Glossifungites* ichnofacies. The *Glossifungites* ichnofacies is one of three substrate controlled ichnofacies. The other two substrate specific ichnofacies are the *Trypanites* ichnofacies (*i.e.* hardgrounds) and the *Teredolites* ichnofacies (*i.e.* woody or peaty substrates). The *Glossifungites* ichnofacies is an assemblage of trace fossils comprising burrows that are pseudobored into semi-lithified firmground substrates under marine to marginal marine conditions (Frey and Seilacher, 1980; Pemberton and Frey, 1985; Pemberton *et al.*, 1992a,e; MacEachern *et al.*, 1992a). The most common substrates include dewatered, stiff muds and, to a lesser extent, incipiently cemented sandstones. The semi-lithification of the substrate was likely facilitated by subaerial exposure during lowstand, or erosional exhumation of a previously buried substrate. It is stressed that although the substrate may have become stiff as a result of subaerial exposure during lowstand, the actual colonisation of that firm substrate occurred in marine to marginal marine conditions. The reason for this is simply that the tracemakers that do the pseudoboring are all essentially marine organisms, with some forms able to extend into marginal marine environments. A schematic of the stage development of the *Glossifungites* ichnofacies is given in Figure 4.8.

Trace fossils of the *Glossifungites* ichnofacies are sharp walled, unlined, dominantly vertical to subvertical dwelling structures of suspension feeding organisms. The most common ichnogenera comprising the *Glossifungites* ichnofacies within the study area are *Skolithos, Diplocraterion, Arenicolites* and *Thalassinoides*. *Thalassinoides* is a dwelling structure of a deposit feeding organism (as opposed to a suspension feeding structure).

Trace fossils of the *Glossifungites* ichnofacies are normally quite robust, can penetrate up to one metre below the bed junction from where they emanate, and are passively filled with material that commonly contrasts the underlying, cross cut material. Examples of the *Glossifungites* ichnofacies within the study area penetrate to a maximum of ~10cm below their corresponding bed junction. The *Glossifungites* assemblages are generally more robust than the unrelated softground ichnofossil suites they cross cut.

The presence of large, deeply penetrative shafts in shaly substrates is highly anomalous. If the muddy substrate was originally soft, the only way an organism could maintain a long vertical shaft would be if it reinforced its burrow walls by lining them with some more stable material. The absence of wall linings in traces of the *Glossifungites* ichnofacies inplies that the substrate burrowed into was stiff or firm. This is the only way the burrow could have been maintained. Furthermore, the passive nature of the fill is extremely important. The implication of a passively filled burrow is that the burrow must have remained open upon burrow vacation by the tracemaker. If the substrate was soft, upon vacation, the burrow would have collapsed in on itself and never had the opportunity to be passively filled. Once again, the only reasonable explanation for observations of trace fossils amenable to the *Glossifungites* ichnofacies is that they were pseudobored into a semi-lithified, firmground substrate. MacEachern *et al.* (1992a) also noted that surfaces demarcated by the *Glossifungites* ichnofacies tend to be colonised by dense populations of tracemakers that were able to exploit the niche of a firm substrate. It is in this sense that the *Glossifungites* ichnofacies can be viewed as an opportunistic suite of trace fossils.

The *Glossifungites* ichnofacies is an extremely important entity to recognise because it has major stratigraphic implications. A surface demarcated by the *Glossifungites* ichnofacies implies that the sediment lying on either side of that surface are fundamentally unrelated in a depositional sense. Although the facies on either side of the *Glossifungites* ichnofacies demarcated surface may be similar, the mere presence of the *Glossifungites* ichnofacies suggests that the facies above and below the surface are not genetically related. MacEachern *et al.* (1992a) deal with the stratigraphic applications of the *Glossifungites* ichnofacies in great detail, citing examples from numerous Cretaceous Formations in the Western Canada Sedimentary Basin.

4.41 The occurrence of the *Glossifungites* ichnofacies at VE3 and VE4

The *Glossifungites* ichnofacies is present at both the VE3 and VE4 surfaces. Examples from several cores (Figs. 4.2C,D; 4.3C,D) suggest that the underlying substrates were firm or semi-lithified, and later colonised by opportunistic biota under marine to marginal marine conditions (*cf.* MacEachern *et al.*, 1992a; Pemberton *et al.*, 1992a). The ensuing transgression (of the Lower Colorado Seaway in the case of VE4) over the previously exposed surface created the marine to marginal marine conditions which allowed some marine organisms to colonise and pseudobore the firm substrate. Alternatively, transgressive wave erosion may have eroded down to a semi-lithified substrate that was subsequently colonised and pseudobored by marine organisms. The first scenario is favoured because the pebbly material commonly found passively filling the burrows, is most easily explained as reworked pre-existing lowstand deposits. In the case of VE4, lowstand exposure is evident as the shoreline succession grades up into non-marine deposits and palaeosols. Palaeosols require significant time to form, and so the lowstand subaerial exposure was likely quite extensive. Figure 4.3D shows an occurrence of the *Glossifungites* ichnofacies that actually pseudobores into non-marine deposits. VE3, however, is somewhat more problematic, as no obvious signs of subaerial exposure are evident in the underlying sediment; therefore, the possibility exists that VE3 is a flooding surface or TSE. The observed sideritisation of the sediments underlying VE3 (Figs. 4.2C,D) and VE4 is commonly associated with interpreted FS/SBs (J.C. Van Wagoner, pers. comm., 1993). Furthermore, oxygen isotope values from the sideritic phase at similar boundaries in studies of the Book Cliffs, Utah, commonly suggest significant freshwater influence; it has been postulated that the freshwater influence was derived from lowstand associated fluvial systems (J.C. Van Wagoner, pers. comm., 1993). This study, however, has not revealed evidence of any lowstand incised channel/valley deposits coeval to the conglomeratic portion of Facies 13.

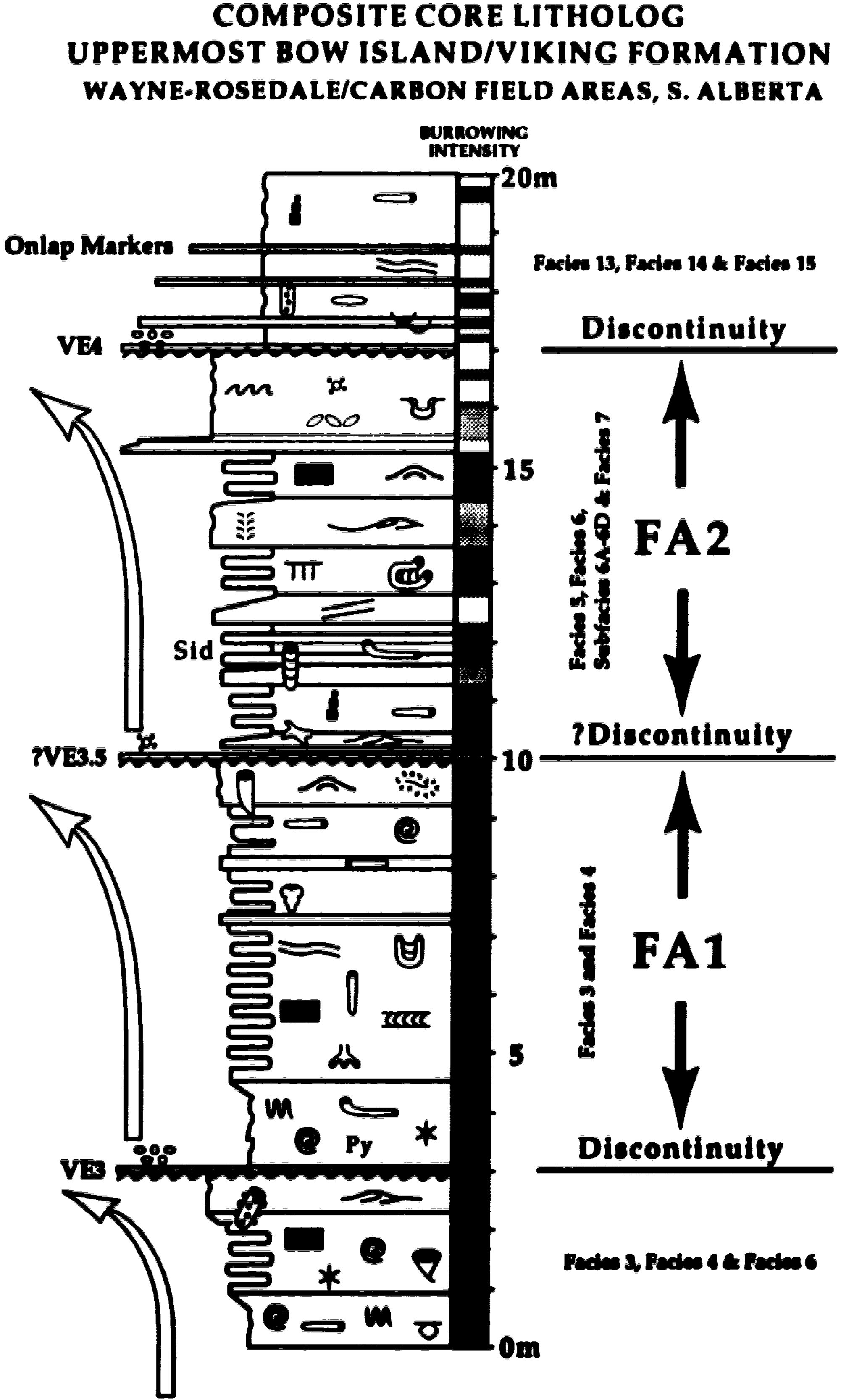


Figure 4.1 Composite litholog illustrating occurrences of Facies Associations and the significant bounding discontinuities. VE terminology after Hadley (1992).

Figure 4.2 **Examples of the ?LSE/TSE surface correlatable to VE3 of Hadley (1992): (A)** Erosive Contact with probable transgressive lag mantling flooding surface/parasequence boundary. Note the HCS bed in the underlying shoreface deposit, 7-27-29-22w4, depth ~1264.2m. **(B)** Erosive Contact with probable transgressive lag mantling flooding surface/parasequence boundary, 6-25-29-23w4, depth 1314.39m. **(C)** VE3 surface with pebbly material piped down into a ?*Thalassinoides* burrow amenable to the *Glossifungites* ichnofacies. Note the reddish-brown sideritised shale of the underlying unit, 11-21-28-17w4, depth 1109.48m. **(D)** Transgressive lag deposit with pebbles above, unconformably overlying sideritised shaly sandstone. Note that the surface is demarcated by a subtle expression of the *Glossifungites* ichnofacies, 6-23-27-21w4, depth 1168m.

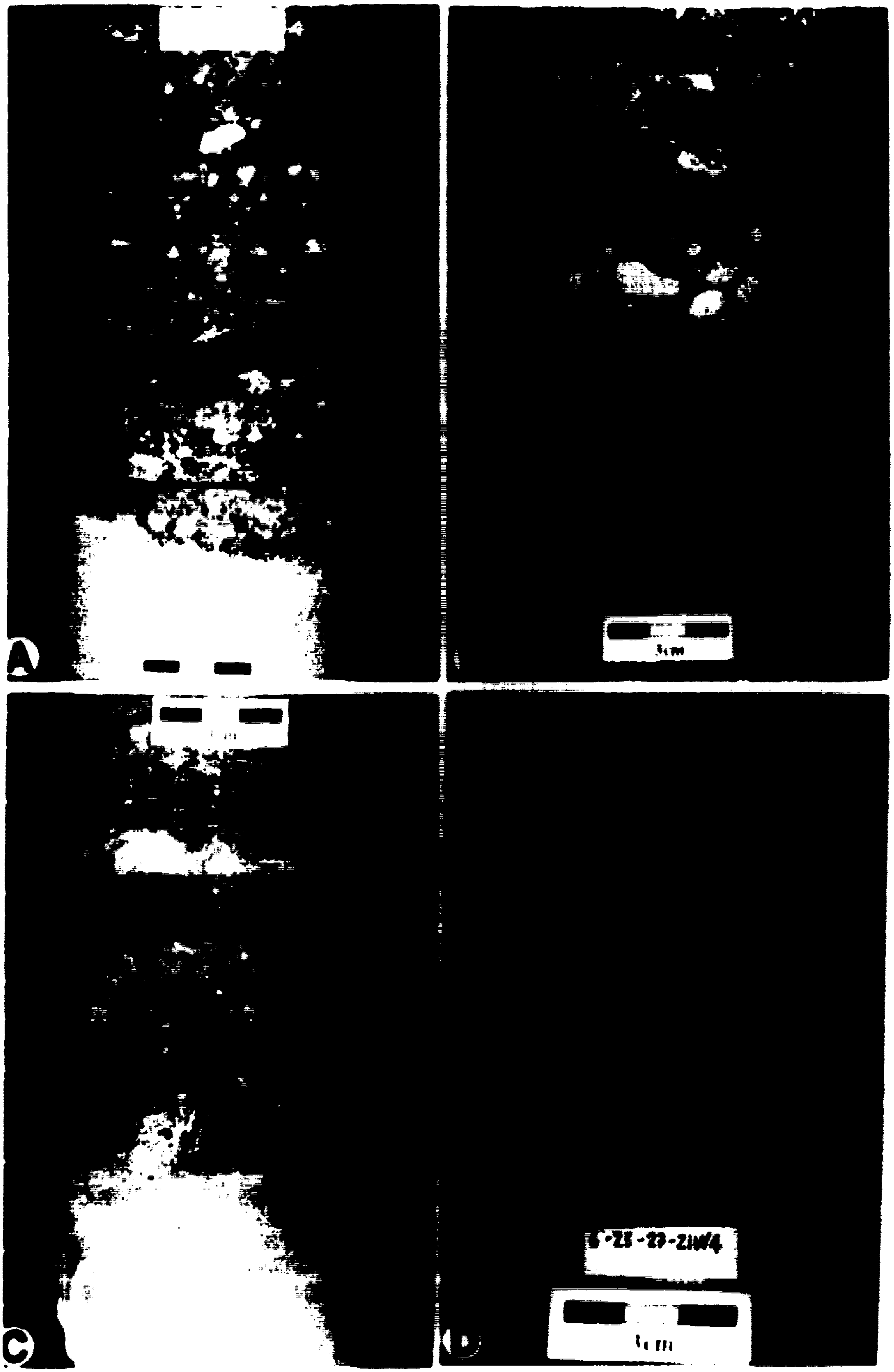

A
1cm
1cm
C
5-23-27-21W4
1cm
D

Figure 4.3 **Examples of the surface correlatable to VE4 of Hadley (1992): (A)** Highly jagged erosive contact into HCS bed below, 10-14-29-24w4, depth 1317m. **(B)** *Anconichnus* in thin storm bed below VE4 surface, 11-19-26-20w4, depth 1250.1m. **(C)** VE4 surface demarcated by a passively filled burrow representative of the *Glossifungites* ichnofacies. Pebbly lag truncates underlying HCS bed of FA2, 6-15-27-23w4, depth 1297.35m. **(D)** Pebbly to granular sandstone piping down into shaly sandstone. Note the sharp walled *Skolithos* amenable to the *Glossifungites* ichnofacies subtending from the VE4 surface, 14-11-22-24w4, depth 1348.12m.

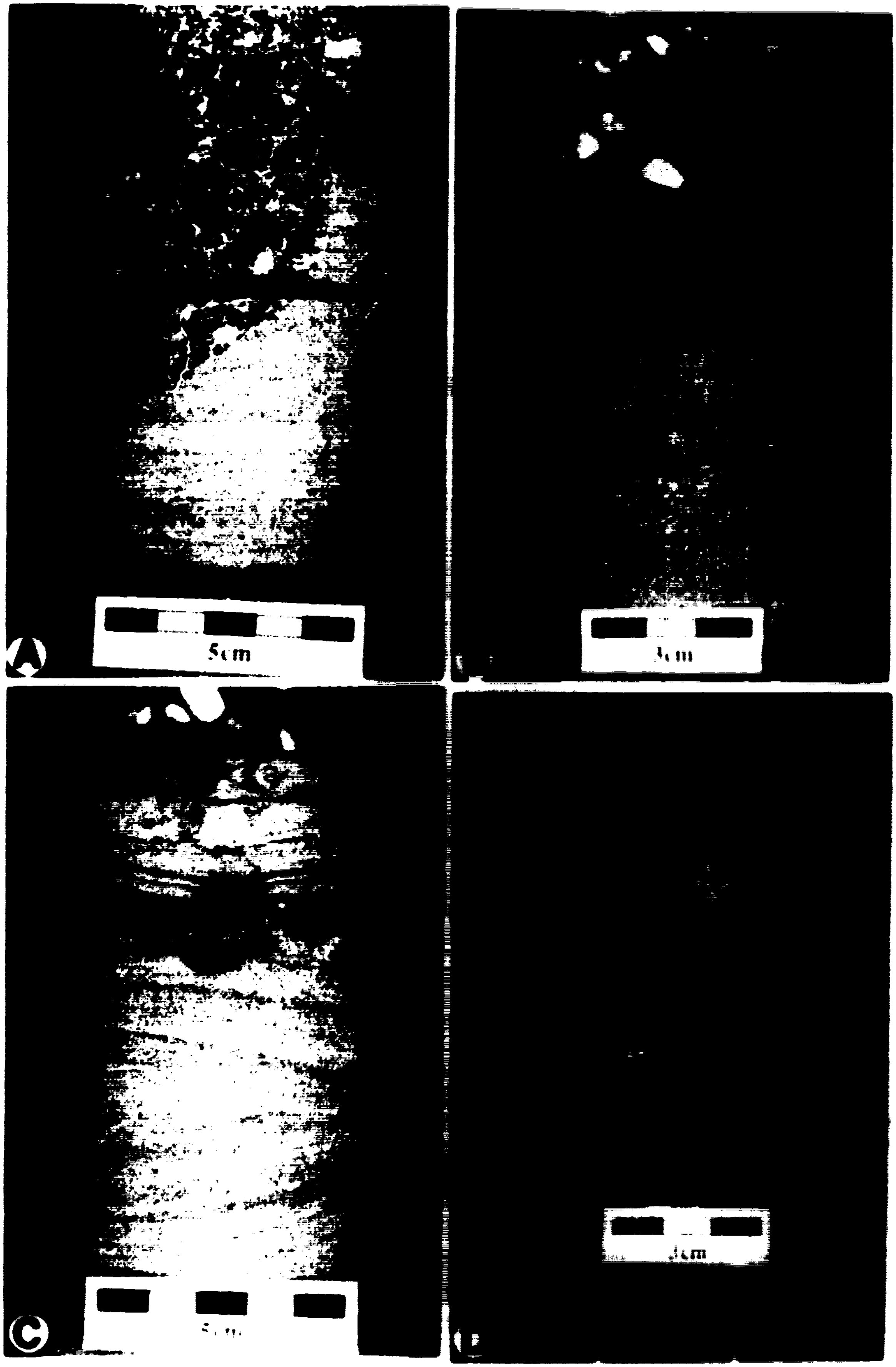

A
5cm
3cm
C
5cm
3cm

Figure 4.4 **Box photos of the 6-9-27-18w4 core (~1118.3-1137m):** "b" represents the base of the core and "t" represents the top of the core; 15cm scale. The core is read successively upwards from the bottom left to the top right. The white arrow marks the FA1/FA2 contact (*i.e.* an expression of VE3.5 relative lowstand surface?).

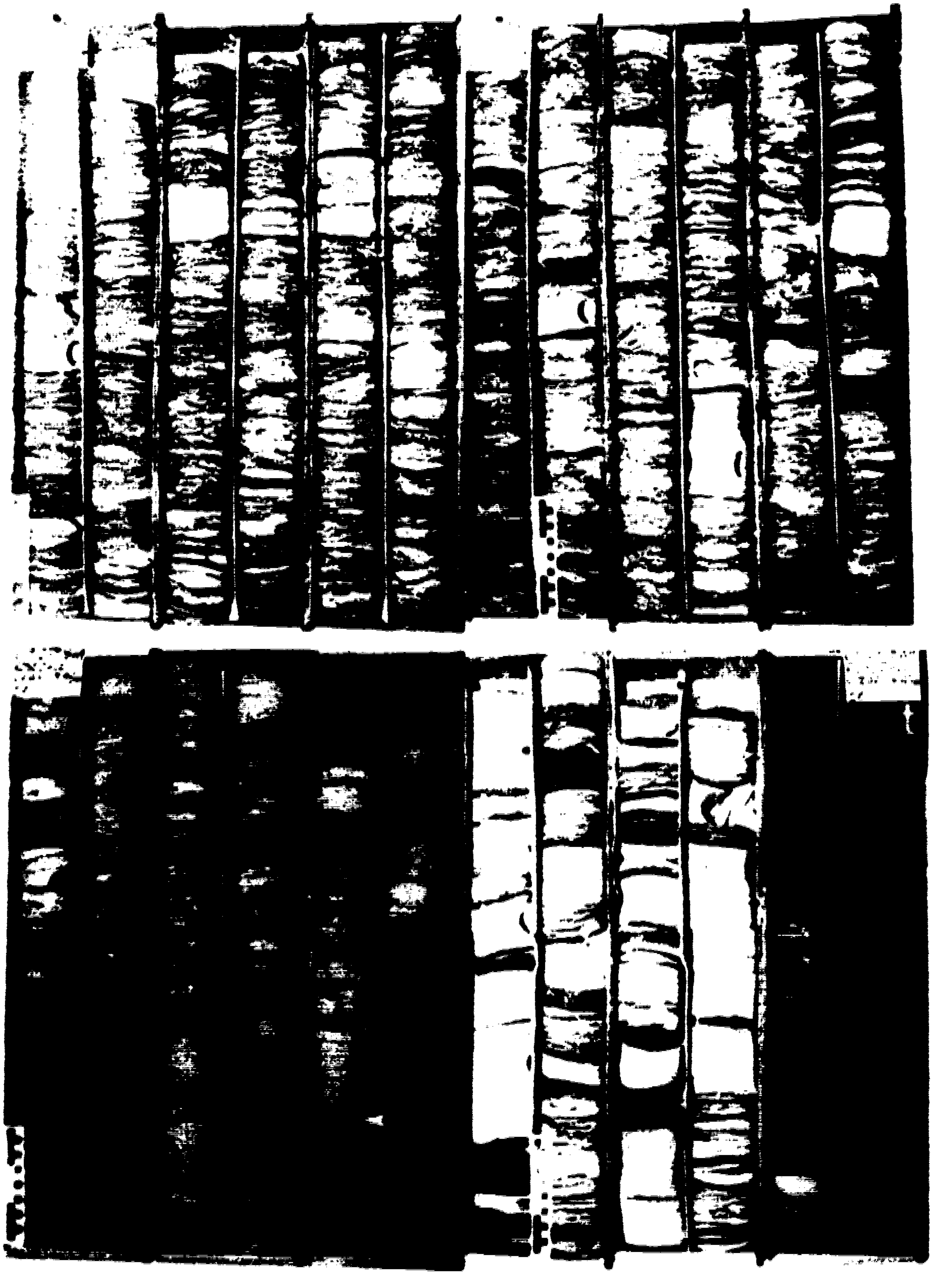


Figure 4.5 **Box photos of the 8-20-26-18w4 core (~1211.9-1229m): The core is read successively upwards from the bottom left to the top right; 15cm scale. (A) Basal three boxes of core; the change from light coloured sandstone to dark coloured shale represents the flooding surface correlative to VE3 of Hadley (1992). (B) Continuation upwards of core. (C) Continuation upwards of core; the small yellow pin marks to the left of the FA1/FA2 contact. The FA1/FA2 contact may represent ?VE3.5. (D) Upper three boxes of core. The small yellow pin near the middle of (D) marks to the left of the surface correlative to VE4 (Hadley, 1992).**

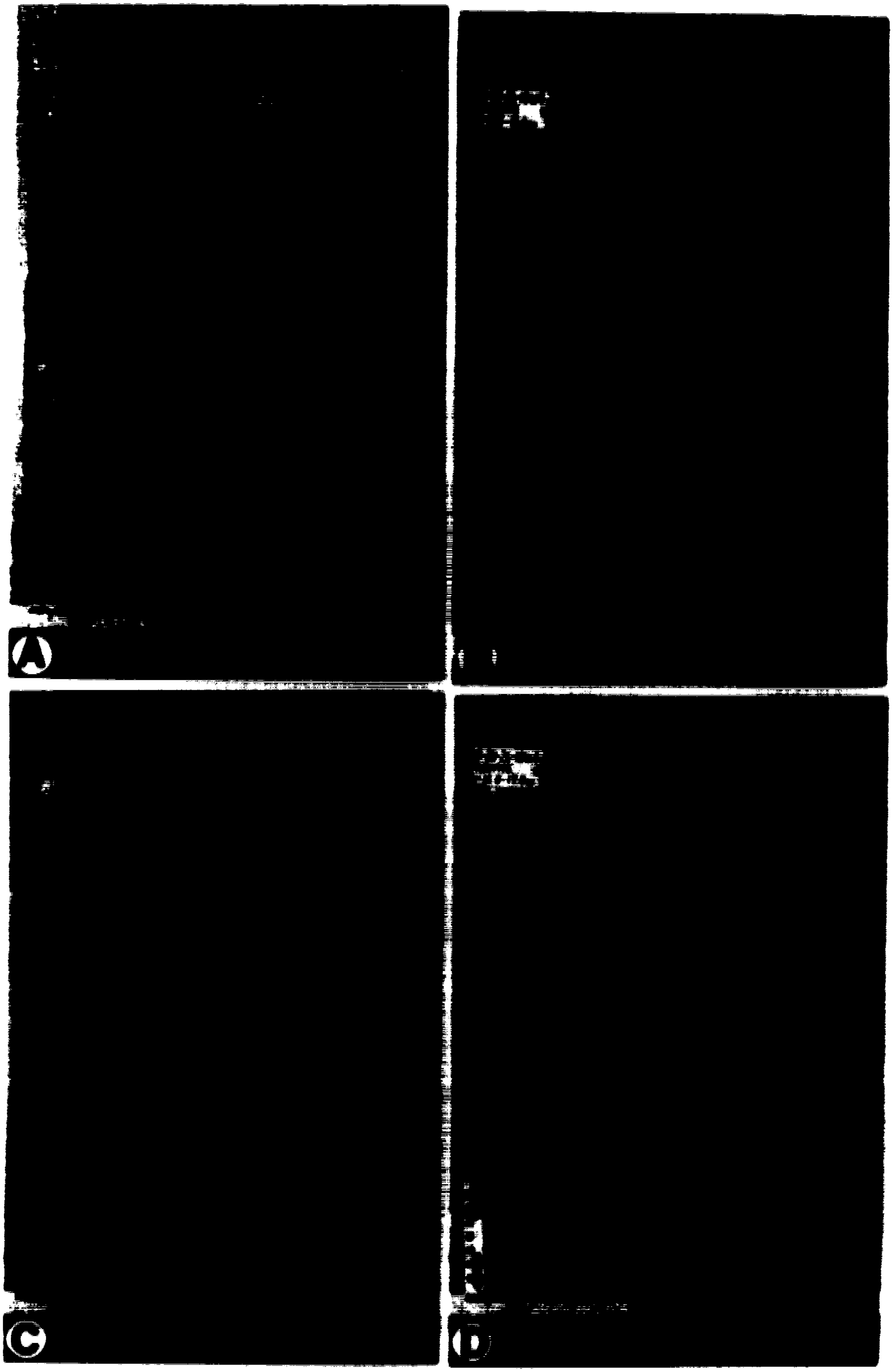

A
C
D

Figure 4.6 **Examples of ?VE3.5 surface:** **(A)** 6cm diameter chert pebble as part of erosively based conglomerate bed which represents the expression of ?VE3.5 surface, 6-25-29-23w4, depth 1306.88m. **(B)** Typical FA1/FA2 contact which may represent a subtler expression of ?VE3.5. Note the well burrowed deposits below, overlain sharply by a low angle laminated HCS bed, 6-9-27-18w4, depth 1124.25m. **Examples of well burrowed Facies 5 that commonly overlies ?VE3.5 surface:** **(C)** Heavily burrow mottled facies sporadically found above VE3.5; ~40cm above a thick conglomerate, 6-18-27-20w4, depth 1173.23m. **(D)** Facies photograph of transitional FA1/FA2 with *Zoophycos, Rhizocorallium, Chondrites etc.* and scattered granules, 6-21-29-22w4, depth 1262.3m.

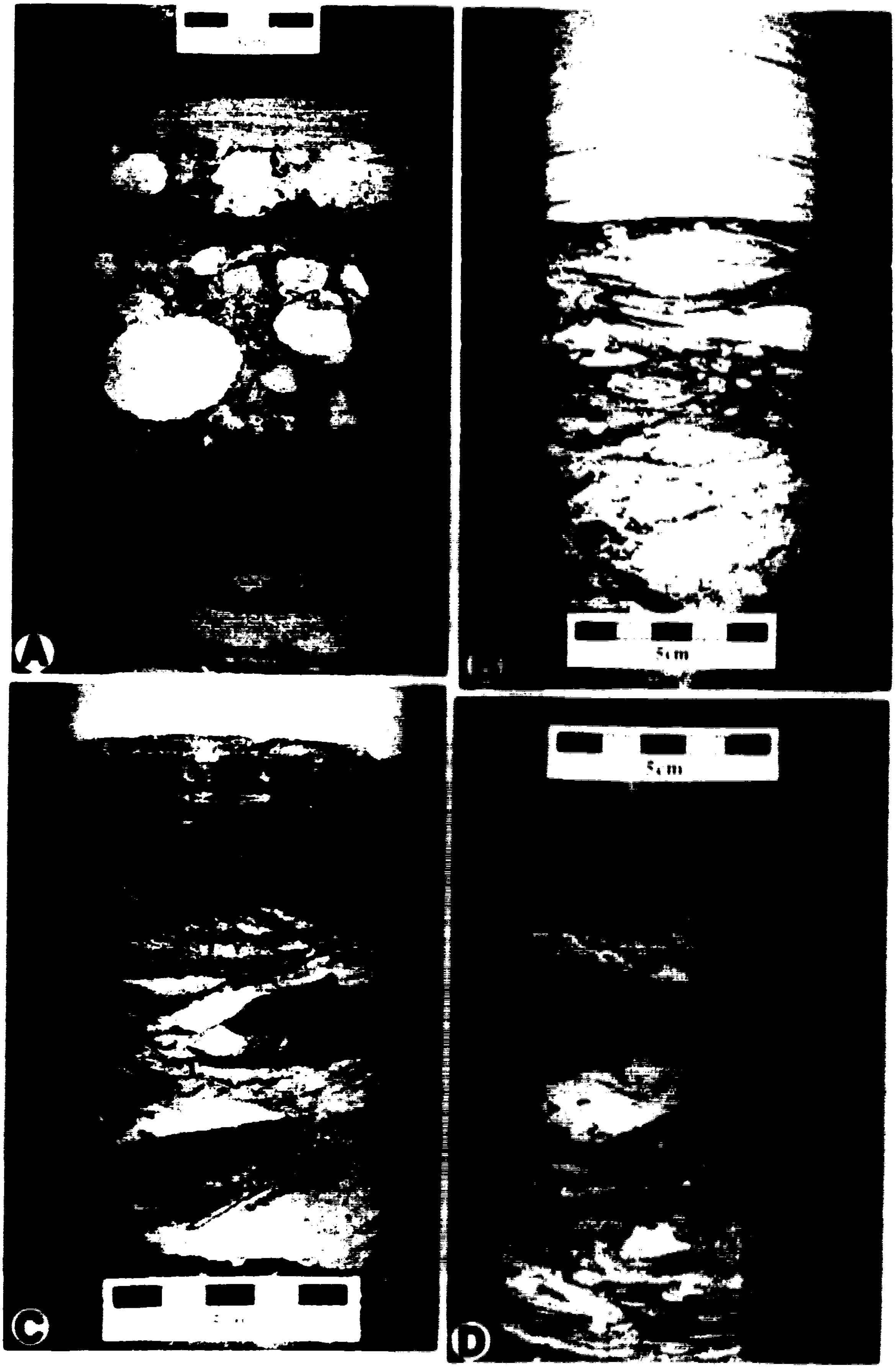
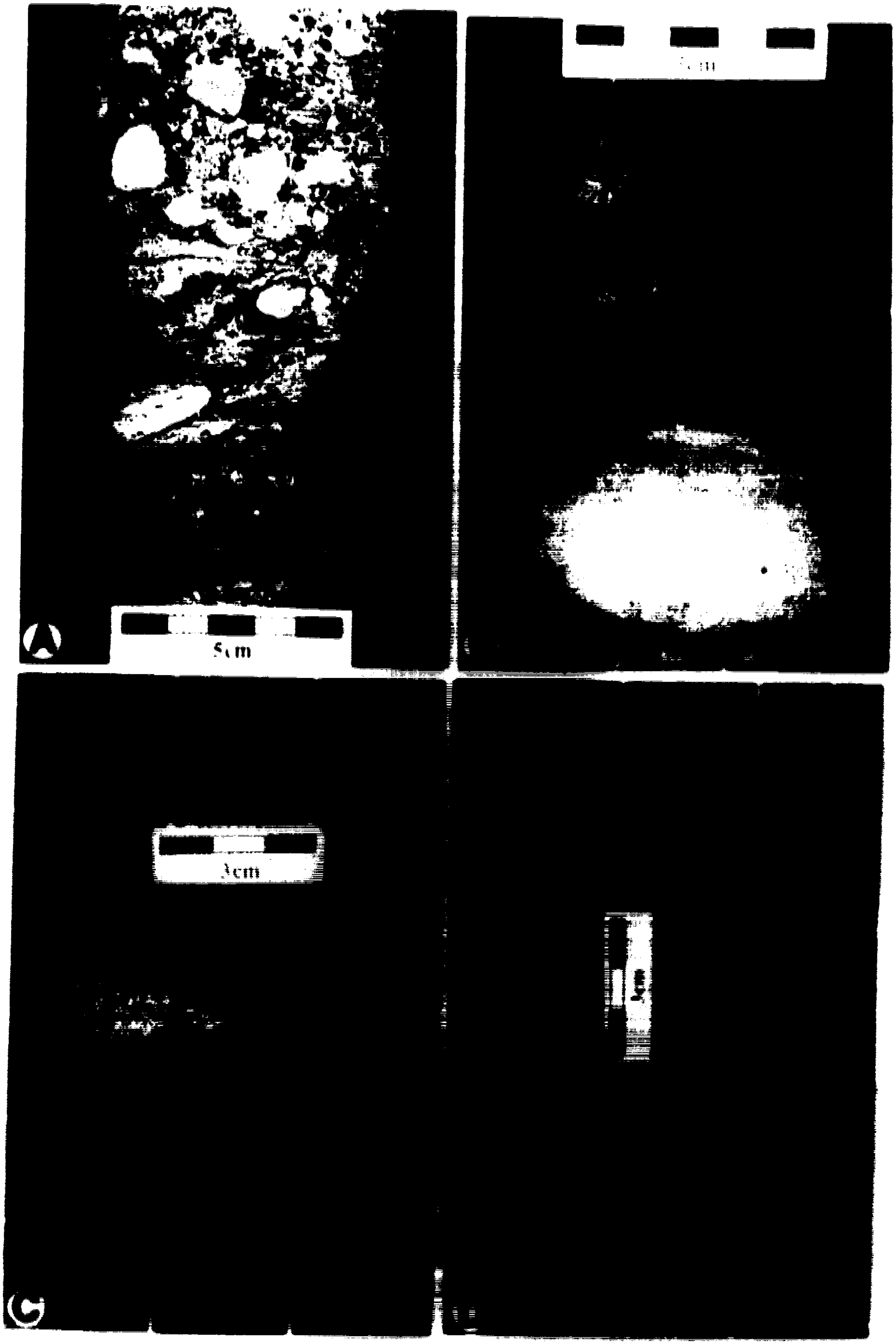

A
5cm
C
5cm
D

Figure 4.7 **Examples of the *Glossifungites* ichnofacies manifest in the complex of transgressive deposits:** **(A)** *Thalassinoides* burrow passively piping transgressive conglomeratic material into transgressive mottled shaly sandstone, 7-4-29-22w4, depth 1246.64m. **(B)** Small "J"-hooked *Arenicolites*. Also note the siderite cemented zone below, 6-21-29-22w4, depth 1251.97m. **(C)** 2-3cm thick mg sandstone with *Diplocraterion habichi* subtending (not visible, refer to (D)), 14-11-22-24w4, depth 1346.01m. **(D)** Same as (C) but bedding plane view showing *D. habichi* (dumbbell-shaped) and *Skolithos*, 14-11-22-24w4, depth 1346.01m.


A
5cm
5cm
3cm
C

Schematic development of a *Glossifungites* Ichnofacies

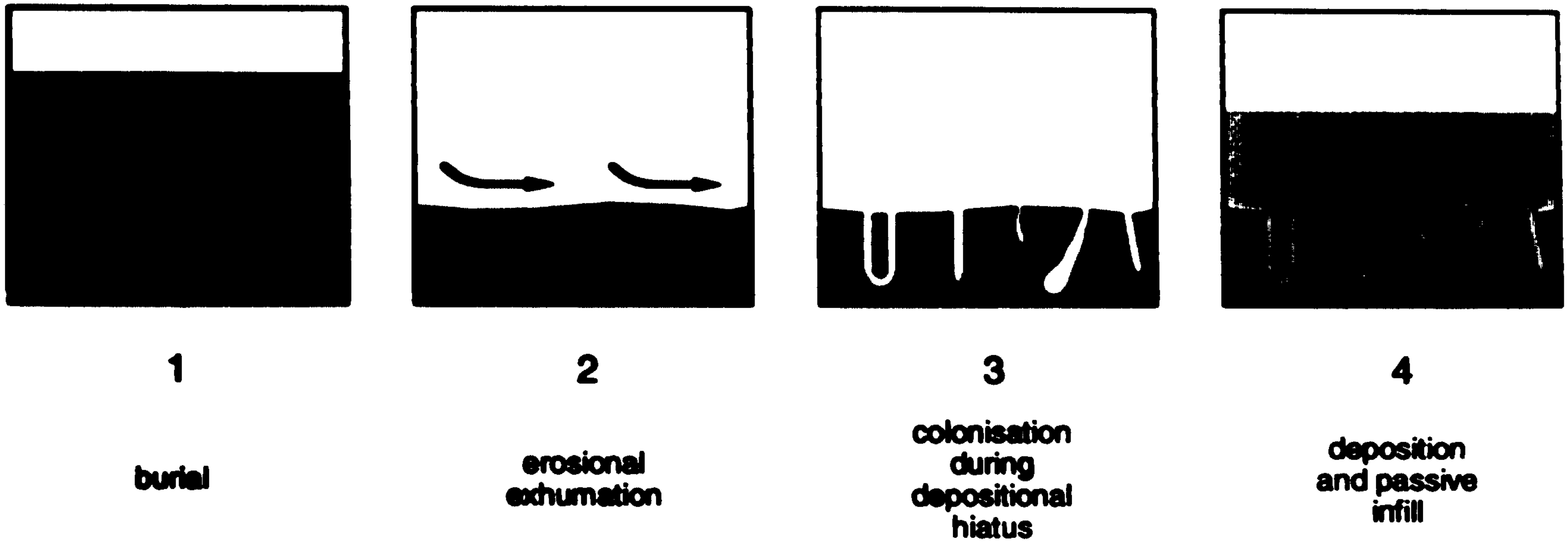


Figure 4.8 Schematic development of a *Glossifungites*-demarcated erosional discontinuity. 1) The muddy substrate is buried and dewatered, resulting in a compacted, stiff character. 2) The shaly bed is erosionally exhumed, exposing a firm substrate. 3) Colonisation of the discontinuity surface by tracemakers of the *Glossifungites* ichnofacies proceeds under marine conditions during a depositional hiatus. 4) The structures are passively filled during a succeeding depositional episode.

TABLE 5: Abbreviations used in Chapters 4 and 5

LSE	Lowstand Surface of Erosion
TSE	Transgressive Surface of Erosion
VE3	Viking Erosion Surface Three [Hadley (1992)]
VE4	Viking Erosion Surface Four [Hadley (1992)]
VE3.5	Viking Erosion Surface Three Point Five
FA1	Facies Association One
FA2	Facies Association Two
FS	Flooding Surface
SB	Sequence Boundary
Sid	Siderite/Sideritised/Sideritic Cement
?	Uncertain

CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 INTRODUCTION

Chapters 3 and 4 provide details regarding the observations made during this study. It is stressed that this study concentrates on detailed ichnologic and sedimentologic descriptions and interpretations. Although this study proposes no formal stratigraphy for the uppermost Bow Island/Viking Formations, the surfaces, facies and facies associations observed can be fit into the context of Hadley's (1992) allostratigraphy. Observations made regarding the key surfaces, facies, facies associations, and stacking patterns is briefly summarised below.

5.2 STRATIGRAPHY

5.21 Allostratigraphic nomenclature of Hadley (1992)

The VE3 and VE4 surfaces documented in the Harmattan area by Hadley (1992) continue into the current study area, and are quite obvious in both drill core and well logs (see Figs. 4.4; 4.5; 5.1). The regional extents of VE3 and VE4 have been documented by Boreen and Walker (1991) and Hadley (1992), and so it is not surprising that the surfaces continue into the study area. Although no well log correlations are presented to illustrate this, comparison of Hadley's (1992) cross sections with well logs from the current study area suggest that the VE3 and VE4 surfaces do, in fact, continue into the area. VE4 locally overlies subaerially exposed deposits; so VE4 could be interpreted as an amalgamated LSE/TSE, or FS/SB in the terminology of Van Wagoner *et al.* (1990). VE3 is also locally mantled by pebbles, but no evidence of subaerially exposed deposits were found in the underlying strata. The pebbles may have been supplied by a lowstand event, followed by a subsequent transgression. The presence of the *Glossifungites* ichnofacies at both VE3 and VE4 also supports their interpretation as surfaces of allostratigraphic significance- they do represent hiatal surfaces, but their exact nature and temporal scale is not known. Regardless, both VE3 and VE4 can be interpreted as unconformities.

VE3 can be interpreted as an ?LSE/TSE, but at the very least, it is a TSE. The only modification to Hadley's (1992) allostratigraphy is the possible presence of the VE3.5 surface. VE3.5 may represent an LSE because of the slight basinward shift in facies manifest by the abrupt change from FA1 to FA2. Pebbles locally associated with VE3.5 also support a lowstand component and the highly burrowed material (Facies 3) or thinly interbedded Facies 5 material that commonly overlies the pebbly material could be interpreted as the initial transgressive deposits. Therefore, VE3.5 could appear to be a simple LSE, an LSE followed by transgression, or an amalgamated LSE/TSE. It should be reiterated that pebbly material at or near the FA1/FA2 contact (*i.e.* VE3.5) is not common, but is quite common over very small areas with tight core control. The nature of the conglomerates themselves is problematic because some sedimentary fabric or texture that might help elucidate their origin may be obscured simply due to the limitations imposed by small diameter cores. Alternatively, the pebbles may have been supplied by major storm events and subsequently reworked by oscillatory currents. In this scenario, VE3.5 would not have an allocyclic significance. Figure 5.2 illustrates the variation by representing the interval between VE3 and VE4 [*i.e.* Allomember D of Hadley (1992)] as one, or potentially two parasequences. If VE3.5 is an LSE or LSE/TSE, then the interval between VE3 and VE4 represents two parasequences (see Fig. 5.2). The internal stratigraphy of Hadley's (1992) Allomember D may be more complicated than originally thought.

5.22 Allocyclicity versus autocyclicity

Throughout this thesis, it has been stressed that the key surfaces documented may not, in fact, represent much, if any, missing time. Examination of arenaceous foraminifera within the study interval and area supports the notion of only minor missing time (C.R. Stelck, pers. comm., 1994). For this reason, the VE3, VE4 and ?VE3.5 surfaces are consistently referred to as discontinuity surfaces that are interpreted to be unconformities. These discontinuity surfaces have been interpreted as LSEs, amalgamated LSE/TSEs *etc.*, but the temporal sense of the surfaces remains a mystery. If the limited biostratigraphic data is essentially correct, then the importance of autocyclic variations inherent to depositional systems must be considered. It is postulated that, although VE3 and VE4 are certainly key surfaces, inclusion of the biostratigraphic data suggests that the variations may be of an autocyclic nature as opposed to larger scale allocyclic phenomena. For example, if a deltaic model were employed, what may appear as a flooding surface in core may have resulted from autocyclic deltaic lobe shifting as opposed to a basinwide marine transgression. It is important to bear these types of factors in mind when interpreting any series of sedimentary rocks.

If autocyclic variation within a deltaic model is correct, then one would expect to see en echelon, lobate sand body geometries along strike cross sections. Unfortunately, the erratic nature of the well log responses in the uppermost Bow Island/Viking would make such documentation difficult (*cf.* Fig. 5.1). If the occurrences of Facies 7 represent reworked fluvially derived sediment in an overall deltaic model, then the interval between VE3 and VE4 would represent one parasequence (see Fig. 5.2). Furthermore, in order to investigate the amounts of missing time, one would have to sample shales from a larger number of cores at closer sampling intervals. This is the only way that statistically meaningful biostratigraphic data is attainable. Without the biostratigraphic control, the interpretation of key discontinuity surfaces as unconformities is, at best, speculative.

5.3 ICHNOLOGY AND SEDIMENTOLOGY

5.31 Depositional environments

The nature of the ichnology and sedimentology of FA1 indicates deposition in an upper offshore to distal lower shoreface setting. Deposition is dominantly from suspension, with sand largely supplied by storm generated translatory currents. The diverse and abundant trace fossil assemblage is typical of the *Cruziana* ichnofacies and indicates well oxygenated, fully marine conditions. The thoroughly burrowed sediments reflect fairweather deposits; the one to fifteen centimetre thick sandstones represent preserved distal storm beds that are commonly colonised by opportunistic endobenthic biota. Thinly interbedded Facies 5 reflects the change from the open marine conditions of FA1, to the pronounced restricted marine conditions of FA2.

The ichnology and physical sedimentary features of FA2 indicate deposition in a wave dominated lower shoreface to middle shoreface environment. The effects of storms are indicated by the widespread preservation of amalgamated hummocky and swaly cross stratified sandstones. The ichnofossils are less diverse and far less abundant than in FA1, presumably in response to environmentally harsh conditions. The ichnologic signature suggests that the most significant stress during FA2 deposition was depleted oxygen levels. The episodic, "quick bed" nature of sand deposition, salinity fluctuations, and water turbidity also contributed to the environmental stress.

Discrimination between wave dominated lower shoreface deposits related to strandplains and those associated with wave dominated delta fronts is exceptionally difficult, however, it is suggested that the ichnologic and sedimentologic aspects of FA2, namely: drastically reduced burrowing intensity, a reduced ichnofossil assemblage, ubiquitous synaeresis cracks, soft sediment deformation features, and micro-faulting, may favour interpretation of a wave dominated delta front setting with periodic fluvially derived input rather than a strandplain. As previously stated, Facies 7 occurrences are extremely localised; at least two localised pods of these occurrences are found within the study area (*e.g.* ~T29, R22w4 and ~T27, R20w4).

Using a deltaic interpretation for FA2 may also explain the anomalous occurrences of Facies 7. It is suggested that the local occurrences of Facies 7 represent loci along a delta/shoreline trend that were point sources of coarser material brought to the shoreline by fluvial systems. This type of scenario could also be employed to explain the many examples of extremely rapidly deposited sediment (*i.e.* some of the "anomalous" facies). It is important to keep in mind that the Bow Island/Viking Formation within the study area is essentially a sandy system with some conglomeratic material. The sedimentology and interpretation of conglomerates are not well understood, particularly in subsurface studies. The conglomerates and "anomalous" facies are found in the study area, and two alternative interpretations have been presented to explain them, namely relative sea level fluctuations and a river influenced deltaic depositional model. A composite core litholog illustrating the depositional interpretations and their relationship to the major discontinuity surfaces is given in Figure 5.2.

It is also proposed that ichnology is a valuable tool in differentiating strandplain from deltaic environments, particularly where only lower shoreface sediments are preserved, because endobenthic organism diversity, abundance, and behaviour change rapidly in response to a myriad of environmental parameters which physical sedimentary processes are not sensitive to.

5.4 CONCLUSIONS

1. The allostratigraphy proposed by Hadley (1992) for the Harmattan area is applicable to this study but may require minor modification. The interval between VE3 and VE4, designated as Allomember D by Hadley (1992), may contain an internal LSE/TSE referred to in this study as VE3.5. If valid, the implication is that Hadley's (1992) Allomember D would have to be divided into two parasequences as opposed to one parasequence [using the terminology of Van Wagoner *et al.* (1990)] as suggested by Hadley (1992).

2. Although VE3, VE4 and VE3.5 represent individual correlatable surfaces, their origins may be of an autocyclic rather than an allocyclic nature. As interpreted, the surfaces likely formed in response to relative sea-level fluctuations, which were most likely tectonically driven. The limited biostratigraphic sampling indicates that the surfaces may not represent significant amounts of missing time (C.R. Stelck, pers. comm., 1993); for this reason, interpretation of the surfaces as autocyclic in origin cannot be ruled out. Detailed microfossil work may clear up this uncertainty.

3. The uppermost Bow Island/Viking Formation represents progradational shoreface and deltaic deposits within the study area.

4. Detailed ichnological analysis shows distinct trace fossil assemblages representative of both open marine wave dominated shoreface (*i.e.* FA1), and restricted marine, wave dominated delta front (*i.e.* FA2) environments.

5. The use of detailed ichnology, in concert with rigorous sedimentologic analysis provides a powerful tool for the discrimination of delta front deposits from strandplain-related shoreface deposits, particularly where little or no data exists for their respective correlative updip deposits.

TYPICAL GEOPHYSICAL WELL LOG RESPONSE

BOW ISLAND/VIKING FORMATION,
WAYNE-ROSEDALE AREA
14-35-26-20W4

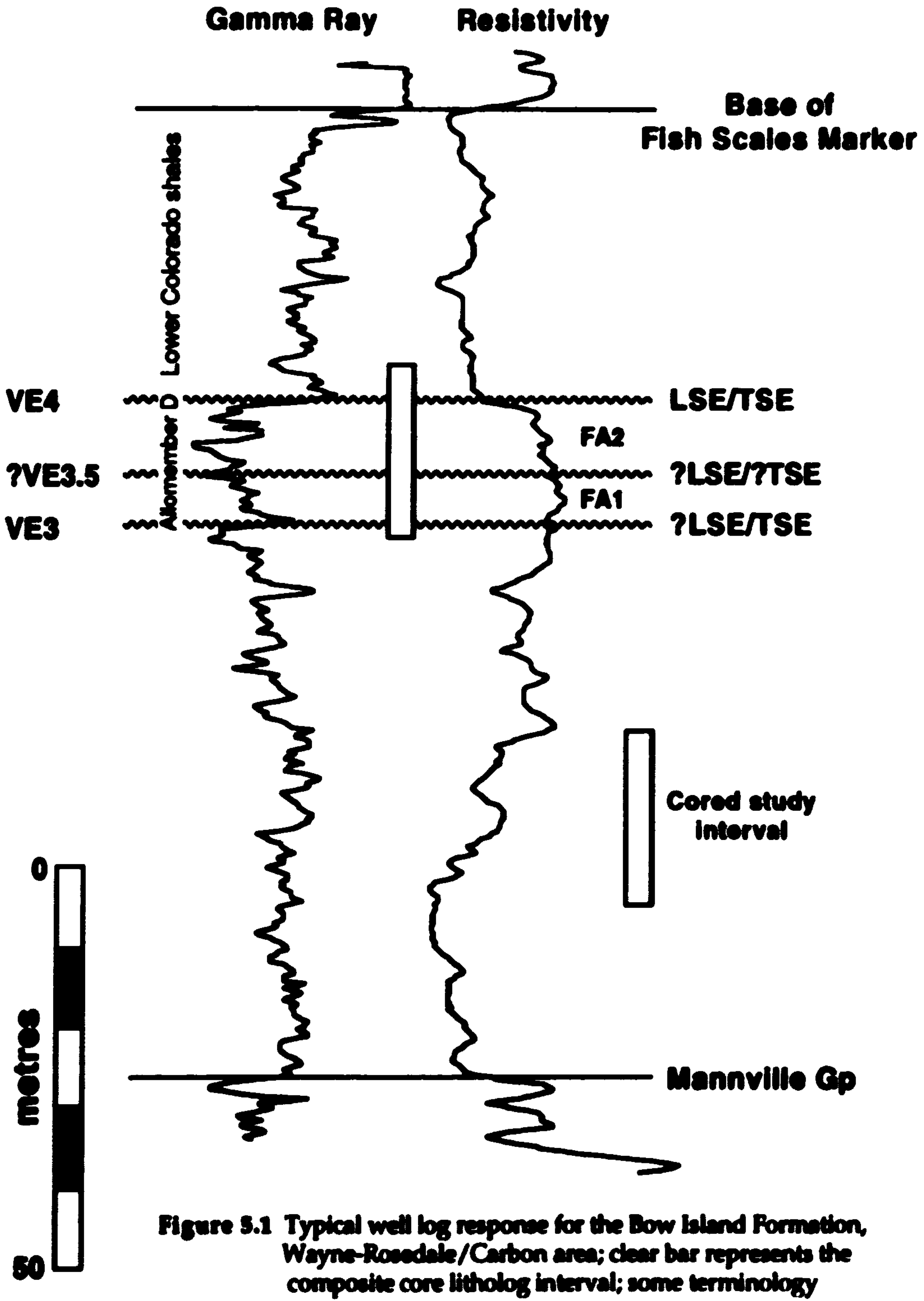


Figure 5.1 Typical well log response for the Bow Island Formation, Wayne-Rosedale/Carbon area; clear bar represents the composite core litholog interval; some terminology modified from Hadley (1992)

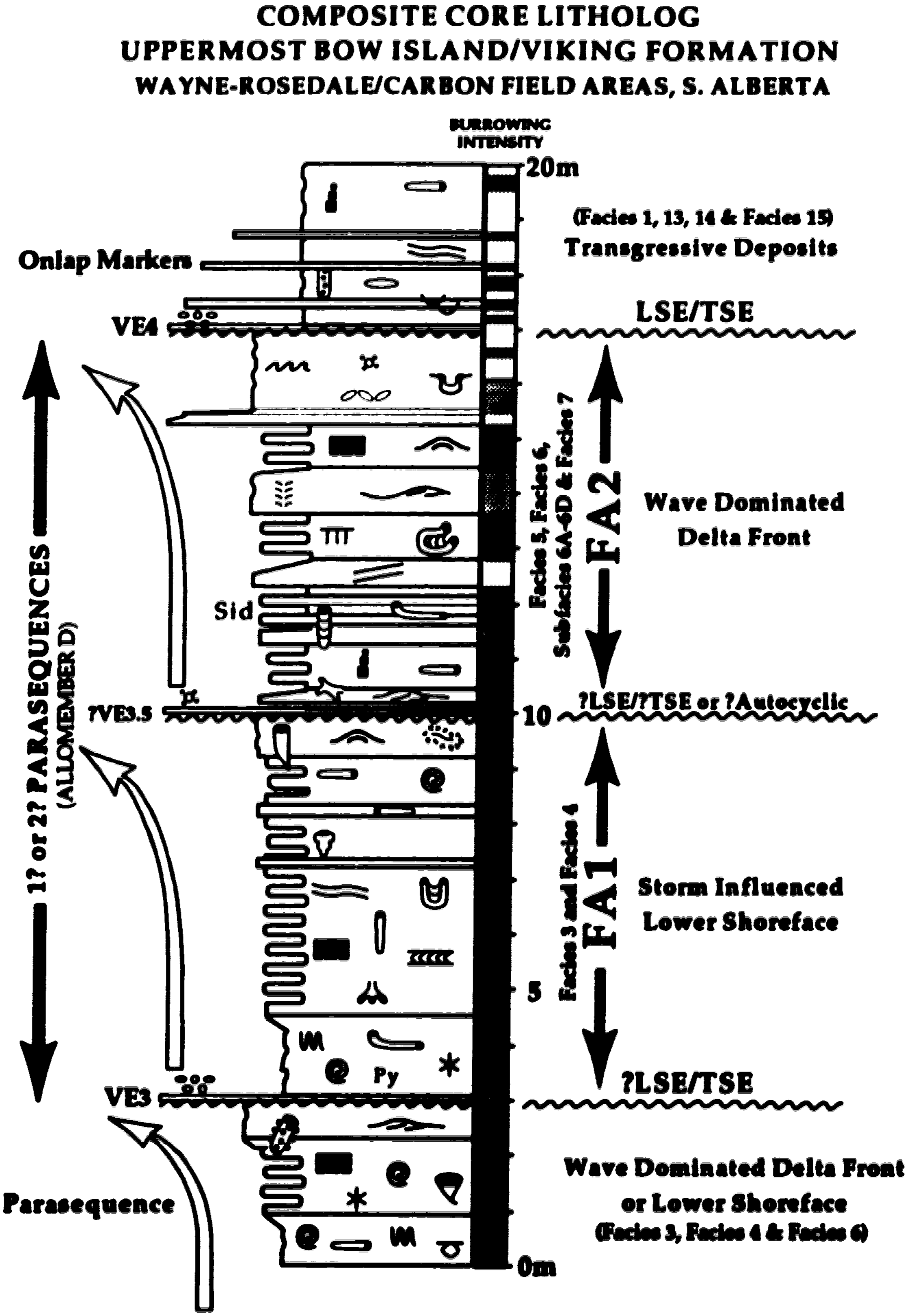


Figure 5.2 Composite core litholog illustrating Facies Associations, depositional environments, key surfaces, and correlative nomenclature of Hadley (1992)

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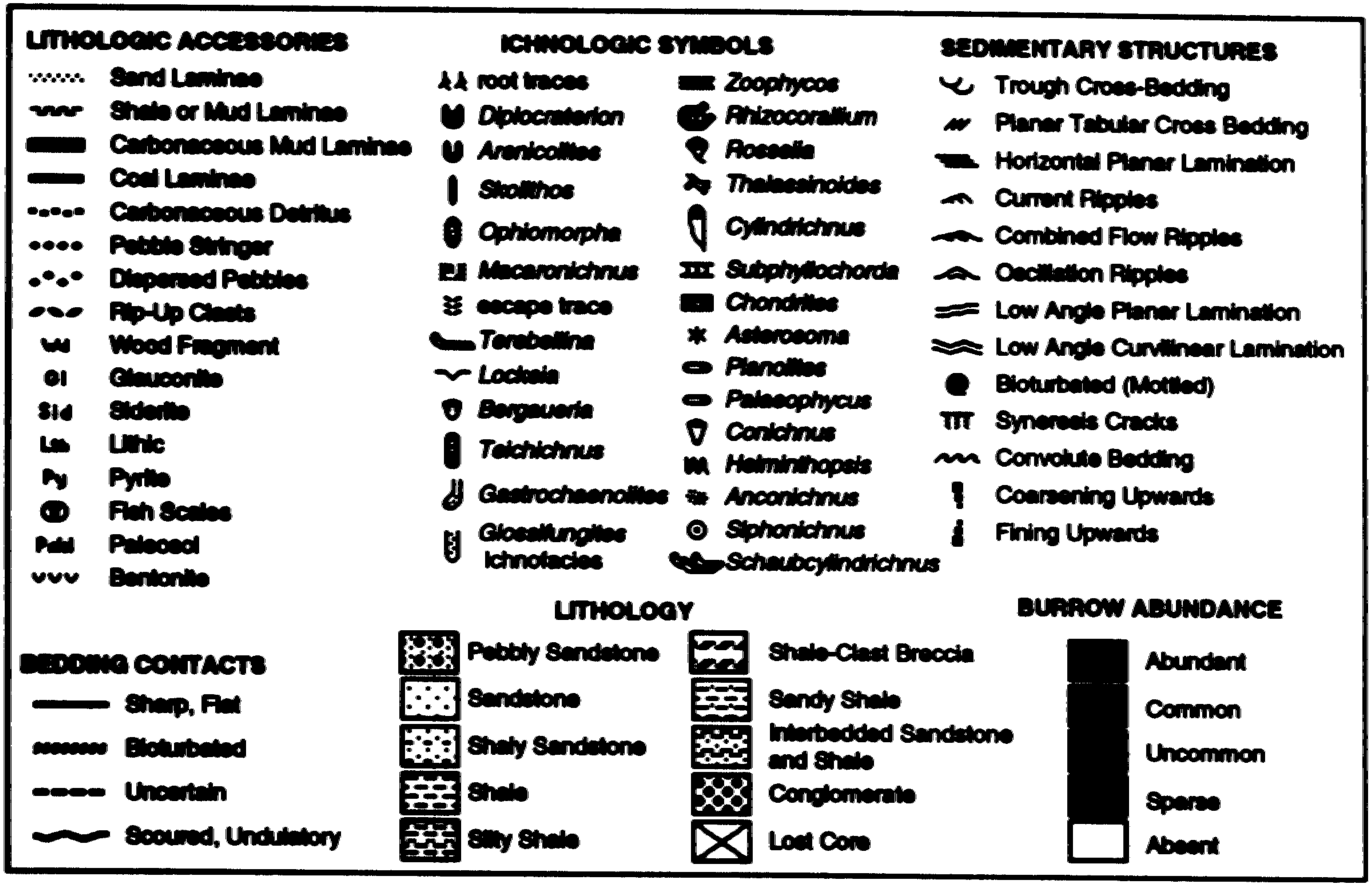
APPENDIX: CORE LITHOLOGS

The following appendix contains drafted lithologs for 64 of the 69 cores that were logged as a part of this study. The following page contains a legend, and is followed by the lithologs. The vast majority of the lithologs are from cores logged from Township 22-29, Range 18-22W4. A few of the lithologs, however, are from Township 22-29, Ranges 17, 23, 24 and 25W4. Each litholog's location is clearly labelled at the top. Most of the lithologs are longer than a page; so each litholog is continued in successive pages. The following is a list of locations and depths for the cores' lithologs which are included in this appendix [all locations are west of the fourth meridian (*i.e.* "W4")]:

14-11-22-24	1336-1362m	07-16-26-22	4105-4202'
11-09-22-25	4750-4779'	10-21-27-17	3374-3457'
06-27-22-25	4789-4806'	06-09-27-18	1119-1137m
06-07-23-17	3286-3321'	07-01-27-19	3768-3808'
06-01-23-18	3277-3299'	11-15-27-19	3818-3870'
07-20-23-18	3385-3435'	06-29-27-19	3750-3775'
11-15-23-23	4530-4572'	07-01-27-20	3903-3954'
06-02-24-17	3185-3215'	10-14-27-20	3800-3860'
11-29-24-17	3525-3575'	06-18-27-20	3827-3872'
10-05-24-18	3615-3655'	06-22-27-20	3759-3811'
07-30-24-19	3795-3855'	06-23-27-21	3780-3830'
08-05-24-20	3765-3821'	10-01-27-22	1215-1233m
06-15-24-20	4010-4105'	14-22-27-22	1268-1286m
10-34-24-20	3872-3919'	06-15-27-23	4253-4305'
02-36-24-22	4075-4140'	11-21-28-17	3590-3650'
07-36-25-18	3665-3725'	09-29-28-20	3840-3970'
10-02-25-20	3851-3911'	09-14-28-21	3952-4004'
07-07-25-20	3950-3985'	11-22-28-21	4060-4089'
06-17-25-20	3927-3987'	15-16-28-22	1268-1280m
06-06-26-18	1226.2-1244m	11-17-29-18	1098-1116.25m
06-09-26-18	1185-1203m	07-01-29-19	3645-3765'
10-14-26-18	1174-1192m	10-16-29-20	3725-3774.5'
08-20-26-18	1209-1227m	07-01-29-22	4022-4072'
06-25-26-18	1170-1188m	07-04-29-22	4080-4165'
16-08-26-19	1220-1238m	07-07-29-22	4190-4230'
08-14-26-19	1242-1251.2m	06-09-29-22	1251.2-1274m
16-21-26-19	1284-1302m	06-19-29-22	4175-4220'
08-22-26-19	1267-1285m	06-21-29-22	4100-4150'
08-17-26-20	1226-1237m	07-27-29-22	4080-4155'
16-25-26-20	1215.3-1234m	06-25-29-23	1295.8-1323.8m
07-35-26-20	4012-4054'	10-14-29-24	4300-4346'
06-36-26-20	1209-1227m	07-01-29-25	1451-1476.25m



Legend of Symbols used in Lithologs shown in Appendix.

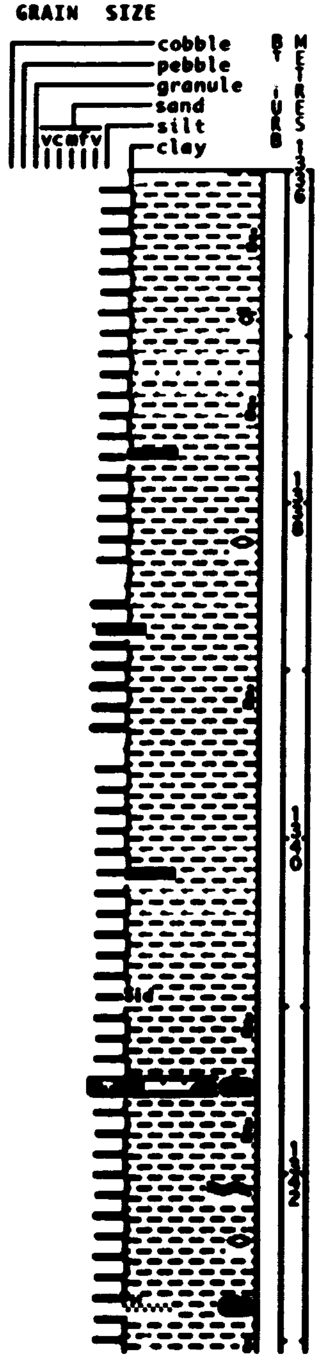
NOVALTA et al NAMAKA
14-11-22-24w4

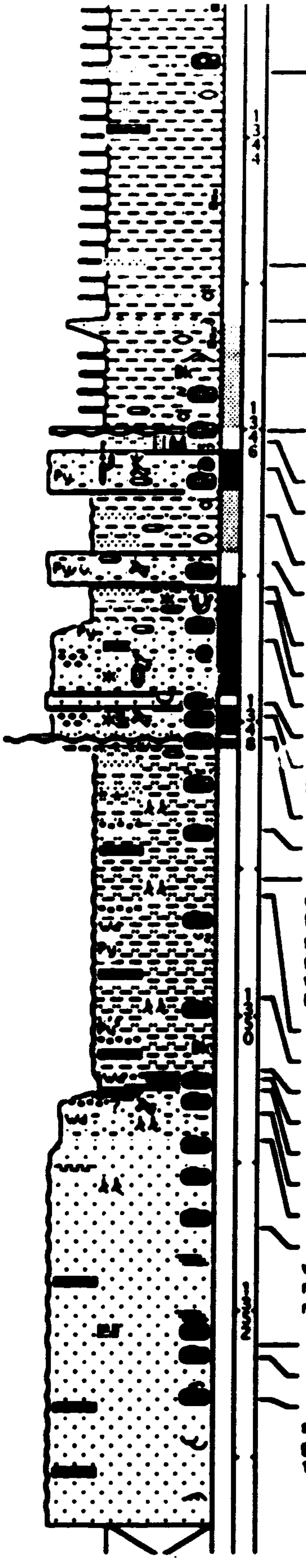
Date logged: December 17, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 914.60 m KB: 918.60 m

Remarks: Core 1, 16 boxes, 1336-1354m, Rec. 17.56m; Core 2, 8 boxes, 1354-1362m, Rec. 8m; 4" full diameter core; well on depth and excellent recovery; photogenic; occurrence of palaeosol, organic-rich shales etc.; upper ~2.4m not box shot





2-3cm thick discontinuous lens of fg-mg salt and pepper sandstone

5mm scale bed of fg-mg salt and pepper sandstone

mottled shaly fg sandstone with apparent ?oil staining

UNIT 19: rarely burrowed shale dominated interbedded vfL sandstone and shale; sand lenses are discontinuous on the scale of the core because they are so thin (mm scale), sharp based fining up; vague remnant wavy parallel and oscillation ripple laminae

UNIT 18: 2-3cm thick bed of dispersed mg sand with possible Glossifungites surface at base with Diplocraterion habichi shafts subtending from the surface

UNIT 17: essentially dark black shale with minor interstitial silt

UNIT 16: similar to UNITS 10, 12 etc. (~muddy transgressive facies B of MacEachern, Bechtel, and Pemberton 1992.)

UNIT 15: friable shale with minor mm scale discontinuous fg-mg sand lenses; Planolites

UNIT 14: mottled sandy shale; Asterosoma, Planolites, otherwise similar to UNITS 10 & 12; ripped up bit of bentonite

thin bentonitic horizon

UNIT 13: mottled sandy shale; sand is mg salt and pepper sand, loading/small guttercasts

UNIT 12: essentially the same as UNIT 10

UNIT 11: thin mg possibly cross bedded salt and pepper sandstone

UNIT 10: mottled shaly sandstone, scattered pebbles granules; highly burrowed; also may be Subphyllochorda; Palaeophycus heberti; dispersed pebbles/granules

UNIT 9: sandy conglomerate; maximum pebble diameter 2.1cm rounded chert pebbles

uppermost ~56cm is unequivocal palaeosol horizon

UNIT 7: essentially a blocky dark mudstone with mm scale silt/vfL sand stringers; unburrowed; rootlets, pyrite, coal fragments, lots of organic detritus, wood fragments; passes from dark grey/black, into grey, into green/grey into green/yellow colour; dark grey/black and grey portions are the original depositional facies (?non-marine overbank or ?floodplain); green/grey cemented colour sandy portion is probably in the process of podsolisation (?with water table rising), and the green/yellow stuff as being the actual palaeosol horizon; rare quite large Planolites near top

upper ~1m is grey/green (mostly green)

basal 50cm is black, passing gradationally up into the same facies but grey in colour

U6/U7 Contact

UNIT 6: organic-rich shale; tonnes of finely comminuted organic detritus; coaly fragments

U5/U6 Contact

UNIT 5: shaly mottled sandstone; roots; organic detritus; coaly fragments

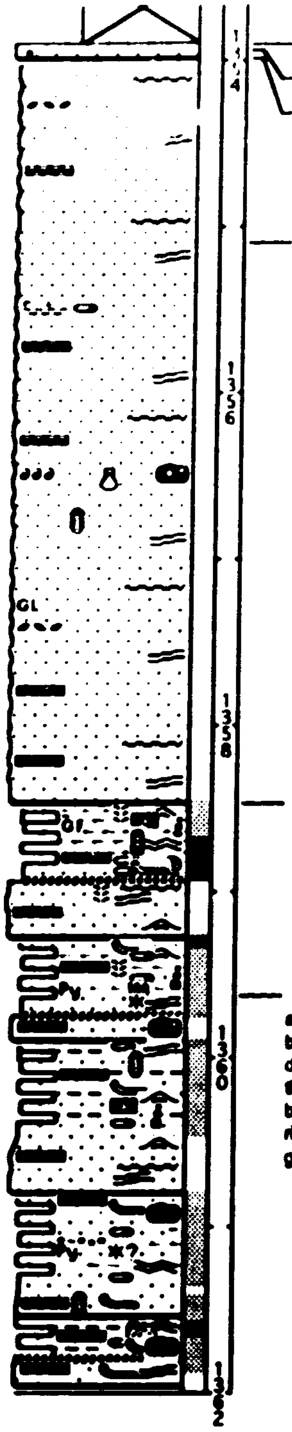
U4/U5 Contact

UNIT 4: probable foreshore/?beach with mg sand; dominantly planar parallel type laminations with rare hint of very low angle planar parallel laminations (?wedge sets); upper 60cm is rooted, mottled and shalier; small Macaronichnus segregatis ~15cm above basal contact as well as right at the U3/U4 contact

lots of Macaronichnus just above the contact

U3/U4 Contact: upper shoreface/foreshore contact

UNIT 3: probable upper shoreface/delta front; fU-mU sand; small scale current ripples; small scale cross bedding (largest set ~3-4cm thick); commonly draped by organic detritus; may not get good thick trough cross bed sets due to the sand grain size (MacEachern, pers.comm., 1992); subtle but relatively sharp upper contact



top of core 2

single 5mm diameter pebble

U2/U3 Contact: lower-middle shoreface/upper shoreface contact

UNIT 2: amalgamated lower to middle shoreface storm-generated SCS sandstone beds (fL-fU); low angle inclined stratification with common low angle truncation surfaces; rare burrowing; local shaly rip-ups; lots of organic detritus accentuating the laminae; some coaly rip-ups; rare burrowed shaly zones; rare small Pelecypod shell halves

U1/U2 Contact

UNIT 1: essentially FA2 with the interbedded zones being rarely to moderately burrowed with a sparse ichnofossil assemblage of small trace fossils, with sharp based fining up sandstone beds with oscillation ripples and wavy parallel laminations; sand beds 1-6cm thick; organic detritus; pyrite
thicker sandstone beds: generally sharp based fL with burrowed or gradational tops; some beds with oscillation ripples, others pass from low angle inclined stratification into oscillation ripples and on into essentially unburrowed organic-rich shales; organic detritus; minor glauconite

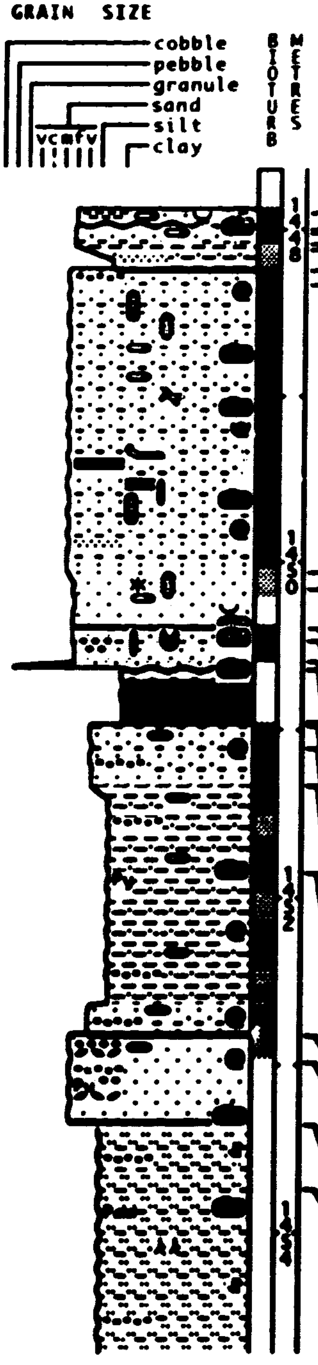
PCP Caresland
11-9-22-25w4

Date logged: March 30, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 938.20 m KB: 941.80 m

Remarks: basal portion not photogenic; gets better upwards
Core 2; 8 boxes, 4" full diameter core, has non-marine facies
4750-4779', Recovered 29', have box shots
no idea where I am on the logs...



UNIT 15: cross bedded sand at base that is more burrowed upwards, with Planolites in the mud streaks, Palaeophycus...

U14/U15 Contact

UNIT 14: similar to U12

U13/U14 Contact

UNIT 13: basically a dark shale with thin stringers of mg-cg sand

U12/U13 Contact

UNIT 12: Thoroughly burrowed shaly sand, shale very friable
- traces include robust Terebellina, Palaeophycus, Planolites, Thalassinoides, Zoophycos, Teichichnus, Ophiomorpha(in sandy lenses), Skolithos(may be another cryptic Glossifungites surface); local lenses of up to cg sand(all salt and pepper)

U11/U12 Contact

UNIT 11: cross bedded fg sandstone
- with Asterosoma(?), Ophiomorpha(?), and/or Palaeophycus; more burrowed upwards

U10/U11 Contact

UNIT 10: Thoroughly burrowed shaly sand
- like transgressive facies B of JAM; scattered pebbles decrease upwards; maximum pebble is 2.5cm diameter, well rounded and chert and lithics; possible cryptic bed junction near top with Glossifungites type Skolithos and Diplocraterion habichi shafts

U9/U10 Contact

U8/U9 Contact: probably transgressive, with 2.5cm diameter pebbles lying on it

U7(Coal)/U8(organic-rich shale) Contact

U6/U7(Coal) Contact

UNIT 6: same as U5 but sandier

U5/U6 Contact

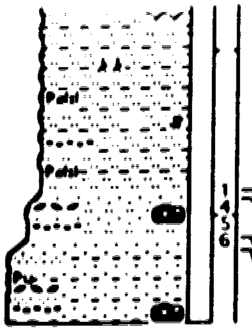
UNIT 5: mostly sandy shale with a minor sandy shale component at unit base, quite mottled but only Planolites seen, similar appearance to U2, with lots of coaly fragments

U4/U5 Contact

UNIT 4: fg "salt and pepper" sandstone
-cross bedded at base with rounded rip-up clasts of shale and sideritised shale (so they look like pebbles); more churned appearing upwards; Planolites near top

U3/U4 Contact

UNIT 3: Grey Palaeosol
- full of swelling clay; waxy texture; possible leached roots; evidence of pedogenic slickensides; some coaly debris near the base; minor disseminated organic material



U2/U3 Contact

UNIT 2: Sandy siltstone

- small coaly fragments; appears churned but no identifiable trace fossils

U1/U2 Contact

UNIT 1: Churned fU-mL "salt and pepper" sandstone

- copious coal rip-ups, coal fragments, wispy shale rip-ups, churned appearance but no discernible trace fossils, local pyrite

PCP Carsland
6-27-22-25w4

Date logged: March 30, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 942.10 m   KB: 945.80 m

Remarks: Core 2; 8 boxes, 4789'-4806'; Recovery 17.5' (probably 4786'-4804'); 4" full diameter core
Nice FA2 with plentiful Terebellina and some coarser than normal sandstones; photogenic; have box shots of basal 4 boxes

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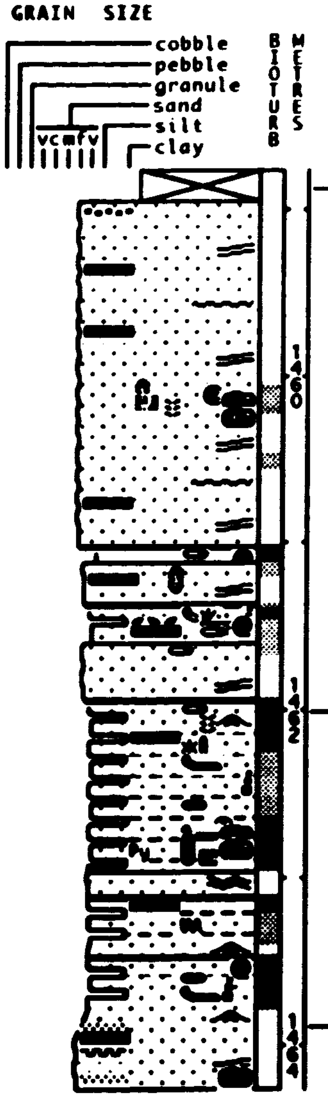


whole well is FA2

typical burrowed portion of FA2: Terebellina is by far the dominant trace in sands and muddy parts, Asterosoma, Teichichnus, Helminthopsis extremely rare; sparse Chondrites-Planolites in dark muds

storm sandstone with alternating laminae of fU and fL sand with organic detritus, large partially sideritised ripped up intraformational clast at base

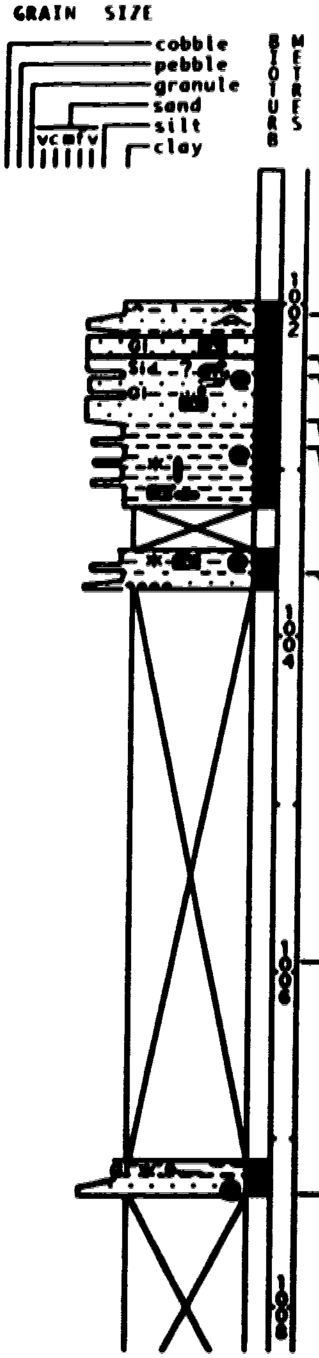
Cdn.Exp.Gas Ohio Mid.Cdn. Gem
6-7-23-17w4

Date logged: July 26, 1990

Logged by:

Ground: 797.40 m KB: 801.00 m

Remarks: 3 core boxes (out of order), 1" core, 3286'-3321', very poor recovery; not a reliable well; not photogenic; no box shots or any photos for this well



UNIT 7: Interbedded vf Sandstone and Shale
- more thickly bedded and continuous vf sandstone beds(3-9cm) than anywhere else in the core with oscillation ripples and getting up into the higher angles indicative of a current influence (i.e. combined flow ripples)
- sub-vertical mud-lined, sand filled trace (?Cylindrichnus or truncated ?Rosselia)

U6/U7 contact

UNIT 6: Burrowed Interbedded vf Sandstone and Shale
- ?Rhizocorallium or ?Zoophycos at top; also siderite

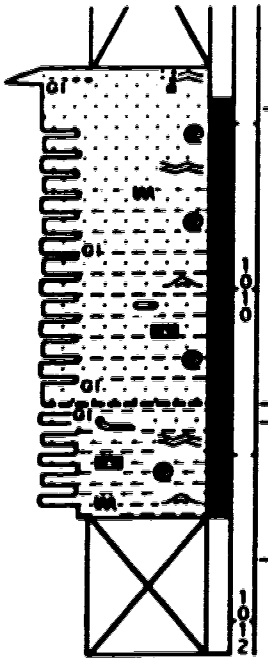
U5/U6 contact

UNIT 5: Burowed Interbedded Shale and vf Sandstone

UNIT 4: Burowed Interbedded vf Sandstone and Shale

Core 4: Rec. ~2.0' of drilling mud

UNIT 3: Burrowed Interbedded vf Sandstone and Shale



UNIT 2 Burrowed Interbedded vf Sandstone and Shale
- no real sandstone beds until the top 15cm of unit where there is a relatively continuous - 10cm thick sandstone bed that is overlain by vc/granules that fines upwards into mg sand to vf sand to shale

U1/U2 "contact"

UNIT 1: Burrowed Interbedded vf Sandstone and Shale
- rare Terebellina, Chondrites, lots of Helminthopsis; sharp based 1-3cm thick sandstone beds (oscillation rippled/wavy parallel bedded) with burrowed tops

GENERAL NOTES:
Core 1: 3286'-3288' No Rec. Core 2: 3288'-3293' Rec.-4.2'
Core 3: 3293'-3300' Rec.-2.0' Core 4: 3300'-3305' Rec.-2.0'
Core 5: 3305'-3310' Rec.-1.0' Core 6: 3310'-3316' Rec.-6.0'
Core 7: 3316'-3321' Rec.-2.3'
NB: where there is unrecovered core, it has been assumed that the core loss was at the bottom of the core

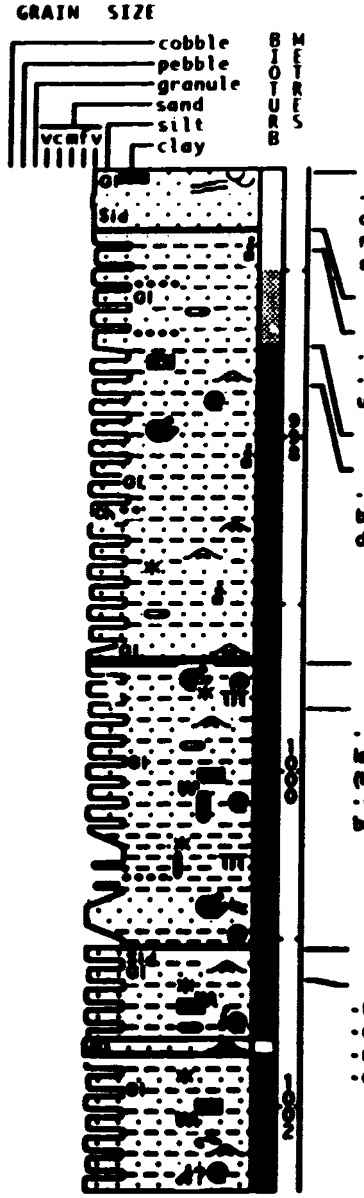
Cdn. Exp. Gas Ohio Mid. Cdn. Gem 6-1
6-1-23-18w4

Date logged: July 25, 1990 (great day!, poured with rain...)

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 791.90 m KB: 795.50 m

Remarks: Cores 1-3, 3277'-3299'; 3 boxes; 1" diameter core; relatively good recovery; fairly photogenic; no box shots or other photographs of this well



UNIT 5: Low to High Angle Laminated vf Sandstone with rare Shale wisps
- very top of unit is getting higher angle (cross?) laminations with coaly ripped up material; base of unit with some siderite and very low angle laminations with "coffee grounds" type organic material accentuating the laminations; well sorted glauconitic, almost exclusively vfU sandstone

U4/U5 contact

UNIT 4: Interbedded vf Sandstone, Siltstone and Mudstone
- interbeds on ~1-2cm scale, sharp based vf sand beds that grade normally into silts & muds
- rare burrowing, chert pebble stringer(avg.~0.5cm diameter)visible on bedding plane near base unit; top 26cm of unit is unburrowed

U3/U4 contact

UNIT 3: Burrowed Interbedded vf Sandstone, Siltstone and Shale
- chert pebble stringer(maximum ~1cm diameter; average ~0.5-0.6cm diameter), some sharp based normally graded, oscillation rippled beds preserved; rare higher angle laminations(~20 degrees)- probably indicating some current component(i.e. combined flow rippling)

U2/U3 contact

UNIT 2: Thoroughly Churned Interbedded vf Sandstone and Shale
- fewer preserved oscillation rippled beds than unit 1; Rhizocorallium here, more Chondrites and less Helminthopsis in this unit; some rare vertical to sub-vertical "mud lined" Skolithos (truncated ?Rosselia), possible Teichichnus
- unit above is similar except for the fact that there are many more sharp based normally graded beds preserved due to a huge decrease in the amount of burrowing

U1/U2 contact

UNIT 1: Churned Interbedded vf Sandstone and Shale
- the sand is very well sorted, almost all vfU, quartz, mafics, glauconite
- quite thoroughly burrowed, possible ?Phycodes
- rare 2-3cm thick/continuous oscillation rippled vf sandstone beds
- one 10cm oscillation rippled vf sandstone bed; siderite in top 5cm of unit

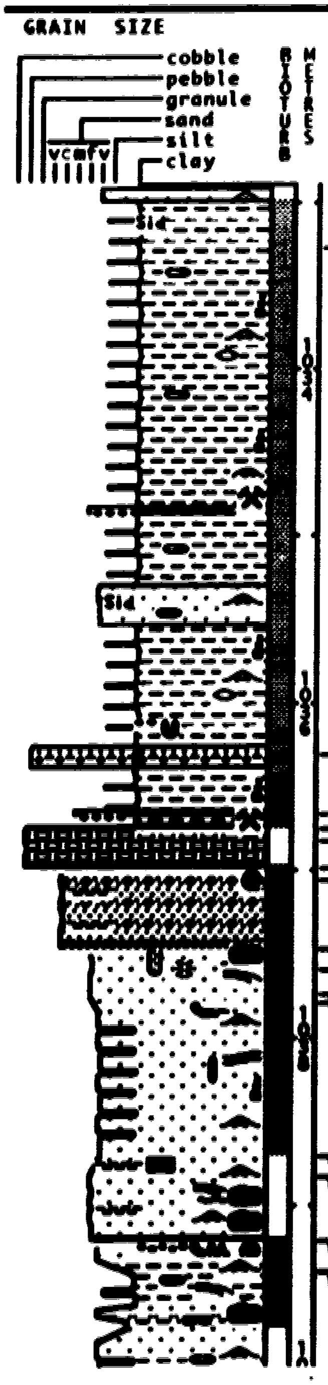
CPOG HUSSAR
7-20-23-18w4

Date logged: July 6, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 821.40 m   **KB:** 826.00 m

Remarks: Core 1; 10 boxes, 3385'-3435'; 3.5" full diameter core; reasonably photogenic, have box shots and prints



UNIT 21: Interbedded Shale, Siltstone and Sandstone
- small scale oscillation/combined flow ripples; patchy sideritisation; rare burrowing; siltstone/vf sandstone interbeds are bedded on a scale of mms to 1cm and are rarely continuous across the scale of the core

Gritty, pebbly poorly sorted Shale; chert pebbles(black, well rounded, maximum ~1cm diameter and lithic fragments)
- looks "transgressive"

mg salt and pepper sand bed with chert granules (average ~0.5cm diameter)

U20/U21 Contact

UNIT 20: Clast Supported Conglomerate
- maximum pebble ~1.4cm diameter, average ~0.5cm diameter; matrix is mg-cg sand; pebbles are chert and lithic fragments; generally sub-rounded to sub-angular grains

U19/U20 Contact

UNIT 19: Pebbly coarse grained Sandstone with Shale
- poorly sorted; many grains quite angular; no discernible trace fossils but appears mottled; some granules/pebbles interspersed (maximum ~8mm diameter)
- may be a part of a transgressive deposit (probably with some erosion associated)

U18/U19 Contact

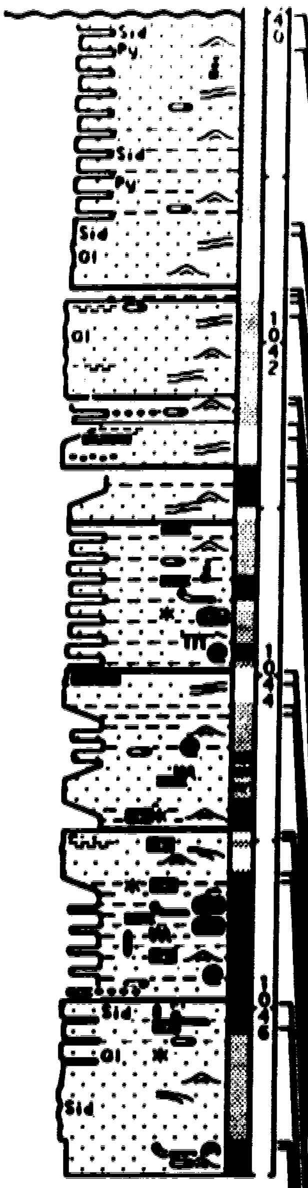
UNIT 18: Oscillation Rippled (probably HCS?) vf-fL Sandstone
- possible Glossifungites "surface" at top with coarser sand being piped down into a vf, tightly compacted sandstone

U17/U18 Contact

UNIT 17: Interbedded Sandstone and Shale; beds are all very sharp based

U16/U17 Contact

UNIT 16: vf Hummocky Cross Stratified Sandstone (HCS)



- rare shale drapes with Chondrites, Planolites, low angle truncations

U15/U16 Contact

UNIT 15: Interbedded Sandstone and Shale
- abundant burrowing where mud dominates, sand beds are sharp based and are oscillation rippled to HCS, probably deposited by intermittent storms; sand interbeds are beginning to be more thickly bedded(5-7cm); pebble stringer is very odd

?possible "VE3.5"; do have increased burrowing intensity above...

UNIT 13: Interbedded Sandstone and Shale
- oscillation rippled/HCS(?); sandstone beds 5-10cm thick separated by 1-4cm thick jet black muds that are rarely burrowed with Planolites; all beds are very sharp based; possible synaeresis cracks near unit top??
capped by UNIT 14: Poorly sorted clast supported Conglomerate
- maximum pebble size ~2.3cm diameter; chert pebbles; matrix is vl-cL sand

U12/U13 Contact

UNIT 12: same as UNIT 10 essentially
grain size varies slightly and it's subjective as to call these units vl or fL

U11/U12 Contact

UNIT 11: Dark Shale

U10/U11 Contact

UNIT 10: LAIS vl-fg Sandstone

U9/U10 Contact

UNIT 9: Interbedded Shale and Sandstone; all beds are sharp based; 2cm thick pebbly zone at base

U8/U9 Contact: with pebbly bed at base

UNIT 8: LAIS vlL-fL Sandstone
- coaly rip-ups; organic rich laminae; no low angle truncations seen

U7/U8 Contact

UNIT 7: Interbedded Sandstone and Shale
- more thickly bedded and less burrowed than the underlying interbedded sandstone/shale units (2-7cm thick sandstones as opposed to intensely burrowed or 1-2cm thick sandstone beds below)

U6/U7 Contact

UNIT 6: Well Sorted vlL-fL Sandstone
- very low angle inclined stratification, no hummocks or truncations; almost planer parallel stratification; some thin(1mm) organic laminations accentuate the stratification

U5/U6 Contact

UNIT 5: similar to UNIT 3 but with less burrowing and more sandstone in areas

U4/U5 Contact

UNIT 4: Sandstone(vf) with Low Angle Inclined Stratification (LAIS)
- the possible HCS sandstone beds are very sharp based however overall, the transition from the interbedded shale/sandstone to LAIS sand beds is relatively gradational

U3/U4 Contact

UNIT 3: Interbedded Shale and Sandstone(vlL-fL)
- lots of traces and good diversity(outer Cruziana); these weird traces that look like REALLY robust Chondrites-photo taken in a unit above(Jambo thinks they're like Asterosoma but I think they're way more like Chondrites; regardless, this trace seems to reflect some complex feeding strategy; NB- likely Asterosoma, less likely as Phycodes)

U2/U3 Contact

UNIT 2: Sandstone with Burrowed Shaly Interbeds
- LAIS(HCS? but not really thick enough ~10cm bed); possible autocyclic Glossifungites with Skolithos and siderite at unit top
- more medium scale interbedded sandstone and shale in upper ~40cm

U1/U2 Contact

UNIT 1: Burrowed Interbedded Shale/Sandstone

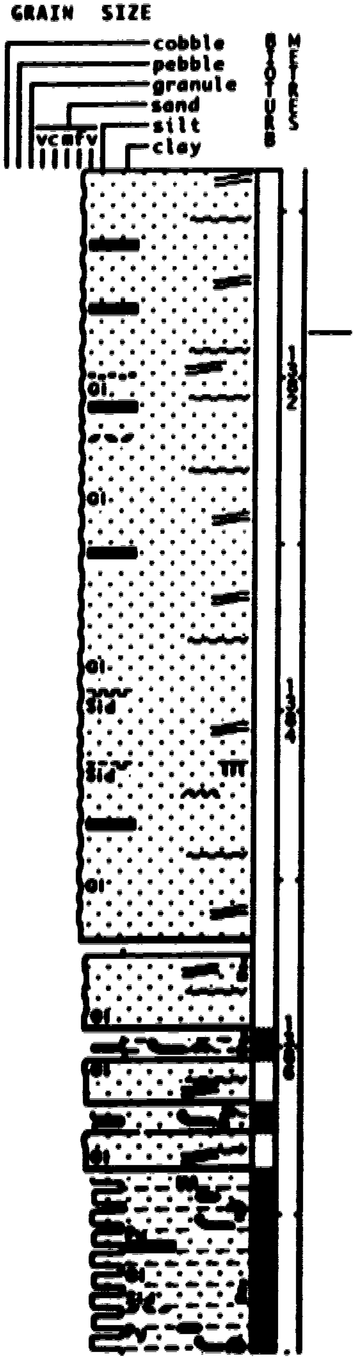
KIDD HAMMERHILL
11-15-23-23w4

Date logged: December 12, 1991

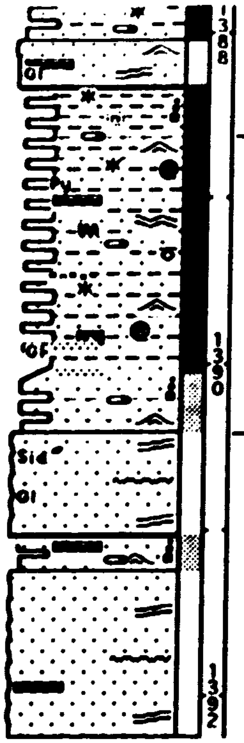
Logged by: ©1993 Indraneel Raychaudhuri

Ground: 975.40 m KB: 979.00 m

Remarks: Core 1; Boxes 1-9, 4530'-4572', Rec. 42' (actual recovery 37.75', therefore basal ~4.25' lost core); BFS 4420' or 1347.22m, tough to hang on log since no Colorado transgression and no gamma-ray log is available; photogenic



this whole core is probably FA2 to transitional FA2
- interbedded portions: sands sharp based and commonly normally grade upwards with oscillation to combined flow rippling
- thick bedded sands: low angle parallel laminations that are commonly truncated by low angle scour surfaces(5-10 degrees); coarser and more organic material in the upper 1.5m of core, local zones of sideritised rip-ups, angular shale clast rip-ups some of which appear to have long synaeresis cracks in them, local soft sediment deformation with well developed ball and pillow type structures



in this zone of interbedded vf sand and shale, rare burrowing in basal 35cm, overlain by a 40cm thick Chondrites dominated zone, and above here is almost solely burrowed by Asterosoma, with minor Helminthopsis, and probable Anconichnus horizontalis

possible flooding surface/parasequence boundary'/?

Grizzly CPOG Gem
6-2-24-17w4

Date logged: November 19, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 798.60 m   **KB:** 802.50 m

Remarks: 3.5" full diameter core; photogenic; excellent example of ball and pillow structures with associated fining upwards conglomerate; Core 1; 7 boxes; 3185'-3215'; not sure if core is on depth, but there is full recovery; box shots

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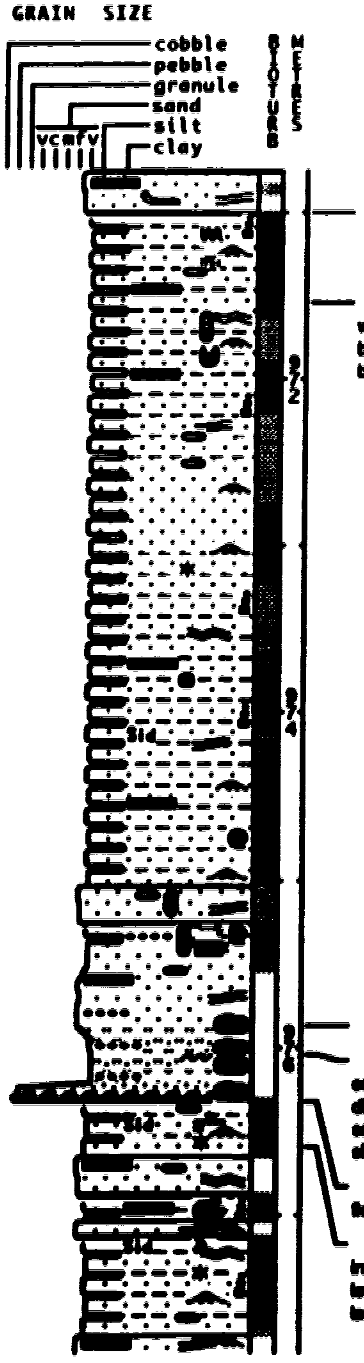


possibly Schaubcylindrichnus although they don't touch and are small

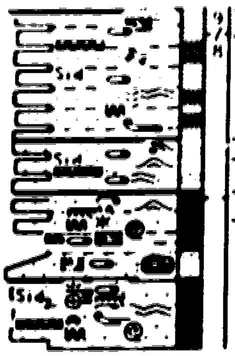
UNIT 6: essentially medium bedded FA2 with sharp based fining up vf sand beds 1-6cm thick with low angle parallel to wavy parallel to oscillation and combined flow ripple laminations; near base there are a few thicker storm-generated sandstone beds that can be fL and commonly are burrowed by an opportunistic suite of trace fossils

U6/U5 Contact

UNIT 5: looks like one mondo event bed that fines upwards from clast supported conglomerate at base (3-6cm rounded pebbles at very base into average granules to 0.5cm diameter rounded to subrounded pebbles) into a pebbly/granuley vf sandstone into a vf sandstone with scattered granules into a totally deformed/ball and pillow structured sandy siltstone with scattered granules and pebbles

U4/U5 Contact: base of contact reveals 5cm diameter rounded pebble ("VE3.5"?? or a grain flow associated with delta front turbidites??)

UNIT 4: medium bedded interbedded vf sandstone and shale with rare to moderate burrowing intensity with local patches of moderate; average sandstone beds 1-4cm beds with ~3 thicker low angle inclined storm-generated sandstone beds with organic detritus accentuating the laminae



U3/U4 Contact

UNIT 3: similar to U2 but is moderately burrowed, local sideritisation, some of the preserved 1-4cm sandstone beds are actually fL in grain size

U2/U3 Contact: drastic change in burrowing intensity, also slightly thicker bedded sandstones

UNIT 2: thin bedded interbedded sandstone and shale, vf sandstone beds 1-4cm thick with wavy parallel to oscillation to combined flow rippling; sharp based fining up beds capped with organic-rich sparsely burrowed shales with Planolites, rare small Palaeophycus in the sandstone beds; like FA2 but thinner bedded (whole core is within FA2 transitional to FA2)

U1/U2 Contact: drastic change in burrowing intensity

UNIT 1: moderately burrowed thinly interbedded vf sandstone and shale, moderate mottling; local zones of almost nil burrowing, storm bed with Macaronichnus; lots of those silty concentrically laminated Asterosoma; interbedded portion has 1-3cm thick preserved sand beds (some fL) with remnant wavy parallel to oscillation ripple stratification

HB P AM ET WINTER H A11-29
11-29-24-17w4

Date logged: July 12, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 857.40 m   KB: 861.70 m

Remarks: Core 1; 11 boxes, 3525'-3575' (1074.42-1089.66m); Hussar/Countess area; OK photogenic; have box shots and prints; cores lower, regional Viking cycles

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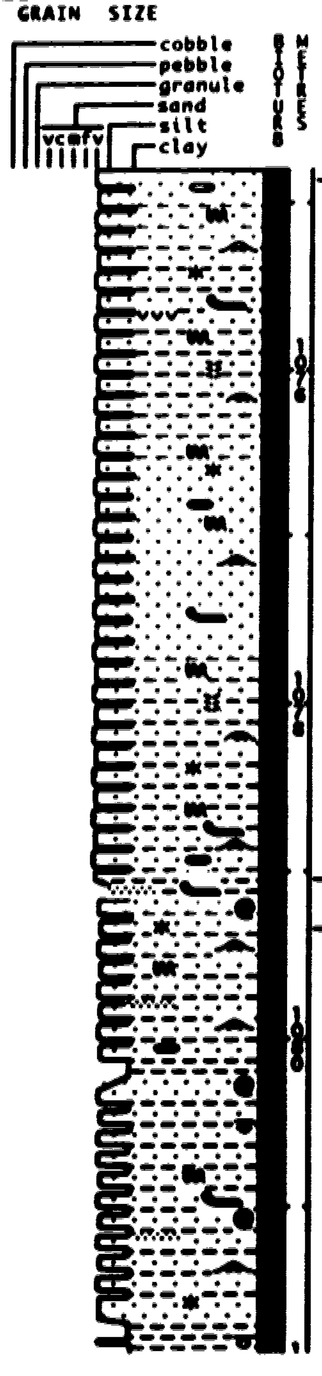
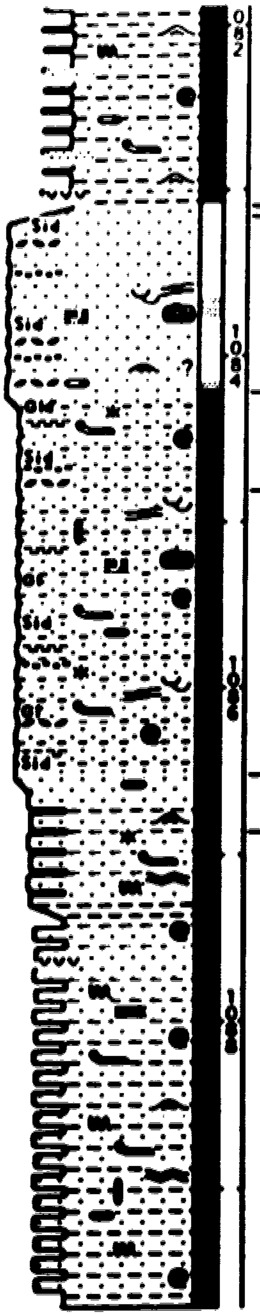


UNIT 5: Interbedded vf Sandstone and Shale
- continuation of the overall sanding upwards sequence; possibly some more of those enigmatic wispy Trichichnus-like things
- sand beds commonly 3-5cm thick and oscillation to combined flow rippled
- rare escape traces in the oscillation rippled vf sandstone beds indicating rapid deposition (storm emplacement ??)

U4/U5 Contact

UNIT 4: Interbedded Shale, Sandstone and Siltstone
- vf sandstone/siltstone beds interbedded on the scale of mms to 1cm with thicker sand beds upwards (3-5cm thick); not abundant traces



U3/U4 Contact

UNIT 3: Apparently Massive mL Sandstone with Siderite
- hints of low to high angle cross bedding but mostly appears massive
- possible Macaronichnus; possibly ?combined flow rippling

U2/U3 Contact

UNIT 2: Shaly fg Glauconitic Sandstone with rare Cross Bedded Interbeds
- very similar to Chigwell association of facies 4/5a; traces more robust than below; Terebellina, Planolites, Asterosoma(small), Skolithos, possible Macaronichnus
- angular to rounded shale/sideritised shale rip-ups; "wispy" mud streaks; slightly less burrowing upwards

U1/U2 Contact

UNIT 1: Churned Interbedded Sandstone and Shale
- unit sands upwards slightly; vf sand; like Chigwell facies 3 (i.e. back-ground Helminthopsis facies); mostly Terebellina and Helminthopsis; swelling clays

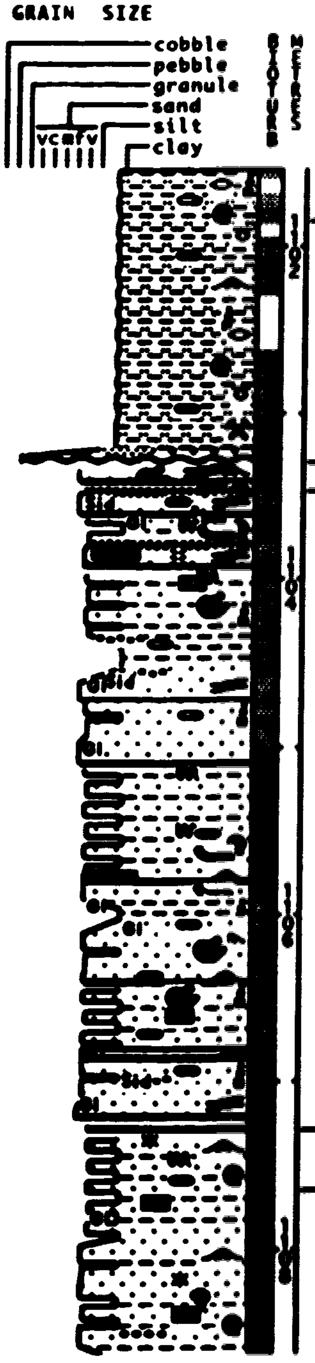
CZAR et al. HUSSAR
10-5-24-18w4

Date logged: August 15, 1990

Logged by:

Ground: 877.20 m KB: 880.30 m

Remarks: Core 1; 9 boxes, 1101.9m-1114m (3615'-3655'); photogenic; 3.5" full diameter core; have box shots and prints



UNIT 4: Dark Shale with mm scale sharp based siltstone/vf Sandstone "beds" that commonly grade normally upwards and are also commonly discontinuous on the scale of the core due to the burrowing

- scattered pebbles at base of unit=probable transgressive lag deposit, pebbles in a muddy to mg salt and pepper sand matrix, pebbles=chert and ?lithics, mostly sub-rounded, maximum ~0.8cm diameter

U3/U4 Contact

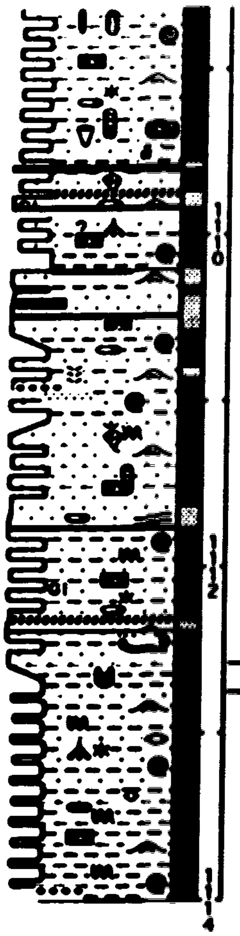
UNIT 3: Essentially Facies Association 2: Interbedded, Rarely Burrowed Normally Colour Graded vf Sandstone to Shale with thicker bedded Low Angle to Oscillation Rippled vf Sandstone Beds

- Interbedded portion: sharp based vf sandstone beds grade up into siltstone and shale with waning flow conditions, common small scale oscillation ripples, some minor burrowing: Rhizocorallium, Planolites, rarer Chondrites, tiny Terebellina, and Helminthopsis; appears to be a restricted offshore setting with probable brackish conditions (as evidenced by synaeresis cracks in this facies elsewhere as well as the restricted, impoverished marine trace fossil assemblage,
- Sandstone portion: oscillation to low angle undulatory laminations, beds are commonly sharp based with burrowed or gradational tops, glauconite, some local sideritisation, rare pyritised traces, some organic detritus highlighting the low angle laminations
- throughout unit there are coaly(ripped up??)fragments

U2/U3 Contact

UNIT 2: Essentially Facies Association 1: Burrowed Interbedded vf sandstone and shale with 2-12cm thick oscillation rippled Sandstones

- Interbedded Portion: way more abundant, thoroughly burrowed with a huge diversity of traces: small Terebellina, rare Teichichnus, ?Phycodes and/or Asterosoma, possible small(0.8cm tubes)vertical ?Ophiomorpha or Skolithos, Helminthopsis, Chondrites, ?Conichnus(some kind of plug anyway), Planolites, muddy truncated Rosselia(small: maximum ~1cm diameter shaft extending vertically ~2-3cm), "wispy" mud streaks could be ?Zoophycos, may even be a couple of [illegible] little Arenicolites and/or Diplocraterion[illegible]



[illegible]

- Sandstone Portion: Palaeophycus and escape traces common, oscillation rippled beds commonly with sharp to burrowed bases and commonly with burrowed or gradational tops, rare organic laminations
- a couple of zones with scattered granules(mostly lithics)/coarser sand

U1/U2 Contact

UNIT 1: Thoroughly Burrowed Interbedded Shale and vf Sandstone

- **1-3cm thick sand beds that are commonly discontinuous on the scale of the core due to burrowing(Helminthopsis, Chondrites, Planolites, ?Asterosoma or ?Phycodes, thin Diplocraterions near unit top), hint of oscillation rippling in the sands which commonly have burrowed bases and tops**
- **base of unit has some scattered granules(lithics and chert)**

CPOG Hussar
7-30-24-19w4

Date logged: March 25, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 893.40 m KB: 897.30 m

Remarks: Core 1; 13 boxes, 3795'-3855', ~ on depth; 3.5" full diameter core; moderately photogenic but no box shots or facies shots were taken; good portion of unnamed Colorado shales are cored in this well

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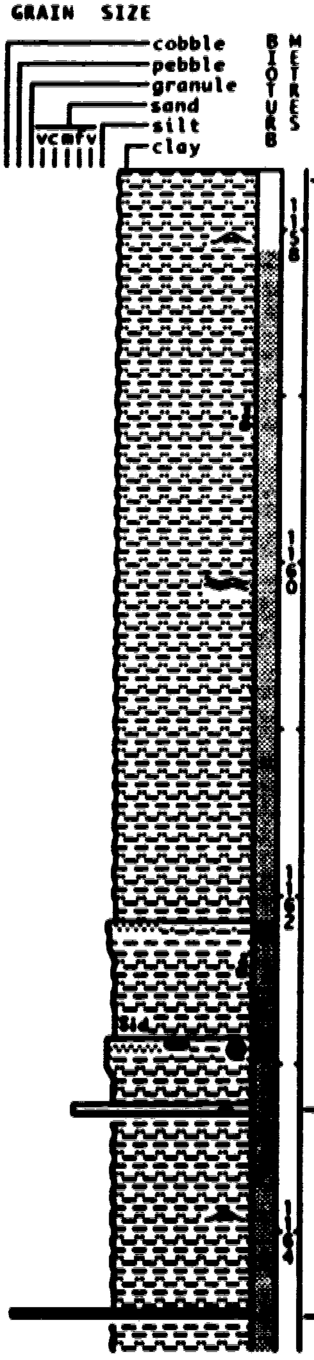
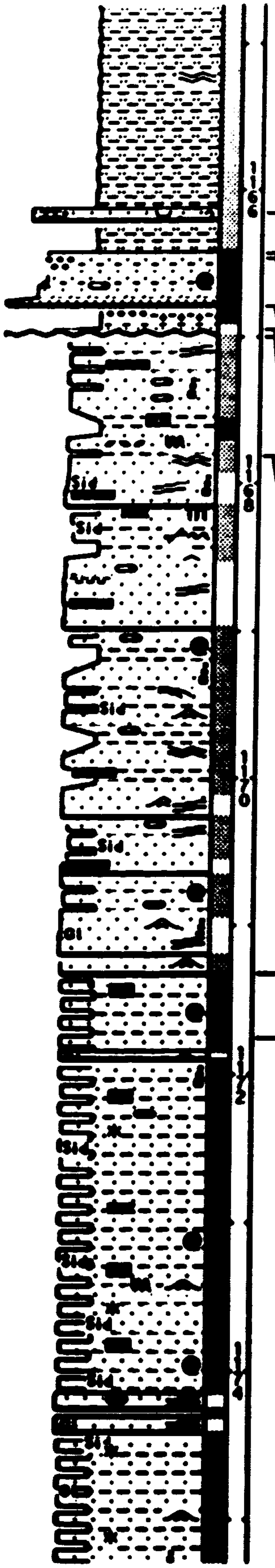


UNIT 6: Dark shale with mm to 5cm thick sharp based discontinuous siltstone/vf sandstone that show hints of wavy parallel to oscillation ripples
- several sub-units (very similar to the type of thing I called facies 7a at Chigwell)
- 2 zones of churned vf-lg sandstone
- local sideritisation of intervals up to 4cm thick
- **NB: may want to pull this core in the future to photograph a good portion of the unnamed Colorado shales with its sandy/pebbly sub-units; should also shoot these as close-ups (can't today because Bourak took the camera lenses)**

U6c: oscillation rippled vfU-fU sandstone with bluish colouration

U6b: sharp based conglomerate bed with mg "salt and pepper" sand matrix; maximum pebble is 2cm diameter, average 0.8-1.1cm diameter; chert pebbles; sub to well rounded; coarse



calcite cement

U6a: cg-vc granular sandstone
- apparently structureless, but vague hint of cross bedding; totally calcite cemented; a few pebbles (maximum 0.8cm diameter); subangular to subrounded grains

U5/U6 Contact

UNIT 5: Burrowed shaley mg sandstone
- basal 7cm is basically a pebbly sandstone with scattered granules and pebbles (chert; maximum 1cm diameter, well rounded) with a matrix of "salt and pepper" mg sand; matrix fines upwards into fine sand but scattered vc sand, granules and pebbles persist
- Planolites, possible Teichichnus??

U4/U5 Contact

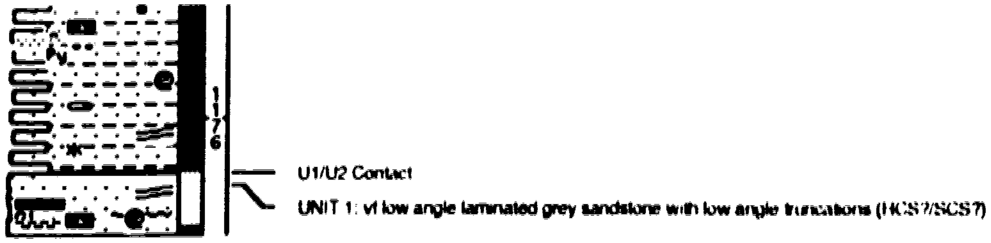
UNIT 4: Poorly sorted conglomerate
- mostly chert pebbles, most are well rounded, maximum 1.5cm diameter, average ~0.6-0.8cm, matrix from mg sand to minor mud
- rapidly up into mud with scattered pebbles, granules and sand

U3(~FA2)/U4 Contact (probably transgressive)

UNIT 3: essentially FA2
- little burrowing, locally abundant, Macaronichnus (simplicatus?) and Palaeophycus in the thick bedded sands; Chondrites in one small portion, Helminthopsis(?): I'm referring to those dark "Trichichnus-like" things that have significant vertical components and are mud filled in vf sand (may be Anconichnus?), Planolites
- some minor incipient sideritization in both mud and sand
- sands: low angle laminations up to ~15 degrees, lower angle truncations, preserved probable hummocks, oscillation ripples, 11-43cm thick, waning flow features capping
- interbedded portion: sands 1-10cm thick, normally colour graded

U2(~FA1)/U3(~FA2) Contact: sharp change in burrowing

UNIT 2: essentially FA1 with moderate to common burrowing in the interbedded portions, minor burrowing in the 5-10cm thick low angle parallel laminated to oscillation rippled vf sandstone beds
- 2 prominent vf sand beds with low angle parallel laminations with organic detritus 10, 11cm thick (similar but not as thick as sands in FA2)
- actually, not much trace diversity: mostly Chondrites, Asterosoma, some Planolites, very minor Helminthopsis(rare); small Palaeophycus and Zoophycos in sands
- minor incipient sideritization
- near base of unit is 20cm zone of dispersed mg-vcU sand/chert granules


1
1
7
6
U1/U2 Contact
UNIT 1: vf low angle laminated grey sandstone with low angle truncations (HCS?/SCS?)

CPOG HUSSAR
8-5-24-20w4

Date logged: August 13, 1990

Logged by: Indraneel Raychaudhuri

Ground: 868.10 m   KB: 871.70 m

Remarks: Core 1; 12 boxes, 3765'-3821' (1147.6m-1164.6m); 3.5" full diameter core; photogenic, have box shots and prints

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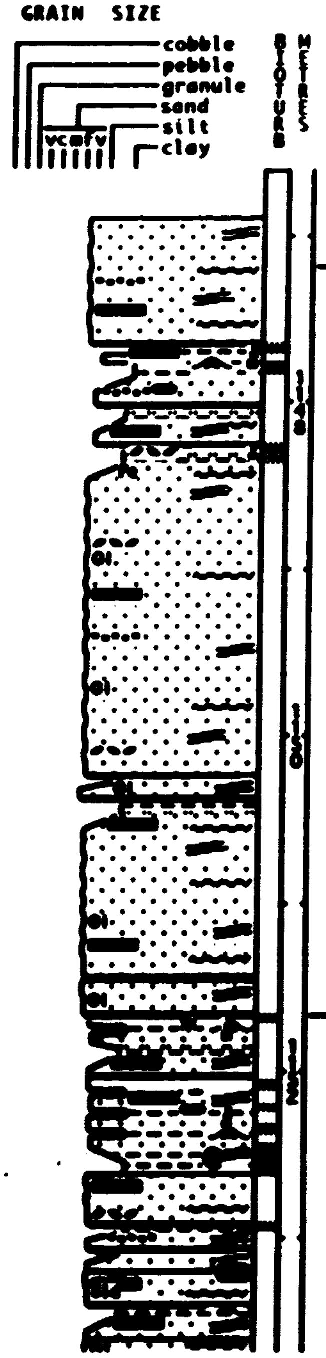
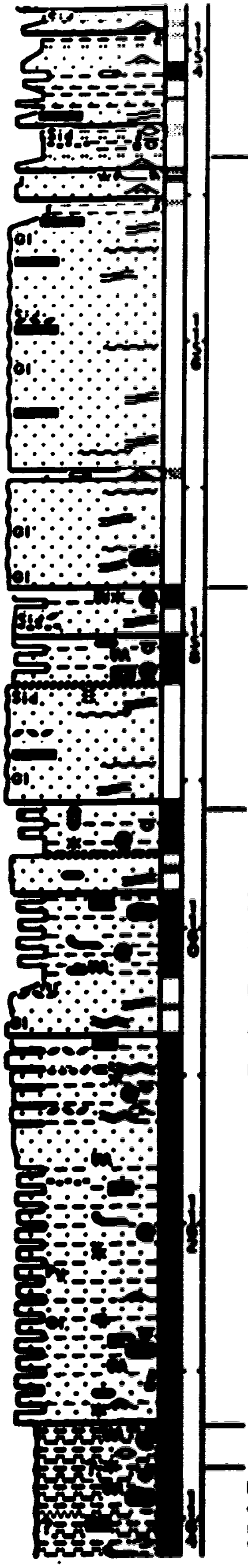


UNIT 3: Essentially Facies Association 2: Interbedded vf-fL Sandstone/Shale with thicker bedded vfU-fL low angle undulatory laminations

- Interbedded portion: rarely to moderately burrowed vf sandstone/siltstone and shale, mostly sharp based normally colour graded vf sandstone into organic-rich shale beds; this interbedded portion also commonly forms the waning flow part of the sequence above the thicker bedded vfU-fL sandstone beds, rare Planolites, even rarer tiny Terebellina(1mm diameter) and possible Asterosoma- HIGHLY RESTRICTED TRACE FOSSIL ASSEMBLAGE, rare synaeresis cracks (nice bedding plane views with spindle shapes)
- Thickly bedded Sandstone portion: low angle undulatory laminations with common low angle truncations(10-15 degrees), rare small scale oscillation rippled beds, glauconitic, lots more organic "coffee ground" detritus accentuating the laminae than in U2, common ripped up shale/ sideritized shale and coaly fragments, no easily visible traces

above here, go back into sandstone dominated FA2, with much more and thicker amalgamated storm-generated sandstone beds; a response to seasonally controlled depositional rates?, delta lobe switching?...



above here, there is a significantly thick portion of FA2 which is for all intents and purposes, shale dominated with fewer and thinner storm-generated sandstone beds

U2/U3(FA2) Contact: essentially nil to rare burrowing above here

UNIT 2: Essentially Facies Association 1: Interbedded burrowed vf sandstone/shale with more thickly bedded vf sandstone beds that are mostly low angle undulatory laminated
- Interbedded portion: quite burrowed but 3-5cm thick burrowed normally graded beds near unit base, gets sandier upwards, diverse trace fossils: lots of Helminthopsis, Chondrites, Asterosoma, rare ?Ophiomorpha (small, ~1cm diameter subvertical tube with hint of knobbled walls; may also be a truncated Rosselia "stem"), ?Trichichnus
- Sandstone beds: mostly low angle laminated with low angle truncations (laminations and truncations maximum ?12-15 degrees), glauconite, common ripped up angular shale/rounded sideritized shale clasts, rarer ripped up coaly fragments, rare pebbles, lower lg sandstone bed has pebbles, glauconite, ripped up coal; rare escape traces, Terebellina, and Palaeophycus in sandstone beds
- the thickly bedded sandstone beds are not characteristic of this facies association, but the U2/U3 contact has been picked in this well on the basis of the major change in burrowing style between facies association1(U2) and facies association 2(U3)

U1/U2 Contact

UNIT 1: Dark, Thoroughly Churned Silty Shale with rare thin siltstone to vfL sandstone beds/lenses
- rare lenses of vf sandstone/siltstone, commonly with loaded bases, no preserved sedimentary structures, highly burrowed, totally dominated by Helminthopsis, rare ?Chondrites, rare Planolites, rare ?Asterosoma, rare Terebellina(very small; mm scale

diameter)
- similar to the dark silty shale commonly seen above the transgression at the top of the Viking except that this is far more burrowed and lacks the scattered pebbles

TENN DI HUSSAR 6-15MU-24-20
6-15-24-20w4

Date logged: December 16, 1992

Logged by:

Ground: 885.70 m KB: 889.10 m

Remarks: 3.5" full diameter core; Core 1, 19 boxes, 4010'-4105'; only logging boxes 17/19 and upwards; probable depth of logged core is 4004.25'-4087.5'; actual thicknesses of units may be off slightly due to the dominantly shaly lithology; not box shot

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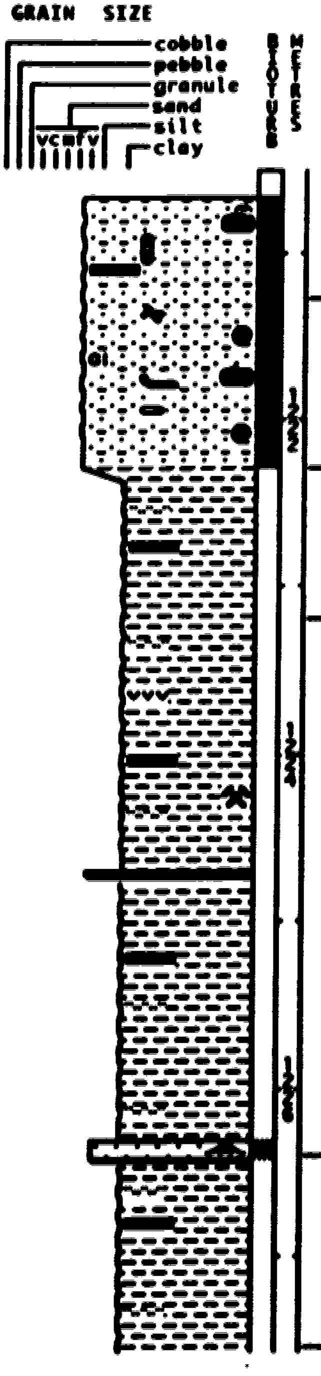


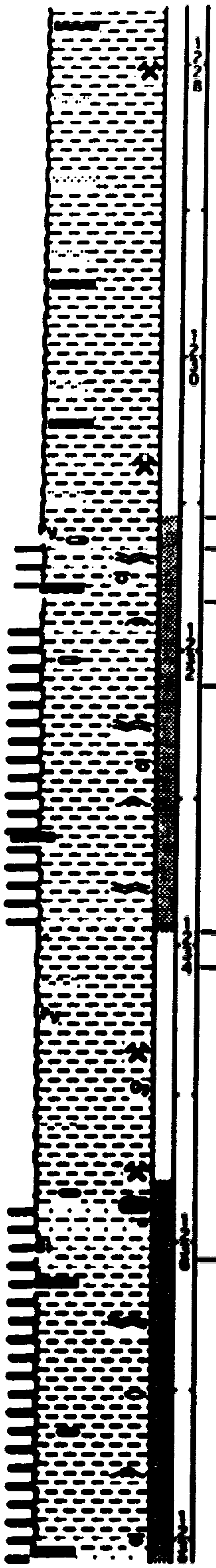
UNIT 20: totally thoroughly burrow mottled shaly sand; full of swelling (probably smectitic/bentonitic clay); traces visible are: Terebellina, Thalassinoides, Teichichnus, Palaeophycus, possibly ?Subphyllochorda; also glauconite, pyritised blebs, organic detritus; dominantly fL sand grain size; mostly has that "Teichichnus/Subphyllochorda-dominated" appearance

U19/U20 Contact

UNIT 19: essentially the same as UNIT 17 with the exception of 1 thin wavy parallel laminated vf sandstone bed; minor bentonitic horizon also

UNIT 18: oscillation rippled vfL sandstone bed

UNIT 17: dark grey shale; fairly high silt content; lots of organic detritus throughout unit; very



rare <1cm thick wavy parallel laminated vfL sandstone beds

U16/U17 Contact

UNIT 16: similar to U15 but with a little less sand %

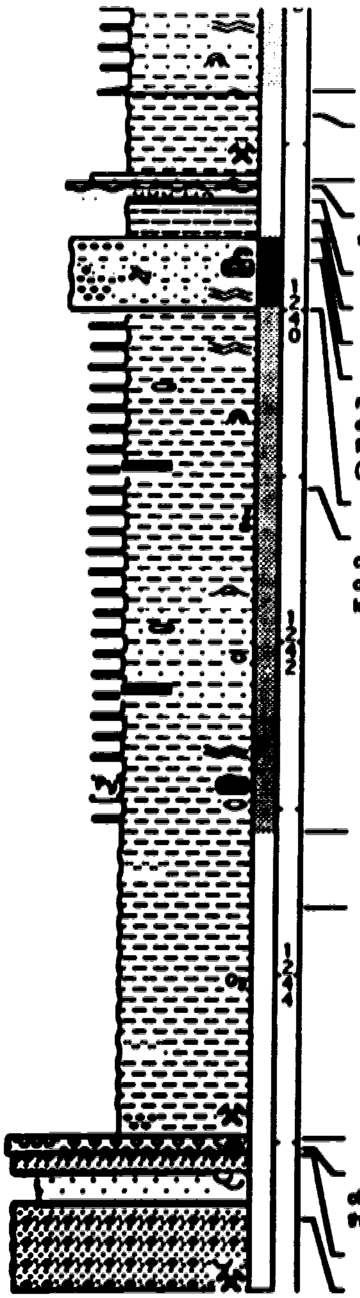
U15/U16 Contact

UNIT 15: essentially the same as UNIT 13; some vf sandstone beds oscillation to combined flow rippled; most sandstone beds †1cm thick but one bed is 6cm thick

U14/U15 Contact

UNIT 14: essentially the same as UNIT 3

UNIT 12: essentially the same as UNIT 4



may be out of place

UNIT 11 : dark grey shale

vf grained oscillation rippled sandstone (may be out of place)

mg sandstone with highly irregular lower contact with possible ?Glossifungites and siderite rip-up clasts, pyritic

siderite cemented shale

UNIT 6: Bentonite

U5/U6 Contact

UNIT 5: mottled shaly sandstone with scattered dispersed sub to well rounded chert pebbles, maximum 1.1cm diameter; scattered granules etc.; some large Thalassinoides; shale is extremely friable; sand is dominantly mg salt and pepper in appearance; ripped up coal fragments; this is transgressive "Facies B" of MacEachern, Bechtel and Pemberton, 1992 (MacEachern, pers.comm., 1992)

U4/U5 Contact: possibly a transgressive lag???

UNIT 4: interbedded shale and 20% vfL-vf sandstone in sharp based, commonly discontinuous mm-1cm thick sandstone beds with remnant wavy parallel and oscillation ripples; organic detritus can accentuate the laminae; lots of small scale soft sediment deformation, load cast ripples etc.; local blebs of pyrite

U3/U4 Contact

UNIT 3: dark grey shale; minor silt component; very broken up in boxes

U2/U3 Contact

UNIT 2: similar to below but appears mottled with more interstitial mud and larger subrounded chert pebbles; may be resumed transgressive reworking of uppermost Basal Colorado during the initial stages of the true major Joli Fou transgression

U1/U2 Contact

UNIT 1: cross bedded pebbly sandstone; highly glauconitic; mostly 2-4mm subrounded granules; matrix sand is mg; rare mg-cg sandstone bed interbedded with pebbly sandstone/conglomerate; probably the Basal Colorado sandstone

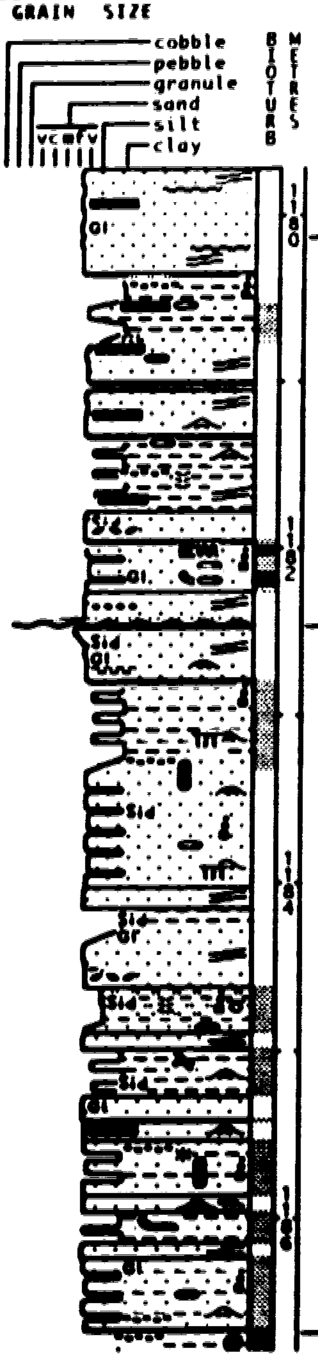
CPOG HUSSAR
10-34-24-20w4

Date logged: August 2, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 900.70 m   KB: 904.30 m

Remarks: Core 1; 10 boxes, 3872'-3919'; Colorado transgression not cored; photogenic; have box shots and prints



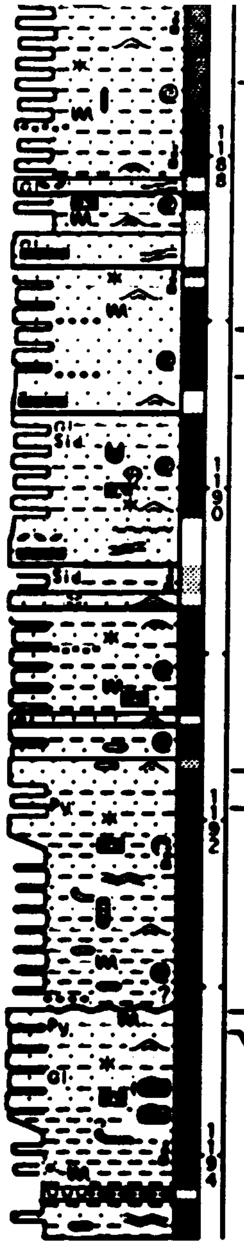
UNIT 4: Facies Association of Interbedded vf Sandstone/Shale with more thickly bedded vf Sandstone

- Sandstone Portion: low angle curvilinear laminations, small scale oscillation to combined flow ripples, apparent waning flow sequences and beds commonly have gradational tops into siltstone and into unburrowed organic-rich shale, above the thin conglomerate the sands have more organic "coffee grounds" detritus accentuating the low angle laminations and are more thickly bedded, some laminations get up into the 15-20 degrees range, possibly indicating some current influence (?combined flow rippling; NB: likely just low angle truncation still accountable for by the erosive nature of storm-generated oscillation to combined flow currents), local rip-ups of shale, sideritized shale or coaly/organic material, glauconite
- Interbedded Portion: rarely burrowed, synaeresis cracks, small and rare stressed Terebellina, Teichichnus, pyritized Planolites, sharp based 1-2cm scale normally graded beds that are commonly oscillation rippled

could be ?"VE3.5"?; but looks like it is simply at the base of a storm generated sandstone bed, with a few granules continuing up into the sand bed above, BUT the pebbles in the clast supported conglomerate are up to a maximum of 2cm diameter rounded chert pebbles and even larger sideritic clasts

- Conglomerate: very thin, clast supported (matrix=vf sand), poorly sorted, granules to rounded chert and ?lithic pebbles and organic/woody material (maximum- 2.5cm diameter), some "pebbles" are probably sideritized mud clasts, above conglomerate could technically be called a separate unit since above conglomerate the sands are thicker, can have burrowed tops(lam-scram?), more organics and the interbedded portions can be more burrowed by a higher trace fossil diversity

U3/U4 Contact



Rippled to Combined flow Rippled Sandstone(one bed low angle Curvilinear)
- Interbedded Portion: less burrowing upwards with corresponding increase upwards in sharp based normally colour graded oscillation rippled beds (one Rhizocorallium near top), one gritty cg-granules zone
- Sandstone portion: essentially all vfU with abundant interstitial clay content, glauconite, rare Terebellina, Palaeophycus, escape trace

looks like "transitional FA1/FA2"-type unit

?"VE3 5"?

Cheel and Leckie, 1992-type granules incorporated into a storm-generated oscillation rippled sandstone

U2/U3 Contact

UNIT 2: Interbedded Burrowed Shale and vf Sandstone
- similar to U1, but abruptly muddy at the base with pebbles (average ~0 3mm diameter) and then sands upwards from there

U1/U2 Contact (stacked sanding upwards cycles?): possibly "VE3" of the McMaster RGW group

UNIT 1: Interbedded Burrowed Shale and vf Sandstone
- thoroughly churned, lots of Helminthopsis, also Chondrites, Asterosoma, Terebellina, Planolites, possible ?Diplocraterion/?Teichichnus, 1-4cm thick vf sand beds that can grade upwards with hints of small scale oscillation ripples, a few scattered pebbles (maximum ~0.25 mm diameter), also some pebbles ~at unit top contact; bentonites this thick in this area typically underlie "VE3"

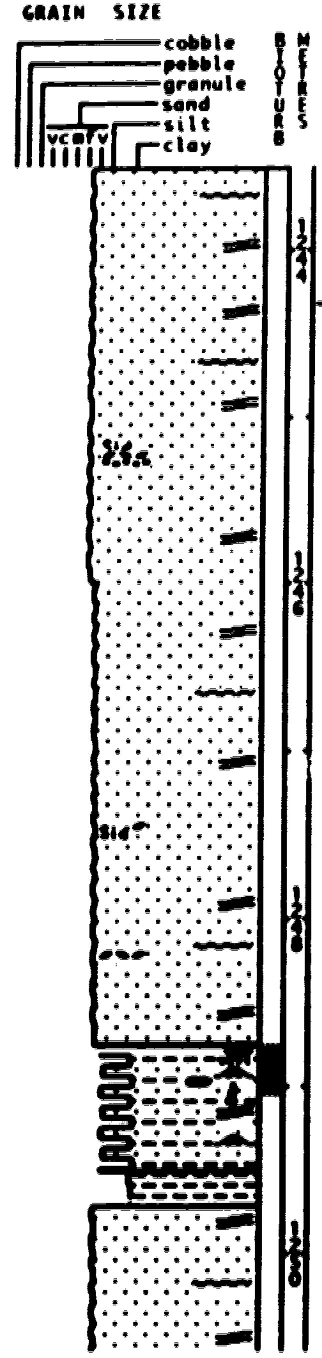
CPOG PARFLESH
2-36-24-22w4

Date logged: December 11, 1991

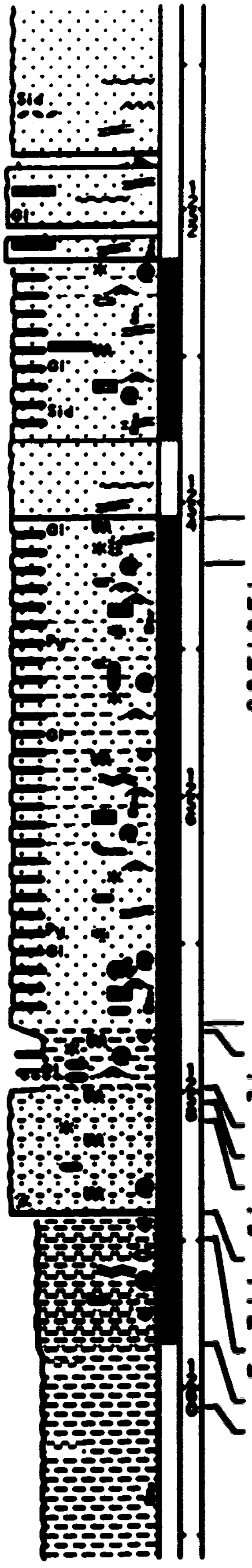
Logged by:

Ground: 888.50 m **KB:** 892.76 m

Remarks: Core 1; Boxes 1-14, 4075-4140' (probably 4079.72'-4143.7') not photogenic at all since core is broken up, heavily sampled and stained by severe acid scoring, well logged relatively quickly, have box shots; BFS 3962' (1207.62m)



UNIT 6: FA2 with stacked sand beds at top
- some of the sand appeared to be almost featureless vf-fL sands



U5(FA1)/U6(FA2) Contact

UNIT 5: Thoroughly Burrowed Interbedded vf sand and shale; FA1
- typical FA1 with large numbers and types of trace fossils; significant proportion of the sand beds are reworked by these robust Helminthopsis that have a significant vertical component and may actually be Anconichnus horizontalis
- sand beds low angle parallel to undulatory or oscillation/combined flow rippled with sharp bases and generally burrowed tops, thickest sand beds are 7-10cm thick, but most are on the order of 2-4cm thick, some of the sand beds are low angle laminated and normally grade up into oscillation rippled tops and capped with mud

U4/U5 Contact

UNIT 4: Shale Dominated Interbedded Shale and vf Sandstone
- Helminthopsis are robust and totally rework the thinly bedded(1-2cm) sands which are normally graded and pass up into shales which are totally reworked by Chondrites

U3/U4 Contact

10-12 dispersed well rounded pebbles, average 5mm diameter, maximum 2cm diameter

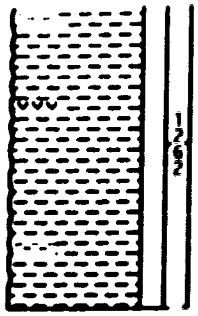
UNIT 3: Totally Burrowed Interbedded vf sand and shale
- totally dominated by Helminthopsis (typical regional background Viking facies, but with a slightly higher sand content)

U2/U3 Contact: 2 or 3 scattered pebbles/granules just above contact
- rounded to subangular, maximum 1.2cm diameter
- *contact may not be real as no pieces of core could be fit together properly near either of the pebbly zones

UNIT 2: basically the same as U1 with more discontinuous mm-1cm silt/vf sand lenses with loaded bases and minor discernible burrowing

U1/U2 Contact

UNIT 1: Dark, slightly Silty Mudstone with very rare mm scale Silt laminae


1262

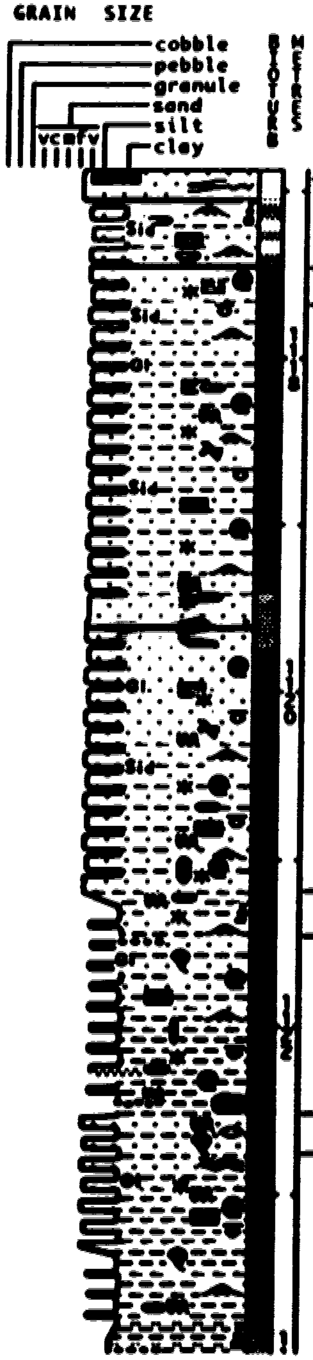
CPOG WINTERING HILLS
7-36-25-18w4

Date logged: August 14, 1990

Logged by: Indraneel Raychaudhuri

Ground: 892.10 m KB: 895.80 m

Remarks: 1117.1m-1135.4m (3665'-3725'); 3.5" full diameter core; photogenic, have box shots and prints; mostly underlying, regional Viking cycles, maybe get "VE3"



UNIT 9: essentially Facies Association 2: Interbedded Burrowed vf Sandstone/Shale with thicker bedded vfU-fL low angle undulatory laminated Sandstone beds
- interbedded portion is oscillation/combined flow rippled vf Sandstone that normally colour grades up into parallel undulatory laminated siltstone and shale as part of the overall waning storm flow sequence
- thicker sand portion is minimal in this well but still displays low angle undulatory laminations and common organic/coaly detritus and rip-ups
- some local sideritization of the dark, organic-rich, essentially unburrowed black shales that cap the thin storm-generated sandstone beds

U8/U9 Contact

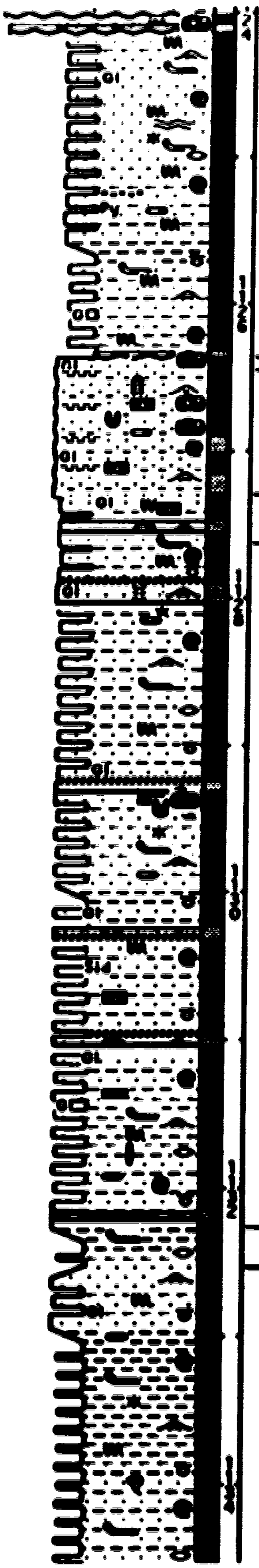
UNIT 8: Essentially Facies Association 1: Thoroughly Burrowed Interbedded vf Sandstone and Shale with (in this case rare) 3-10cm thick oscillation rippled Sandstone beds
- lots of Asterosoma some of which have silty/sandy walls and therefore may actually have to be called thick walled Palaeophycus, possible ?Macaronichnus near top of unit in a 5cm thick sand, some siderite; overall this unit has a "bulbous"-looking burrowing style

U7/U8 Contact

UNIT 7: a sanding upwards unit of Burrowed Interbedded Shale and vf Sandstone, gradationally overlain by U8 which is the continuation of the sanding upwards(i.e. the sandstone dominated portion)
- rare 1-2cm thick vf oscillation rippled sandstone beds
- base of unit has ripped up coaly fragments, and dispersed mg sand and granules in "lenses" that were probably created by the burrowing

U6/U7 Contact

UNIT 6: Thoroughly Churned Interbedded vf Sandstone and Shale
- basal 20cm is silty shale with mm scale sharp based siltstone/vf sandstone "lenses", unit sands upwards, rare 1-3cm oscillation rippled to parallel wavy bedded sandstone beds preserved with some burrowing throughout them



U5/U6 Contact

UNIT 5: basal conglomerate is poorly sorted ?matrix supported conglomerate (pebbles are chert and lithics, maximum ~1.7cm diameter, matrix is mg sand), then ~7cm of burrowed interbedded vf sandstone and shale capped by a couple of cm of shaly vf sandstone with some fairly large pebbles (maximum ~2cm diameter, sub to well rounded)
- **probably represents two separate surfaces**

U4/U5 Contact

UNIT 4: Thoroughly Burrowed Interbedded vf Sandstone and Shale
- 1-5cm sharp or burrowed based vf sandstone beds with hints of oscillation ripples where sedimentary structures are not obliterated by burrowing, glauconite
- riddled with Helminthopsis, lots of Terebellina, rare Planolites, thin squiggly mud lined sub-vertical trace(?Skolithos), rare Asterosoma
- similar to U2 but with different traces and not quite as thickly bedded sandstone beds

U3/U4 Contact: with a few scattered pebbles

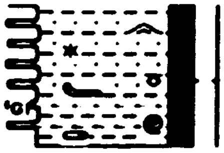
UNIT 3: Thoroughly Burrowed Shaly vf-fL Sandstone
- "wispy" shale that is probably a result of the muddy linings of numerous Ophiomorpha burrows(2-4.5cm diameter); the shalyy "wisps" and Ophiomorpha linings are commonly re-burrowed by Chondrites, ?Palaeophycus, ?Thalassinoides, one probable mud lined Arenicolites
- sand is vfU-fL, well sorted, glauconitic, rare preserved oscillation to combined flow rippled beds
- this facies probably represents the continuation of the underlying sanding upwards sequence, however it is sharply overlain by a far less sandy facies with a few pebbles at its base (probably represents an erosion/flooding surface "VE3"; also the typical Ophiomorpha and Rosselia-rich sandstones that are most common below "VE3" in the study area)

U2/U3 Contact

UNIT 2: Thoroughly Burrowed Interbedded vf Sandstone and Shale
- likely just a continuation of U1 within an overall sanding upwards cycle
- vf sand dominated, a few 5-15cm thick oscillation to parallel wavy bed- ded sands(more and thicker sandstone beds preserved than in underlying unit), sand beds are commonly sharp or burrowed at the base and are mostly burrowed at the top, wide trace fossil diversity, rare sub-vertical to vertical traces (short, thin ?Skolithos or ?Ophiomorpha)
- good "regional Viking" development

U1/U2 Contact

UNIT 1: Thoroughly Burrowed Interbedded vf Sandstone and Shale
- rare 1-8cm thick vf sandstone beds preserved with small scale oscillation rippling; these beds are not commonly continuous across the scale of the core due to thorough burrowing and therefore can appear as "lenses" of sand, commonly loaded bases; some glauconite
- traces include small Terebellina, Helminthopsis, Asterosoma, Planolites, rare small truncated Rosselia



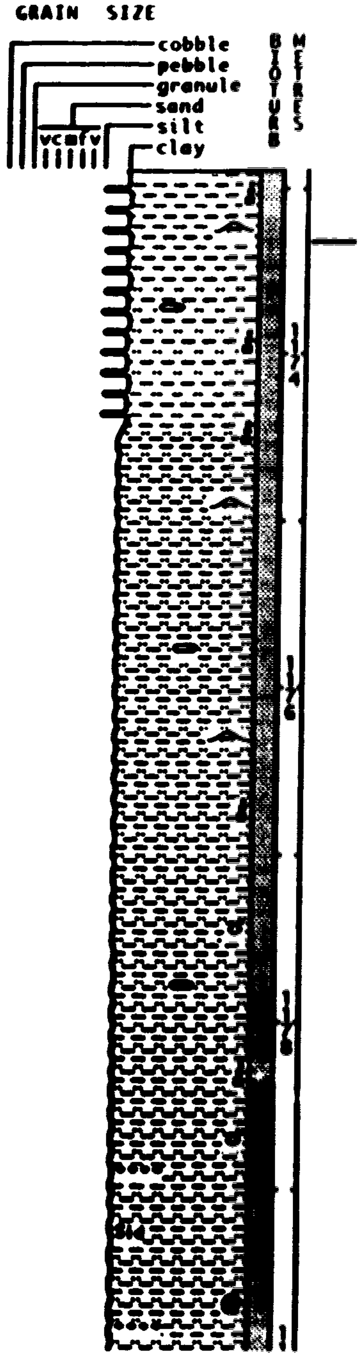
CPOG HUSSAR
10-2-25-20w4

Date logged: August 8, 1990

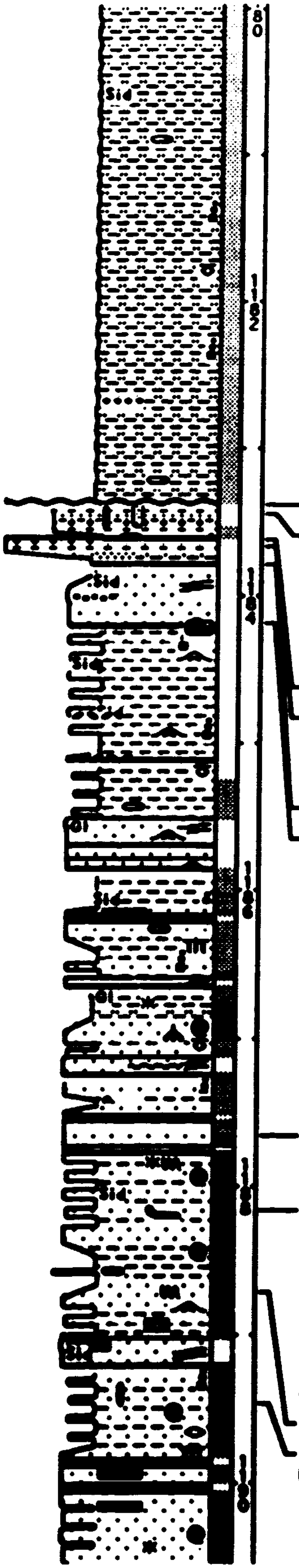
Logged by: ©1993 Indraneel Raychaudhuri

Ground: 902.20 m KB: 906.20 m

Remarks: Core 1; 13 boxes (1-6 are unnamed Colorado shale), 3851'-3911', full recovery, photogenic; have box shots and prints of basal ~8.8m of core



UNIT 5: Dark Shale with mm scale vf Sandstone/siltstone lenses that are sharp based and colour graded with hints of oscillation rippling
- a few areas are sideritised for ~5cm, rare pebble stringers within the unit
- more siltstone/sandstone in the top 1.5m



U4/U5 Contact

UNIT 4: Interbedded sandstone and Shale
- basal 5cm is sharp based colour graded vf sandstone/siltstone and shale with rare Planolites, then into a 19cm zone that is a sandy shale (sand=fg-mg salt and pepper sand) with scattered sand grains, granules and pebbles, and all this is overlain by 2cm matrix(=salt and pepper fU-mL sand) supported conglomerate with an undulatory basal contact that may be a Glossifungites "surface", maximum pebble size ~1.7cm diameter, chert and lithic pebbles/granules, fairly well rounded

U3/U4 Contact

UNIT 3: Probable Transgressive Deposit
- basal 11cm is sandy shale with scattered pebbles, overlain by 8cm of poorly sorted matrix(=mud) supported conglomerate with granules, pebbles (maximum ~1.7cm diameter, average ~1.1cm diameter, chert and lithics, fairly well rounded) and coarse sand

U2/U3 Contact

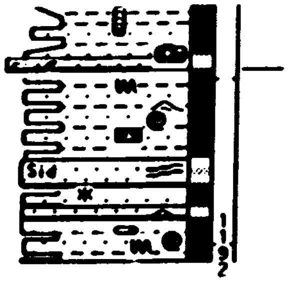
UNIT 2: Facies Association of Normally colour graded Interbedded vf Sandstone/Shale with thicker bedded Oscillation Rippled/Low angle Undulatory/Wavy Parallel Sandstones
- rare stressed Terebellina with "crinkled" walls, mostly Planolites, rare burrows and much less diversity than U1, Asterosoma
- interbedded portion: normally colour graded, commonly oscillation/combined flow rippled vf sand passing up into wavy parallel silts and shale= probable waning storm flow sequences
- thicker sand beds commonly have low angle undulatory laminations with low angle truncations, or low angle parallel laminations (larger bedforms?) or wavy parallel laminations
- shales have good synaeresis cracks, some sideritised areas, some angular sideritised(or not) mud rip-up clasts

U1/U2 Contact: sharp change in nature of burrowing

UNIT 1: Facies Association of Burrowed Interbedded vf Sandstone and Shale with Oscillation rippled vf Sandstones
- one cross bedded fU-mL glauconitic sand bed with sideritic rip-ups
- oscillation rippled sand beds-generally 5-10cm thick, one ~20cm thick, organic material scattered and organic laminae
- rare synaeresis, traces: lots of Helminthopsis, Chondrites, some ?Asterosoma, ?Skolithos or small ?Ophiomorpha, or small Diplocraterion, Terebellina (quite robust in burrowed portion; small ones in sand beds), Planolites, rare Teichichnus (1 seen, quite small), probably small Palaeophycus in sand beds
- some sideritised areas, glauconite

also "transitional FA1/FA2"-looking stuff

"transitional FA1/FA2"-looking stuff; also note that this portion of the core is more intensely burrowed and shalier than the relatively poorly burrowed sandier facies below. ??VE3.5"??



??very tenuous ?"VE3.5"; probably not, "VE3.5" probably lies lower than the cored section

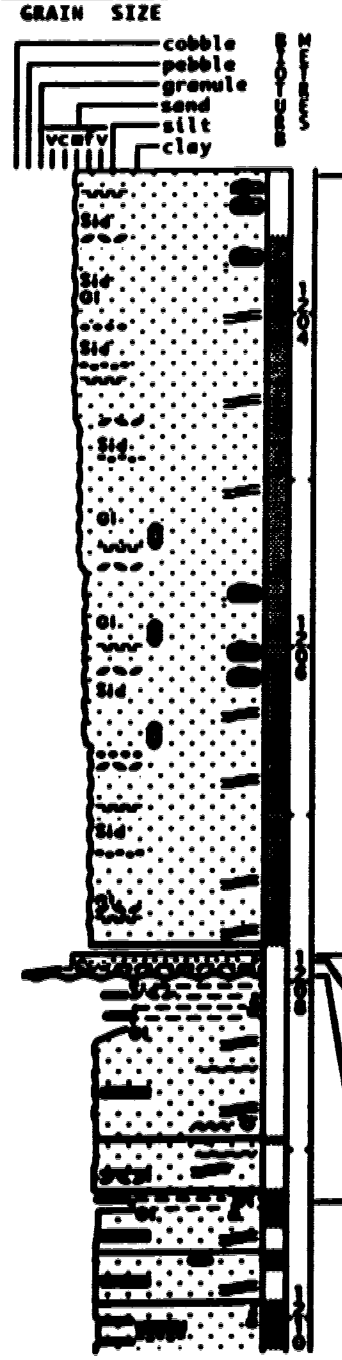
CPOG EC HUSSAR
7-7-25-20w4

Date logged: August 9, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 903.10 m **KB:** 906.50 m

Remarks: Core 1; 8 boxes, 3950'-3985'; 3.5" full diameter core; photogenic, have box shots and prints; only well logged in study area with fg-mg shoreface sediment (just above "VE3.5"-type conglomerate OR whole core could be above "VE3.5")



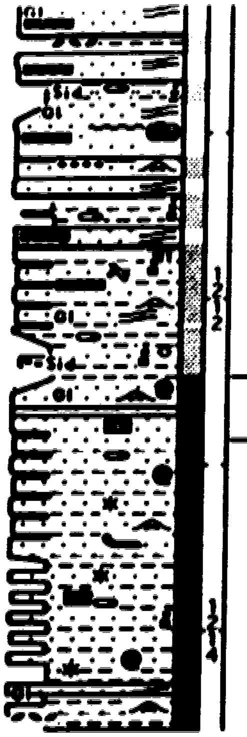
UNIT 4: Fine to mg Low Angle Laminated Glauconitic Sandstone with Rip-Up clasts
- unit coarsens upwards from fL through fU, mL to mU
- unit characterised by: numerous rip-up clasts, most of which are angular sideritised shale; "wispy" shale streaks(some of which are Ophiomorpha as observed on slabbed and bedding planes); Ophiomorpha with spiky walls (i.e. Ophiomorpha irregulaire); glauconite; carbonised wood fragments; ripped up coaly material
- above the conglomerate looks like middle shoreface-type sediment

U3/U4 Contact

UNIT 3: Poorly Sorted Clast Supported Conglomerate
- pebble maximum ~2.2cm diameter, average ~granules to 0.5cm diameter, chert and lithics, angular to well rounded, mostly sub-rounded, matrix is mud through to coarse sand, ripped up angular shale and sideritised shale, fewer pebbles upwards with more mg sand

U2/U3 Contact

UNIT 2: Essentially Facies Association 2: Rarely Burrowed/Normally Colour Graded Interbedded vf Sandstone, Siltstone, Shale, Interbedded with Thicker Bedded Gradational/Burrowed topped Low angle Undulatory Laminated vf Sandstone beds
- rare pebble/granule stringers, one area is loaded/chaotically/soft sediment deformed bedded, more and thicker sandstone beds upwards within the unit, rare sideritised areas, abruptly far less burrowed than U1



U1/U2 Contact

UNIT 1: Facies Association 1: Interbedded Burrowed vf Sandstone/Shale with 1-10cm thick Oscillation to combined flow rippled sandstone beds

- sandstone between vfU-fL, some glauconite, well sorted, generally pretty sharp based beds but not many of them and average ~5cm thick, commonly normally grade upwards and have gradational to burrowed tops
- Interbedded portion is moderately burrowed, no visible Helminthopsis, some Asterosoma

CPOG Clark Hussar
6-17-25-20w4

Date logged: March 26, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 903.40 m KB: 907.40 m

Remarks: Core 1; 13 boxes, 3927'-3987' (probably 3925.6'-3985.6'); ~1196.5-1214.8m; photogenic, slump features; have box shots and prints

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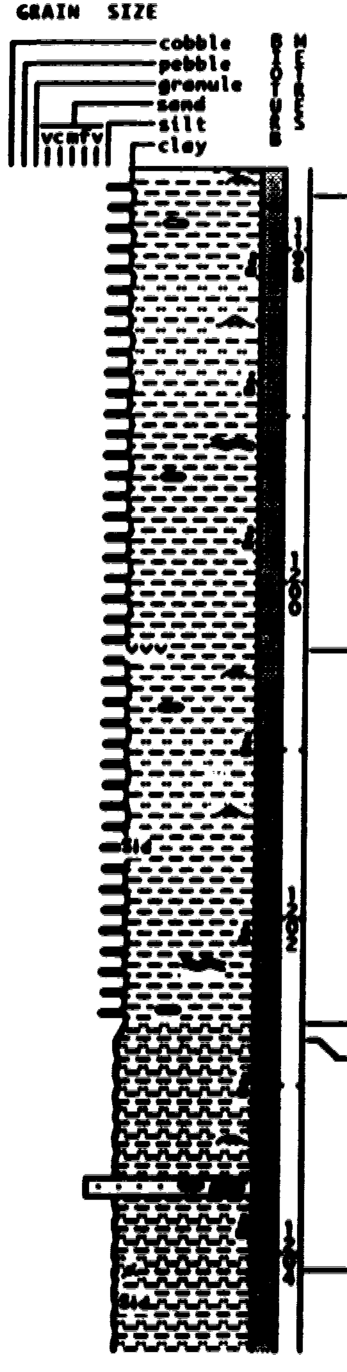


UNIT 5: Interbedded Silty Shale and Siltstone/vf Sandstone

- vf sandstone/siltstone beds are very sharp based, commonly loaded or burrowed, thicker beds than the mm-1cm scale ones below, i.e. up to 5cm thick, commonly normally colour graded beds with oscillation to combined flow ripples
- sandier/siltier facies overall than U4
- 1 2cm thick bentonite in this unit
- locally there are zones of sideritized shale

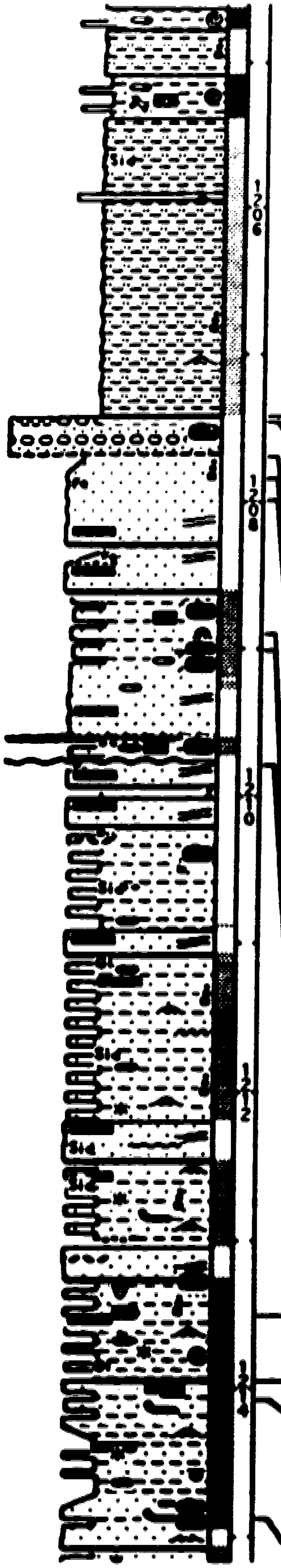
2cm thick bentonite

U4/U5 Contact

UNIT 4: Dark silty shale with mm-1cm thick sharp based discontinuous vf sandstone/siltstone beds

- contains a few zones of burrowed vf-fL sandstone and shale: Planolites, Thalassinoides, rare Chondrites??
- local zones of sideritized shale
- remnant hints of oscillation to combined flow ripples

a single subrounded chert pebble 0.8cm diameter



U3/U4 Contact

UNIT 3: probably Transgressive Poorly sorted matrix supported chert pebble Conglomerate
- looks like lithic pebbles also present but I think that there are just multi-coloured chert pebbles (hardness checked on several pebbles)
- maximum ~1.85cm diameter, average ~0.8cm diameter, range 0.2-1cm diameter, quite a few 1-1.3cm diameter pebbles
- poor sorting may in part be due to burrowing, but no recognisable trace fossils
- matrix is mud to mg sand with lots of "salt and pepper" mg sand in the top 4cm of unit

U2(FA2)/U3(Transgressive Conglomerate) "Contact"
- actual contact not visible due to sampling of the core

upper 30-40cm of this sand is apparently structureless (?possibly quickly dumped wave liquified sediment?)

UNIT 2/FA2: typical FA2 but with some of the more "exotic" facies also
- thickly bedded sands: thicker sands upwards, low angle parallel laminations with low angle truncation surfaces(SCS?), laminations accentuated by organic laminae, local Fe/Siderite, local mud, sideritised mud rip-ups, coaly rip-ups, rare traces, some oscillation/combined flow rippling, generally sharp based, zone near top of unit with extensive soft sediment deformation, rare apparently structureless sand at top of unit also
- interbedded portions: rare to moderate burrowing which dramatically decreases in numbers, diversity and intensity upwards through the unit, 1-10cm thick vf sandstone beds with oscillation/combined flow rippling, minor glauconite, organic/coaly detritus, traces: Bergaueria(?), Palaeophycus, Terebellina, Chondrites, Asterosoma, Planolites BUT ALL TRACE FOSSILS VERY RARE!, locally there are spectacular synaeresis cracks, local small scale soft sediment deformation, patchy incipient sideritisation

represents ball and pillow structure (i.e. soft sediment deformation)

soft sediment deformation with micro-faulting

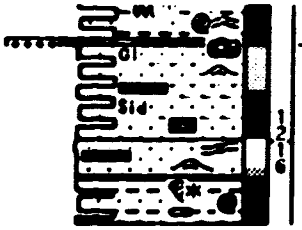
sharp based thin chert pebble conglomerate; maximum ~1.75cm diameter, up to 3.4cm diameter sideritic clasts, average ~0.8cm diameter; sub to well rounded; some small granules incorporated into small scale oscillation to combined flow ripples; base of overlying sand is very pebbly for the basal 2-3cm: maximum~1cm diameter, average ~0.7cm diameter

last solid occurence of Chondrites

U1(FA1?)/U2(FA2) Contact

UNIT 1/FA1?: 2 thicker bedded vf sandstone beds noted on lithalog with low angle inclined stratification and low angle(12-15 degrees) truncations (probably storm generated); otherwise, 3-6cm thick oscillation rippled/combined flow rippled sandstones
- good diversity of traces: 2 Rosselia, 1 Zoophycos, moderate amount of Helminthopsis, minor Terebellina? or Schaubcylindrichnus?, but this unit is totally dominated by Chondrites and Asterosoma

this Terebellina represents a cluster of them: Schaubcylindrichnus??



discontinuous(due to burrowing?) 1cm thick lens of vc sand, granules and pebbles, mostly chert and subangular to subrounded (maximum 0.5cm diameter; average ~0.3-0.4cm diameter, maximum sideritised clast 2cm diameter), SGP says pebbles are in a Thalassinoides burrow

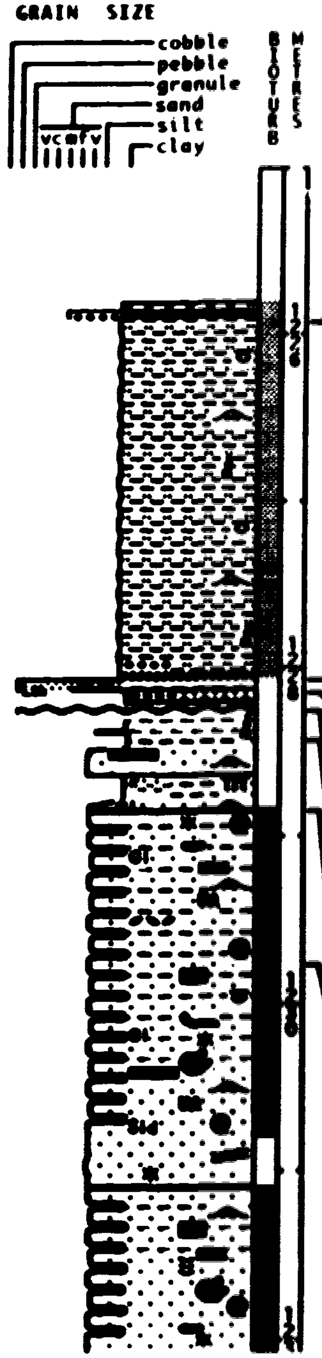
Sundance et al. WAYNE
6-6-26-18w4

Date logged: February 26, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 982.50 m KB: 986.90 m

Remarks: Core 1; 5 boxes (boxed backwards), 1226.2-1232.8m; Core 2; 9 boxes, 1232-1244m; ~on depth; full recovery; 3.5" full diameter core; photogenic; have box shots and prints



UNIT 8: Dark Shale with mm to 2cm thick sharp based vf sandstone/siltstone beds with remnant oscillation ripples
- some loaded bases, mostly discontinuous vf sand/silt; rare burrowing (lack of lithologic contrast)
- scattered pebbles/granules near base (probably burrowed up from underlying unit)
- one 5cm thick poorly sorted mg-cg sand bed with granules/pebbles near unit top

U7/U8 Contact

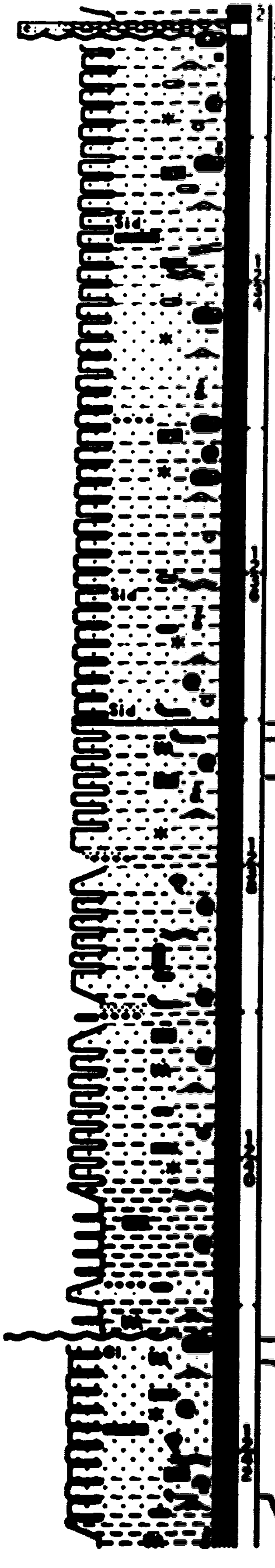
UNIT 7: Poorly Sorted Conglomerate
- commonly seen on transgressive surface, only 1-2cm thick (maximum pebble ~1.5cm diameter) conglomerate with coarse-mg sand and granules (mostly chert with a few lithics; this is overlain by ~ 5cm of silty bentonite; which is overlain by ~8cm of sandy shale with dispersed granules/pebbles; which is overlain by ~6cm of clast supported granular conglomerate (range from 3-6mm diameter on average); mostly rounded chert but a significant proportion of colourful lithics and this has a "salt and pepper" matrix of mg sand

U6/U7 Contact (Transgressive surface)

UNIT 6: much more like FA2 but the "thick" sand beds are only 7-17cm thick, oscillation/low angle undulatory bedded
- waning flow type tops that normally grade into rather thick continuous shale/silty shale
- no burrowing, synaeresis cracks

U5/U6 Contact

UNIT 5: aspects of both FA1 and FA2
- one thickly bedded vf sand bed(~27cm with low-undulatory laminations); sand beds on average were probably 5-10cm thick but have been burrowed significantly
- reappearance of more fully marine trace assemblage which is curious- "be wary since there was a mix up with the boxing of this core"-NB- this is not too curious as the burrowing intensity commonly increases above one of the "anomalous" clast supported conglomeratic horizons
- rare Terebellina, moderate Helminthopsis and Chondrites, Asterosoma, Rhizocorallium (more than elsewhere), Zoophycos, Palaeophycus in sands, possible Teichichnus??



U4/U5 Contact *this is ~ where Core 2 starts and my suspicion is that it is boxed backwards*

UNIT 4: clast supported conglomerate
- pebbles are chert and colourful lithics, generally well rounded but there are some shredded-looking siderite angular rip-ups also
- maximum pebble size= ~2.1cm diameter, range from 0.5-1.7cm diameter, matrix is clean, well sorted vf sand
- lower contact is undulatory and probably erosive, the C (i.e. long)-axis of one of the pebbles at the base of the bed is essentially vertical- my feeling is that this bed was deposited very very quickly
- conglomerate bed fines up into mU-cL and even finer sand that appears to have some oscillation rippling/wavy parallel bedding

U3(FA2)/U4(CGL) Contact

UNIT 3: essentially medium bedded FA2 with less intense burrowing upwards, lots of sharp based fining upwards vf sandstone beds that are oscillation rippled and pass up into essentially unburrowed black shales

U2(FA1)/U3(FA2) Contact

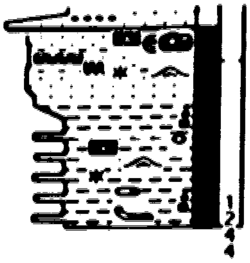
a few small clusters of 5 or 6, 1mm diam. scale Terebellinas- Schaubcylindrichnus??

UNIT 2: FA1: typical FA1 except there is even more trace diversity than normally seen, and the sharp based vf oscillation rippled sand beds are only 1-3cm thick on average (probably due to the intensive burrowing), rare graded beds
- also, at least 3 zones of localized scattered granules and fg-mg sand that are, coincidentally, typically overlain by shale dominated burrowed interbedded shale and vf sandstone (??micro-"flooding surfaces"??)
- quite sharply overlain by FA2...
- Terebellina(Schaubcylindrichnus??), truncated Rosselia stems, Helminthopsis, Chondrites, Zoophycos??, Teichichnus, Asterosoma, Palaeophycus...

U1/U2(FA1) Contact: probable parasequence boundary

UNIT 1: interbedded vf sandstone and shale
- mud dominated areas tend to be burrowed much less and by fewer types of traces, with sharp based colour graded oscillation rippled sandstone beds (like FA2); vice versa for sand dominated areas, churned (like FA1); synaeresis cracks(?)
- one 10cm zone of 2 sharp based graded beds from granules/small pebbles (maximum~1.6cm diameter) to mg sand and finer; rounded sideritized rip-ups; sand is oscillation rippled; incipient sideritization
- upper contact is pebbly and may represent an E/T type parasequence boundary

there is one cluster of Terebellina: maybe Schaubcylindrichnus?????


1
2
4
4

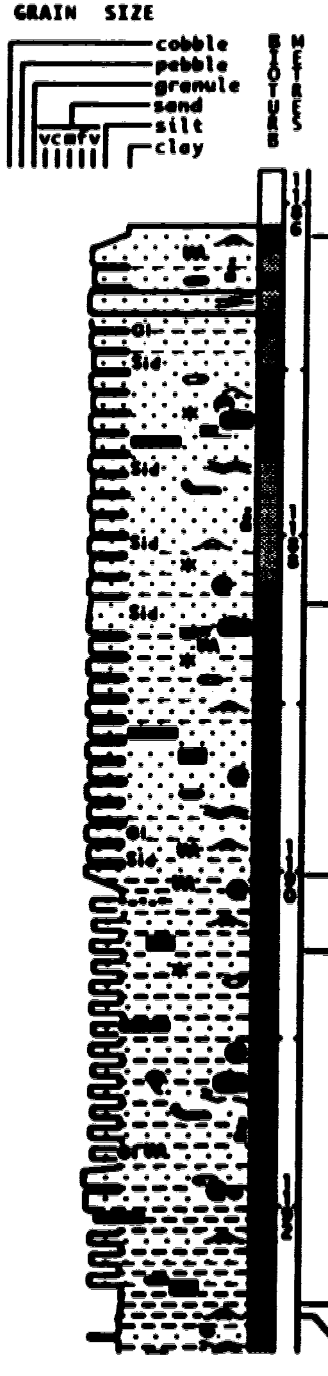
Sundance et al. WAYNE
6-9-26-18w4

Date logged: March 25, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 942.70 m KB: 946.40 m

Remarks: Core 1; 13 boxes, 1185m-1203m (actually 1185.8m-1203.8m), 3.5" full diameter core; photogenic; core goes through lots of underlying regional cycles; have box shots and prints



UNIT 7: much like FA1 but top ~2.3m has less diversity of traces and is totally dominated by small bulbous Asterosoma(which may actually be shallow burrowed Teichichnus) with rare Zoophycos; also Planolites, Chondrites, Helminthopsis but these too are less abundant in the upper 2.3m where 7-13cm thick vf low angle undulatory laminated sands are also seen; Palaeophycus in the "thicker" preserved sands
- upper ~2.3m has that sharp based normally graded nature that characterises FA2; also the incipient sideritisation; black muds with only Planolites burrows
- lower portion of this unit looks like typical regional Viking facies

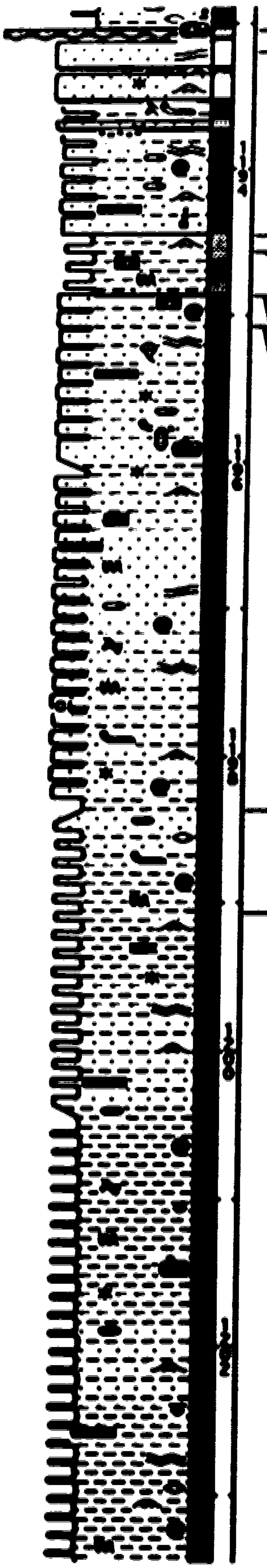
contact within U7 above which there is less burrowing intensity and a corresponding increase in "FA2-type" sharp based rippled vf sandstone beds (medium bedded, ~5-13cm thick)

U6/U7 Contact: actually quite sharp, but part of overall sanding upwards sequence

UNIT 6: Churned Interbedded vf sandstone, siltstone and shale
- transitional between U1 and U2 with ~50/50 vf sandstone and mud; 24cm zone that is truly vf sand dominated
- traces etc. given on litholog

U5/U6 Contact: gradational; part of sanding upwards package

UNIT 5: essentially the same as U1



U4/U5 Contact: probable flooding surface/parasequence boundary (likely "VE3")

UNIT 4: essentially the same as U2 but with fewer trace types and two nearly unburrowed vf sand beds that display low angle undulatory laminations
- unit top is a 4cm thick sharp based oscillation rippled(?) vc/granular sandstone with well rounded chert granules/pebbles(maximum ~1cm diameter, average ~0.3-0.4cm diameter)

U3/U4 Contact

UNIT 3: Mud dominated Relatively Poorly Burrowed Interbedded vf sand and mud
- sharp change in intensity of burrowing and change to mud dominated; few types and amount of traces: Helminthopsis, Chondrites; sharp based, normally colour and grain size graded oscillation rippled vf sand beds (1-2cm thick); minor organic detritus; bases of sand beds commonly loaded into underlying mud

U2/U3 Contact: relative flooding surface?; can see significant break on the well logs

UNIT 2: vf Sand dominated churned Interbedded mud, silt and sand
- continuation of sanding/coarsening upwards package that started in U1
- more trace types than U1: Rosselia, Helminthopsis, Asterosoma, Planolites, Thalassinoides?, Chondrites, Palaeophycus, Terebellina etc.
- most sand beds discontinuous on the scale of the core due to intensive burrowing, but with remnant oscillation, low angle parallel, and wavy parallel laminations, minor organic detritus, glauconite; sands ~2-7cm thick
- sharp upper contact

U1/U2 Contact

UNIT 1: Churned/shredded Mud dominated Interbedded vf sandstone, siltstone and mudstone
- bit of a transition zone into the more sand dominated facies of U2 above
- traces: 1 Zoophycos, mostly Terebellina, Helminthopsis, Asterosoma and Planolites
- vf sandstone beds: generally discontinuous on the scale of the core which gives this facies a "shredded" appearance; sharp based; locally loaded bed bases; wavy parallel, oscillation rippled and combined flow ripple laminations; 1-4cm thick, minor organic detritus accentuating the laminae
- internally, this unit sands upwards

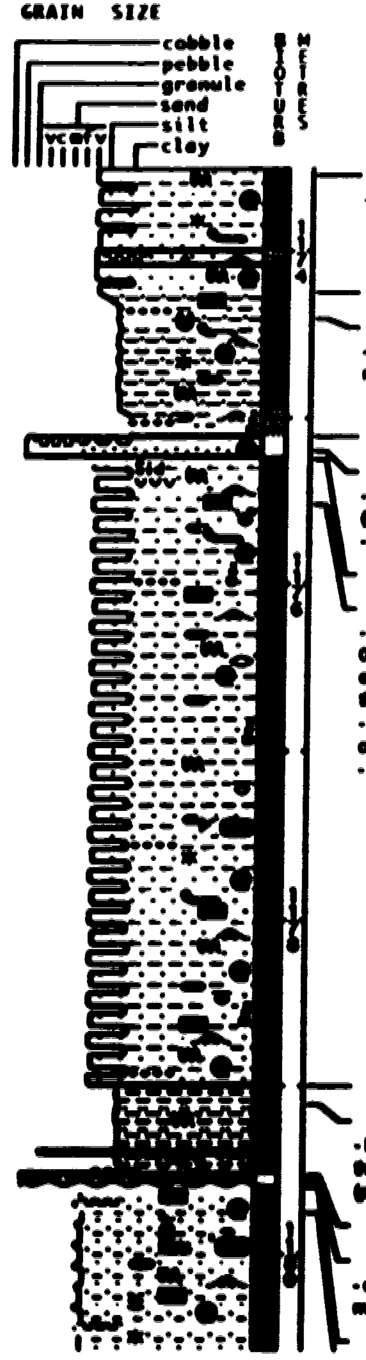
Sundance et. al. ROSEDALE
10-14-26-18w4

Date logged: July 13, 1990

Logged by: Indraneel Raychaudhuri

Ground: 943.60 m KB: 947.80 m

Remarks: Core 1; 13 boxes, 1174m-1192m; photogenic; no box shots



UNIT 11: Thoroughly churned Interbedded Sandstone and shale
- riddled with Helminthopsis, one 10cm thick oscillation rippled bed with Skolithos

U10/U11 Contact

UNIT 10: basically Interbedded Churned Mudstone and vf Sandstone
- basal ~15cm is normally graded, sharp based/burrowed tops, oscillation rippled vf sand to mud and above this it gets into thoroughly churned sandy shale

U9/U10 Contact: ?flooding surface

UNIT 9: Very Poorly Sorted Matrix Supported Conglomerate
- not really a true conglomerate, but has rounded chert clasts commonly 2-3cm diameter (maximum 3.5cm/X2cm wide)
- matrix is churned mudstone, sandstone, with fewer smaller pebbles scattered upwards

U8/U9 Contact

UNIT 8: Interbedded vf Sandstone and shale
- thoroughly churned, riddled with Helminthopsis galore, basal contact is sharp and has three 0.5cm diameter rounded chert pebbles, sand beds are 3-6cm thick but rarely continuous due to extensive burrowing, show evidence of remnant oscillation ripples, also small Palaeophycus in the sharp based/burrowed top oscillation rippled vf sandstones
- ~1.44m from unit base is the beginning of an ~25cm thick zone that contains dispersed gritty chert material (granules, sub-angular to sub-rounded), sideritized rip-up, fish bone fragment
- upper 15cm of unit is heavily sideritized

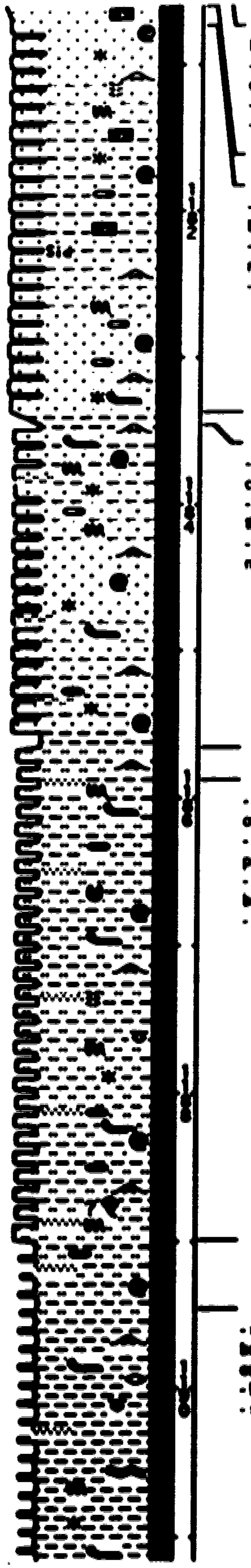
U7/U8 Contact

UNIT 7: Mostly a Dark silty shale with mm scale silty/vf sand stringers
- basal bit is interbedded normally colour graded oscillation rippled sandstone and shale, 3cm thick vc sand with lots of rounded chert granules that are piping down into the lower sub-unit (possible Glossifungites with Thalassinoides)

U6/U7 Contact

UNIT 6: Poorly Sorted Matrix Supported Conglomerate
- chert pebbles up to 3cm long, average ~1cm, mostly well rounded pebbles and granules, matrix is quite well sorted vf-fg sand

U5/U6 Contact: "VES"?



UNIT 5: Interbedded (Thoroughly Burrowed vf Sandstone/shale) and vf Oscillation Rippled/HCS?? Sandstone
- "background" appears to be Interbedded vf sandstone/shale with "anomalous" vf oscillation/HCS?? rippled sandstone of probable storm origin
- the interbedded vf sand/shale part closely resembles U4 below
- "storm" beds can contain Palaeophycus, Ophiomorpha

U4/U5 Contact

UNIT 4: Thoroughly Burrowed Interbedded Sandstone and Mudstone
- 4-7cm thick sand beds, very little silt, sharp based oscillation rippled beds commonly with burrowed tops
- Helminthopsis, very rare Terebellina, Asterosoma, Palaeophycus in the intermittent oscillation rippled sandstone, rare Zoophycos, ?Chondrites
- continuation of overall sanding upwards sequence

U3/U4 Contact

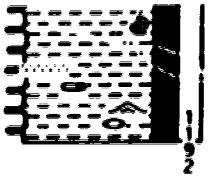
UNIT 3: Interbedded Mudstone, vf Sandstone and minor Siltstone
- sharp based sand beds commonly with burrowed tops, beds 3-4cm thick and relatively continuous across the scale of the core
- part 3 within an overall sanding upward cycle, although there is certainly some variation within the individual "units" of the cycle
- more Helminthopsis and much more Asterosoma than elsewhere and the Asterosoma are way more robust than anywhere below; possible ?Zoophycos

U2/U3 Contact

UNIT 2: Interbedded Shale/Siltstone/vfL Sandstone
- more vfL sand in thicker beds on average (1-3cm thick, and more continuous across the scale of the core than in U1); sands are sharp based, commonly with burrowed tops
- more numbers, and more diverse trace fossil assemblage than U1 (probably due to more pronounced lithologic contrast)
- Palaeophycus found only in the thicker sand beds (opportunistic trace maker colonising storm beds??)
- possible small Rosselia

U1/U2 Contact

UNIT 1: Interbedded Mudstone, Siltstone and vf Sandstone
- sharp based siltstone/sandstone beds, can be slightly loaded, commonly burrowed tops, beds are discontinuous on the scale of the core due to burrowing, very small traces with extremely rare Helminthopsis, Asterosoma
- basal part of 4 "units" that make up an overall sanding/slight coarsening upwards cycle
- siltstone/sandstone beds mm-1cm thick


1192

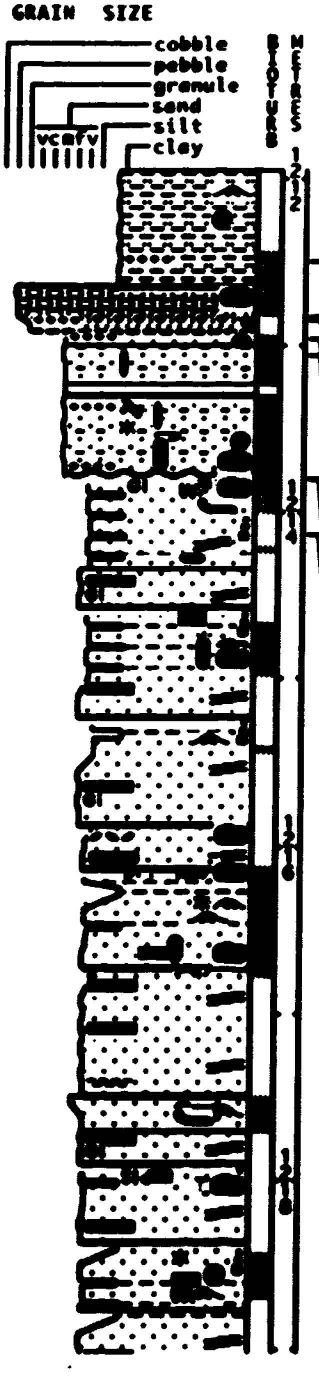
Sundance et al. WAYNE
8-20-26-18w4

Date logged: February 21, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 967.70 m KB: 971.90 m

Remarks: Core 1; 13 boxes, 1209-1227m, (probably 1211.25-1229m); photogenic, 3.5" full diameter core; have box shots and prints



UNIT 8: Dark silty shale with discontinuous mm-1cm scale remnant vf oscillation rippled sharp based sandstone beds

U7/U8 Contact

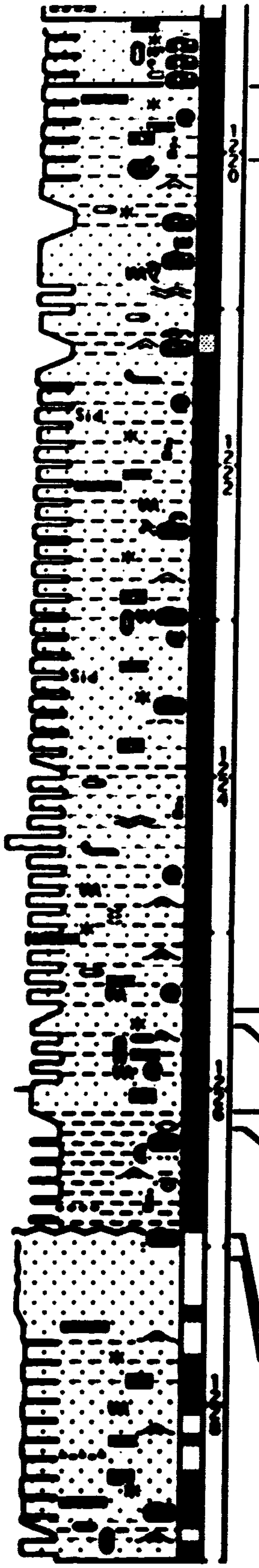
UNIT 7: (Trogh?) Cross Bedded pebbly/granuley mg sandstone at base that appears to be inversely graded into (trough?) cross bedded conglomerate and then up into apparently massive clast supported conglomerate
- In cross bedded portion, the pebbles are approximately granules to an average of 0.4-0.6cm in diameter, chert and lithics
- In more massively bedded conglomerate, maximum pebble size observed ~1.2cm diameter, average around 0.6-0.7cm diameter; chert and lithics
- In both cases, pebbles/granules are mostly sub-rounded

U6/U7 Contact

UNIT 6: Highly burrowed muddy mg sandstone
- thoroughly churned, "salt and pepper" mg sand with scattered pebbles throughout
- rounded chert grains at unit base; average ~0.6-0.8cm in diameter
- Teichichnus, Asterosoma, Planolites, Skolithos
- 1 ~6cm thick massively bedded sand that is unburrowed

U5(FA2)/U6(transgressive) Contact

UNIT 5: essentially FA2
- typical FA2, although between thickly bedded sands, the intervals tend to be more burrowed, occurrence of Macaronichnus simplicatus
- thick beds from 20-65cm in thickness, organic material accentuate laminations
- sharp upper contact



U4(FA1)/U5(FA2) Contact

UNIT 4: continuation of sanding upwards cycle, basically FA1
- 1-8cm thick oscillation rippled/wavy parallel bedded vf sandstones, commonly with burrowed tops (Zoophycos, Palaeophycus, rare escape burrows, Asterosoma??)
- most of unit is heavily churned; amazing number and diversity of traces: Asterosoma, Helminthopsis, Terebellina, Chondrites, Zoophycos, Rhizocorallium, one Rosselia?, small knobbly walled Ophiomorpha? or is it a mud lined small Skolithos?, Planolites, Thalassinoides
- up to 10cm thick intervals which are sharp based normally colour graded beds similar to what is more commonly seen in FA2

U3/U4(FA1) Contact

UNIT 3: continuation of sanding upwards sequence; more traces(type and numbers) probably due to increased lithologic contrast, lots of burrowing

U2/U3 Contact

UNIT 2: silty interbedded shale (dominated) and sand, shredded appearance, discontinuous 2-10mm thick sharp based graded sand beds with remnant oscillation/combined flow ripples
- burrowed but individual traces tough to discern due to lack of lithologic contrast, rare Chondrites, Helminthopsis near unit top
- upper "contact" gradational into similar but sandier facies
- basal contact is sharp, has coarse sand to granules(average 0.6cm diameter) to pebbles(up to 1-1.2cm diameter); mostly chert pebbles/granules
- 2 granule stringers 8 and 15cm above lower contact

U1/U2 Contact: probably "VE3" equivalent

UNIT 1: sand dominated burrowed interbedded vf sand and shale; very little shale, rather dominated by oscillation rippled 7-10cm thick beds separated by 2-7cm thick burrowed vf sand and mud that have good diversity but low numbers of traces: Planolites, Ophiomorpha, Asterosoma, Chondrites, rare Helminthopsis, rare Zoophycos
- sands upwards into thick bedded vf sand with low angle undulatory/parallel laminations with low angle truncations (maximum 12 degrees)
- sharp, undulatory upper contact

Sun. et al. Rosedale

6-25-26-18w4

Date logged: April 16, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 942.40 m KB: 946.80 m

Remarks: Core 1; 13 boxes, 1170m-1188m, Rec. 18.1m, actually ~1171.5-1189.5m, OK photogenic, have box shots and prints from box shots

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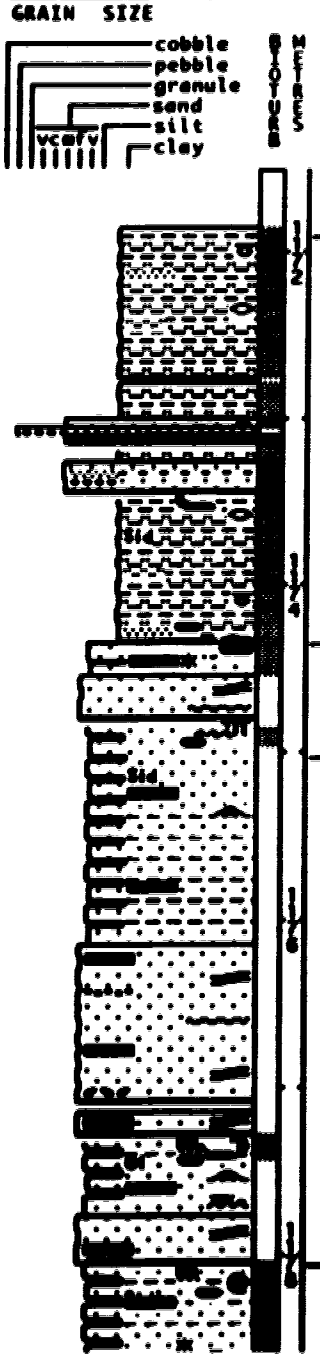
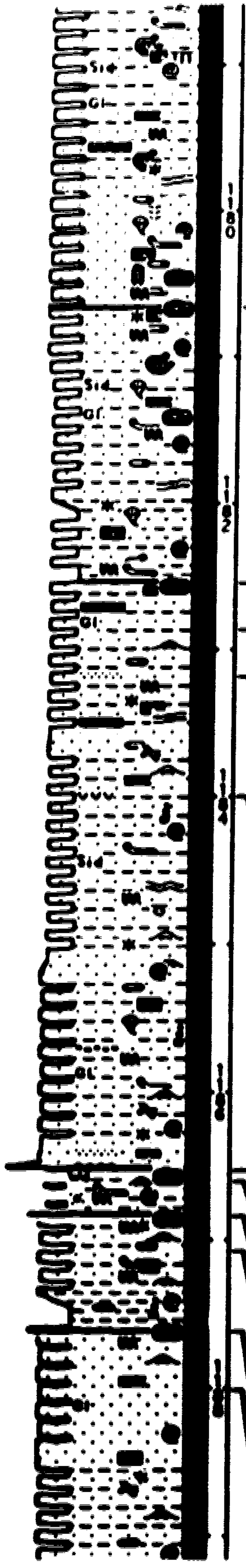


U6: Black Silty/vf Shale with discontinuous mm-cm scale silt/vf sand laminae
- variations within this unit: sharp based zones of burrowed fg-mg sand ("salt and pepper") with scattered granules/pebbles(chert) (average= granules; maximum= 0.8cm diameter
- one 3cm thick bentonite

U5(FA2)/U6(Transgressive) Contact: mm scale thin band of mg "salt and pepper" sand ("transgressive lag"?)

U5: FA2
- thick bedded vf sands maximum 84cm thick, low < parallel to low < undulatory but at lesser angles than in FA1 (i.e. 2-10 degrees), ubiquitous organic detritus throughout the unit, minor coaly or shaly rip-ups in the thickly bedded sands, virtually no burrowing in this unit, rare escape trace
- in the interbedded portions : still vf sand dominated with similar features to the thickly bedded sands but beds are thinner and the mud dominated portions are virtually unburrowed
- some minor loading/soft sediment deformation features, synaeresis cracks

U4(FA1)/U5(FA2) Contact: minor burrowing in the interbedded portions above here, as well as much thicker preserved vf sand beds



U4: FA1(?)

- FA1 because of its position with respect to definite FA2 above, transitional zone in the upper metre that grades into FA1, basal 75cm of unit is totally burrowed with a wide diversity of trace fossils and no vf sand beds preserved
- "upwards within this unit, trace fossil diversity/number/ burrowing intensity decreases, thickness of preserved vf sand beds/ sand percentage increases, also, incipient sideritisation increases upwards
- sedimentary structures are dominantly low < undulatory laminations with truncations of up to 15 degrees, but with some of the hummocks preserved: probably HCS

sharp contact within U4; sandier with thicker bedded sands above

U3/U4(FA1): sharply shalier above (U4 sands upwards); but mostly just a lot more burrowed above

U3: Burrowed interbedded vf sand and shale

- sand beds 2-12cm thick, some with low < undulatory to parallel laminations, some thin sharp based normally colour graded vf sand to mud beds(these are only moderately burrowed, similar to FA2), some of the thicker bedded sands have coaly rip-ups, organic detritus, and fg-mg sand at their bases, unit basically sands upwards with less Helminthopsis upwards and more Zoophycos
- lots of traces, highly diverse assemblage: Helminthopsis, Terebellina, Planolites, Thalassinoides, Chondrites, Asterosoma, Zoophycos, Rosselia?, Palaeophycus, possible Skolithos near the top
- thin bentonite and minor rare sideritisation
- minor "lenses" of fg-mg sand dispersed throughout the unit

base of 4cm thick low < undulatory laminated vf sand bed with a sharp base and mg sand at its base

thin bentonite

U2/U3 Contact: sandier above, dispersed pebbles and coarser sand for ~20 cm above the contact; maximum pebble 1.2cm diameter (2 or 3 of them), average vc sand/granules; chert pebbles, rounded to subrounded; could this one be VE3? (Davies, 1980)

U2.5: Burrowed interbedded shale and sand (shale dominated)

- Helminthopsis, Terebellina; 1-3cm thick vf sands commonly with loaded bases

U2/U2.5 Contact: shalier above and 7cm zone above with dispersed cg to vc sand/granules; may represent VE3? (Davies, 1980)

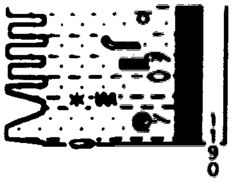
U2: Burrowed interbedded vf sandstone and shale

- burrowing intensity slightly less than U1 and totally dominated by Helminthopsis, 1 Terebellina, rare Palaeophycus, Planolites and Asterosoma, Chondrites; sand beds 2-4cm thick with remnant oscillation to CFR rippling, more undisturbed sand beds preserved with sharp bases and beds fine upwards into silt and mud

U1/U2 Contact: lens of pebbles, shalier above (parasequence boundary?); maximum pebble 1.46cm diameter, average 0.5cm diameter, well to subrounded chert pebbles, discontinuous on the scale of the core; may represent VE3? (Davies, 1980)

U1: Burrowed interbedded vf sandstone and shale

- rare sand beds preserved, sharp based 2-3cm thick with remnant oscillation rippled to CFR,



minor glauconite
- "shredded" appearance, trace fossils as indicated on litholog

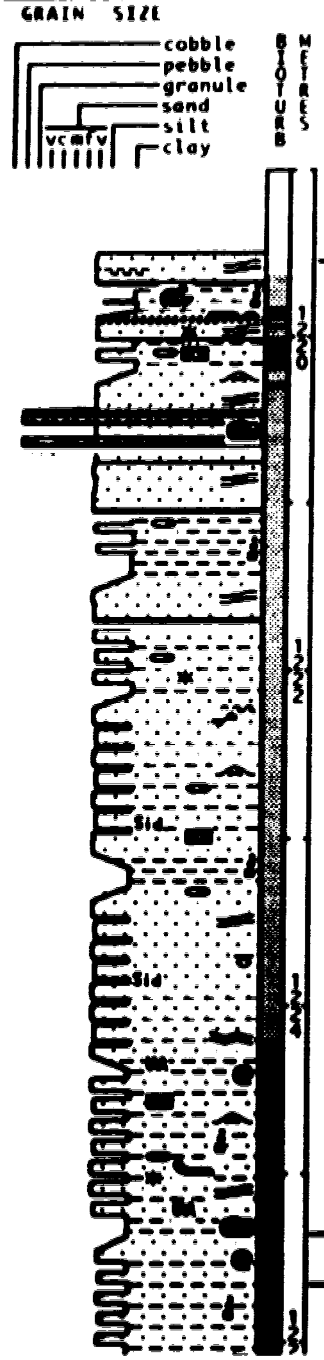
Sundance et al. HUSSAR
16-8-26-19w4

Date logged: February 27, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 944.20 m KB: 948.40 m

Remarks: Core 1; 13 boxes, 1220-1238m (Rec. 18.9m); photogenic, ~on depth; I have a suspicion that some of the boxes could be out of order or core sleeves boxed upside down (especially around U2/U3 Contact)



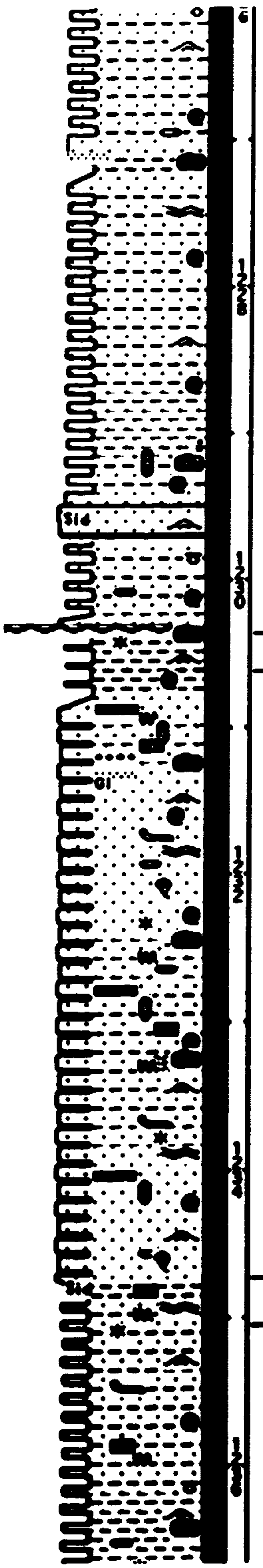
UNIT 4: basically FA2

- less types and numbers of traces upwards; "thick" bedded low angle parallel/undulatory laminated vf sands–only 5-30cm thick; thicker beds upwards
- incipient(?) siderite; very rare Chondrites, Helminthopsis (near unit base) and Asterosoma; lots of small Planolites, but then more burrows and types above the conglomerate/pebbly interval including a muddy Zoophycos
- conglomerate: very thin and in my opinion probably due to one HUGE autocyclic event; monstrous pebbles (well rounded chert and lithics, maximum ~4.4cm diameter); but finer upwards into average 0.8-1cm diameter well rounded chert and lithics, also 1-3mm diameter well rounded granules in interstices; vf sand and silt is BEDDED with these pebbly bits and the pebbles distort their fine laminations

U3(~FA1)/U4(~FA2) Contact

UNIT 3: basically similar to FA1 except vf sand beds in this well tend to be only 1-5cm thick and therefore little physical sedimentary structures preserved, rather, heavily burrowed with only remnant oscillation ripples

about 50/50 sand and shale; traces include: Rosselia, Helminthopsis, Teichichnus



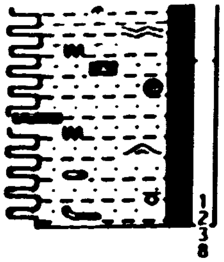
[illegible]
Chondrites, Planolites, Palaeophycus in the sands, Terebellina
- one zone of gritty dispersed mg sand
- upper contact is gradational and there is a bit of a transition zone between FA1 looking stuff into FA2 looking stuff

U2/U3 Contact

UNIT 2: very similar to U1 but more sand, thicker sandstone beds (5-12cm) with more types of trace fossils
- same traces as below with the addition of Ophiomorpha (generally restricted to the thicker bedded sands), and probably Rosselia (mostly truncated Rosselia "stems")
- pebble stringer near top of unit(0.8-2.1cm diameter+granules and some vc sand)

U1/U2 Contact

UNIT 1: Shale dominated interbedded shale and vf Sandstone
- much like Chigwell facies 3: i.e. "shredded" appearance of sands which were undoubtedly originally emplaced with sharp bases; now, due to burrowing, the beds appear "shredded" with hints of original oscillation ripples to wavy parallel bedding
- bits of preserved sands are ~ 1-3cm thick, some with loaded bases
- traces: Helminthopsis, Chondrites, Asterosoma, Terebellina, Planolites, Palaeophycus in some of the thicker preserved lenses of sandstone


1
2
3
8

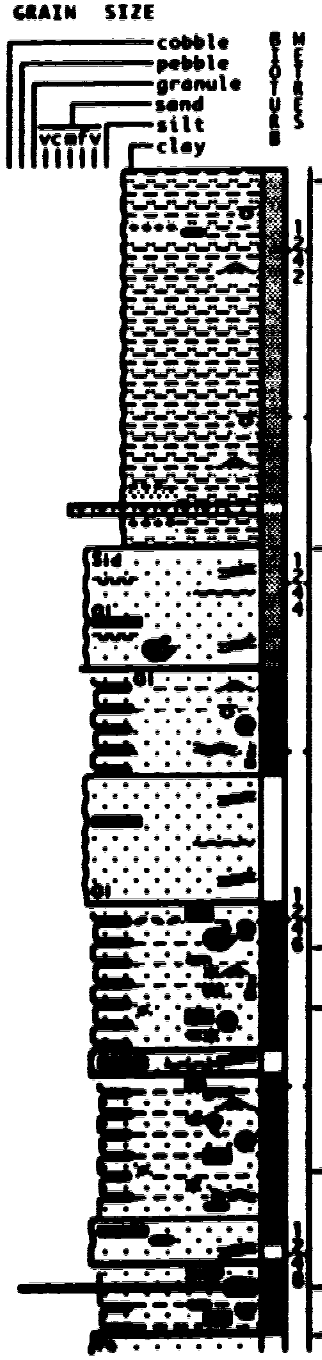
Sundance et al. WAYNE
8-14-26-19w4

Date logged: December 13, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 987.20 m   KB: 990.90 m

Remarks: Core 1; Boxes 1-6, 1242-1251.2m Rec. 8.6m (1241.5-1250.7m)
3.5" unslabbed full diameter core
unphotogenic due to extensive sampling of sands, no box photos



UNIT 2. Dark Silty Shale with mm scale sharp/loaded based silt/vf sand lenses
- 6-7cm thick mU rippled salt and pepper sand with scattered pebbles; pebbles average 5mm and are subangular to well rounded chert and lithic fragments
- gritty zone 35cm from top of core with a cg sand filled Planolites (somewhat like a Glossifungites trace looks like, but no "surface" is visible

U1/U2 Contact

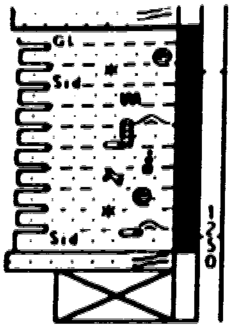
UNIT 1: similar to FA1/FA2 transitional
- sand beds 1-10cm thick, oscillation/combined flow rippled
- lots of burrowing and burrowers, basal part of core dominated by those small ball-like Asterosoma (may be shallow Teichichnus)

rare scattered 1-2mm diameter granules

1 or 2 scattered 2mm diameter granules

discrete pebble bed with well rounded pebbles which are mostly chert, average 2cm diameter, maximum 3.4cm diameter; "VE3.5" candidate?- increased burrowing intensity upwards

discrete 1cm thick pebble bed, pebbles well rounded, mostly chert, well sorted, all pebbles



around 1cm diameter, matrix is vf sand found throughout this unit

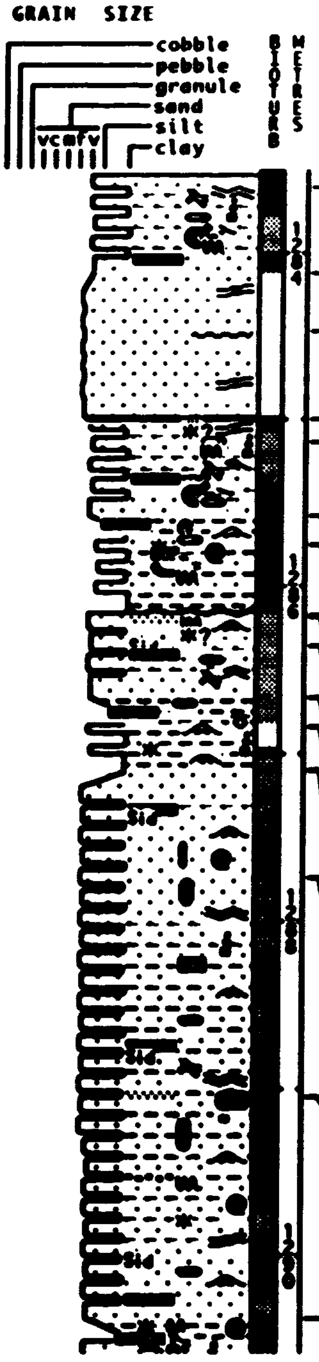
SUN et al HUSSAR
16-21-26-19w4

Date logged: December 10, 1992

Logged by:

Ground: 1005.90 m KB: 1010.10 m

Remarks: 3.5" full diameter core; Core 1; 13 boxes, 1284-1302m (no log; so can't check depths); quite photogenic, but basal few boxes are a little broken up; essentially full recovery; box shot



UNIT 19: essentially the same as U17

U18/U19 Contact

UNIT 18: amalgamated storm beds with low angle parallel laminations and low angle truncation surfaces

U17/U18 Contact

UNIT 17: moderate to rarely burrowed medium bedded interbedded vf sandstone and shale; 2-11cm sandstone beds, some lam-scram; sand beds with low angle inclined to wavy parallel to oscillation ripple laminated; organic detritus; quite a few types of burrows; some sharp based fining up beds that go from sand to silt into organic-rich shale; U19 has nice single Rhizocorallium going through one of the otherwise unburrowed organic-rich shale beds; like transitional FA2...

U16/U17 Contact

UNIT 16: essentially totally burrow mottled vf sandstone and shale with one 10cm thick oscillation rippled sandstone bed near top of unit; unit is totally dominated by Helminthopsis

U15/U16 Contact: extremely sharp and undulatory

a few coarse sand grains

UNIT 15: essentially back to U13-type facies

U14/U15 Contact

UNIT 14: similar to U13 but much more shale and much less burrowing by fewer types of trace fossils; "pinstripe" appearance to the unit with 1-2cm thick sharp based fining upwards vf sandstone beds that are oscillation and combined flow rippled passing up into essentially unburrowed organic-rich shales

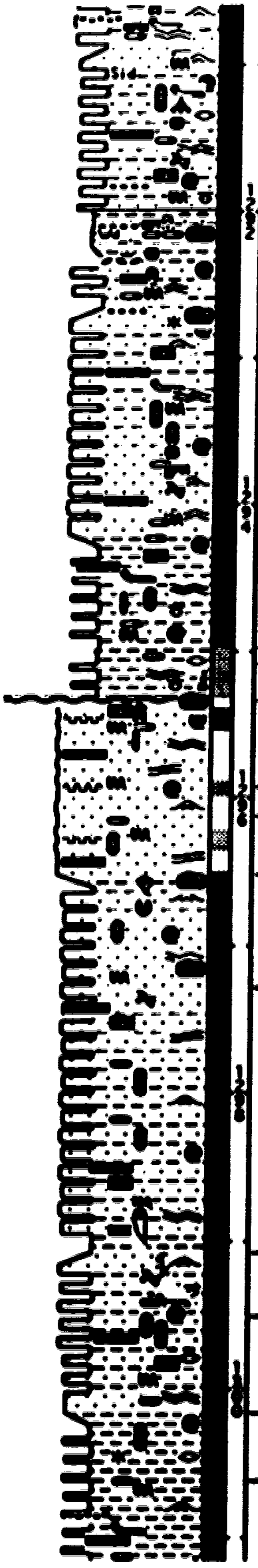
U13/U14 Contact

UNIT 13: rarely to moderately burrowed medium bedded interbedded vf-fL sandstone and shale; sandstone beds 1-8cm thick (most ~5cm) with oscillation, combined flow, low angle inclined and wavy parallel laminations; sandstone beds commonly sharp based, fining up and capped with organic-rich shales with only 1 or 2 cheesy Planolites; decent trace fossil diversity but sizes and populations of each of the ichnogenera are very low; FA2 type stuff; rare cg rippled sands

2cm thick rippled bed of cg-vc sandstone/granules (Cheel and Leckie, 1992)

U12/U13 Contact

[illegible]



UNIT 12: similar to U11 but a little more sand content and lesser burrowing intensity; also that overall "bulbous" nature of the burrowing that SGP suggest are tiny little Teichichnus (could also be clusters of Asterosoma or Palaeophycus); more sharp based fining up oscillation rippled beds with relatively unburrowed organic-rich shales on top of them (storm buried organic detritus??); transitional facies into U13; sand beds 1-4cm thick

U11/U12 Contact

UNIT 11: highly burrow mottled/churned interbedded vf sandstone and shale; sandstone beds mm-1cm thick, commonly lensoidal/discontinuous with rare hints of remnant wavy parallel to oscillation rippling

two 3-4mm granules scattered here

U10/U11 Contact

UNIT 10: silty shale with rare <1cm sharp based vfL sandstone bed; scattered granules; abundant burrows

U9/U10 Contact: probable flooding surface

UNIT 9: similar to U8 but slightly shalier

U8/U9 Contact: possible initial surface of transgression/flooding??

1-2cm thick "lens" of vc sand/granules with maximum clast size 5mm diameter; curious that lens is so close to where there appears to be a slight flooding

UNIT 8: sanding upwards continuation of U7; diverse trace fossil suite; 1-4cm thick sandstone beds with wavy parallel to oscillation ripple laminae; slightly shalier above in unit 9

U7/U8 Contact

UNIT 7: sanding up continuation of U6; unit is quite churned but not really many types of traces seen; mostly Helminthopsis; rare 1-2cm thick loaded based sandstone beds

U6/U7 Contact

UNIT 6: rarely burrowed shale dominated interbedded shale and vfL sandstone in 1-2cm sharp based fining upwards beds that are commonly discontinuous on the scale of the core due to burrowing; rare Planolites visible; unit overlies a flooding surface at the base of U5

UNIT 5: grain supported conglomerate; mostly well to subrounded chert granules (2-6mm diameter), with 4 or 5 rounded pebbles at base of which maximum diameter is 2.1cm; unit is lens-like on the scale of the core; likely a transgressive lag on the "VE3" surface

a single 1cm diameter rounded chert pebble

UNIT 4: fL-vf sandstone with wavy parallel to oscillation rippled sand with some low angle inclined stratification also; organic detritus; shaly zones with minor burrowing; continuation of sanding/coarsening upwards cycle started with U1

U3/U4 Contact

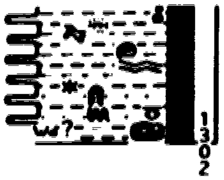
UNIT 3: similar to U2 but with more sandstone percentage; 3-10cm thick sandstone beds that commonly have burrowed tops (lam-scram); sandstones are dominantly wavy parallel to oscillation rippled with rarer low angle inclined stratification; lots of traces with an unusually abundant population of Ophiomorpha nodosa (I find that the O. nodosa and irregulaire are much more common in the pre-"VE3" sanding/coarsening upwards succession); organic detritus accentuating laminae

U2/U3 Contact

UNIT 2: similar to U1 but more sandstone percentage; very rare Terebellina and Teichichnus; Ophiomorpha in U1&2 are commonly the spiky walled O. irregulaire and are very commonly heavily reburrowed with Chondrites or Helminthopsis

U1/U2 Contact

UNIT 1: shale dominated interbedded shale and sandstone; "shredded" appearance due to burrowing which makes beds of mm-3cm thick vfL sandstone beds discontinuous; diverse ichnofossils but not totally burrowed; dominated by nice concentrically laminated Asterosoma and Helminthopsis (to the exclusion of definite Chondrites); wavy parallel to oscillation rippled



[illegible]
accentuating laminae, basal part of one overall sanding upwards cycle comprising Units 1-4

SUNDANCE et al. WAYNE
8-22-26-19w4

Date logged: August 1, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 1003.00 m KB: 1007.20 m

Remarks: Core 1; 12 boxes, 1267m-1285m, Recovered 16.5m; 3.5" full diameter core; OK/marginally photogenic, no box shots, so I couldn't recheck this well

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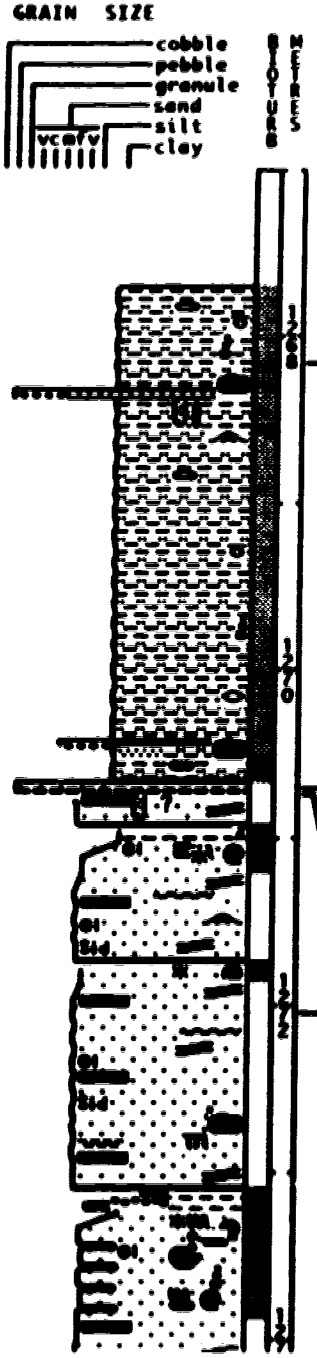
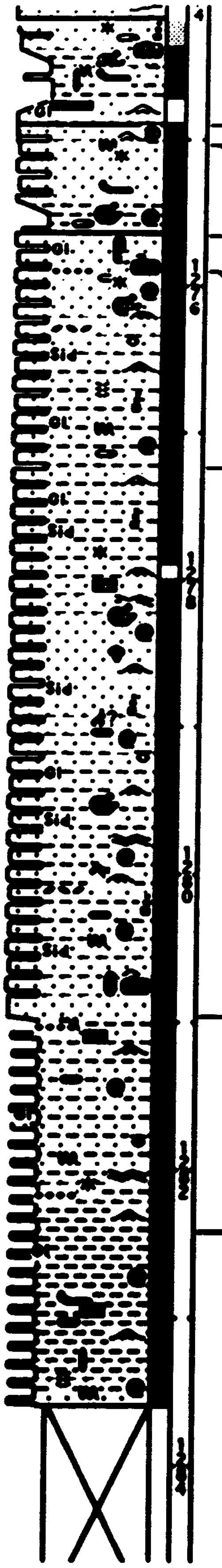


UNIT 6: Dark Shale with mm scale Discontinuous Siltstone lenses
- some sharp based vf sandstone/siltstone beds with vague hints of oscillation ripples, two sharp based/loaded salt and pepper mg pebbly sandstone beds with pebbles(lower one has only a couple of granules, upper one has pebbles up to 1.6cm diameter)

UNIT 5: Poorly Sorted ?Matrix Supported Conglomerate
- transgressive lag, matrix is mg salt and pepper sandstone, vague hint of coarser material being piped down into lower unit(Glossifungites?), pebbles: chert and lithics, maximum ~1.2cm diameter, average ~0.75-1.1cm diameter

U4/U5 "Contact": actual contact has been plugged/is missing

UNIT 4: Facies Association, really of Interbedded vf Sandstone/Shale with thickly bedded vf-fL Sandstone
- thickly bedded sandstone beds (16cm-1.2m thick) are low angle parallel to curvilinear, some combined flow rippling, low angle truncation/scoured surfaces indicating probable amalgamated storm-generated sandstone beds; "coffee grounds" type of organic material accentuating the laminae, possible waning flow sequences
- interbedded portions are either burrowed or normally colour graded with oscillation to combined flow ripples



U3/U4 Contact

UNIT 3: Thoroughly Burrowed Interbedded vf Sandstune and Shale
- goes from shale to vf sandstone dominated, 1-2cm burrowed but relatively continuous vf sandstone beds near unit top

U2/U3 Contact: interesting that burrowing intensity does increase just above here, but due to lack of box shots, I am unable to confirm for sure

this is a Cheel and Leckie, 1992 type pebbly horizon

UNIT 2: Interbedded vf Sandstone and Shale (minor Siltstone)
- parts of unit are moderately burrowed while other parts are preserved as sharp based oscillation/combined flow rippled vf Sandstone that normally colour grade up into siltstone and shale(waning flow sequences)
- the trace diversity is quite good, however there aren't very many of any of them: 1 Rosselia, 1 tenuous Teichichnus, 1 Ophiomorpha, a couple of nice Rhizocoralliums, rare Asterosoma(unless the clusters of Planolites are actually arms of Asterosoma; also may be ?Phycodes), rare Chondrites, lots of Helminthopsis in basal couple of metres but less upwards, abundant Planolites
- portions of this unit are mud dominated strictly speaking
- rare rip-up clasts in sandstone beds

U1/U2 Contact

UNIT 1: Thoroughly Burrowed Interbedded vf Sandstone and Shale
- 1-3cm thick sandstone beds, some with loaded bases, typical background regional Viking traces: Helminthopsis, small Terebellina, Chondrites, Asterosoma, Planolites, small mud-lined Skolithos, scattered granules/coarse sand

SUNDANCE Hussar
8-17-26-20w4

Date logged: July 27, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 916.10 m KB: 920.60 m

Remarks: Core 1; 8 boxes, 1226m-1237m (actually 1225.78-1237.47m), Recovered 11m (actually recovered 11.69m); 3.5" full diameter core; photogenic, have box shots and prints; BFS 1190m

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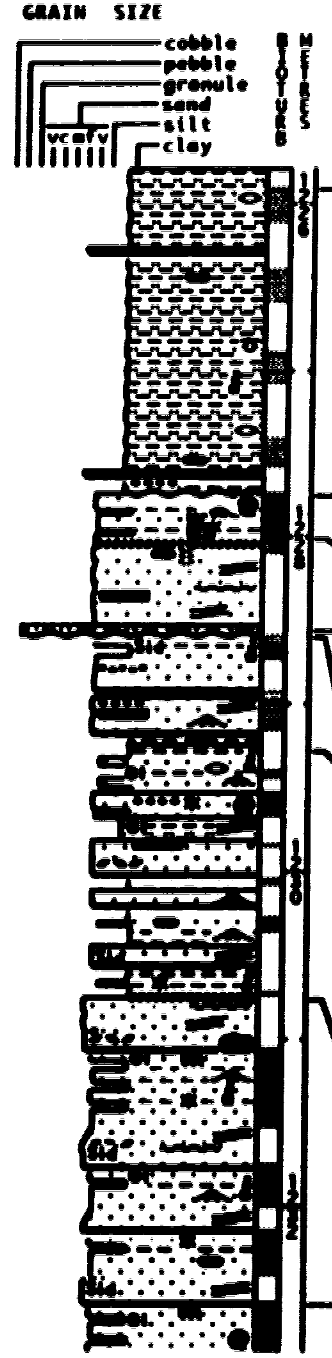


UNIT 6: Dark Silty Shale with mm scale sharp based siltstone/vf sandstone beds which are commonly discontinuous on the scale of the core; maximum sandstone bed thickness=2cm (2 of them are lg)
- a few pebbles at base, rounded chert, maximum ~1.2cm diameter, average ~0.75cm diameter

U5/U6 Contact: Transgressive surface of erosion with rare black chert pebbles mantling the surface

UNIT 5: Low Angle Laminated vf Sandstone that grades up into a Burrowed Interbedded vf Sandstone and Shale

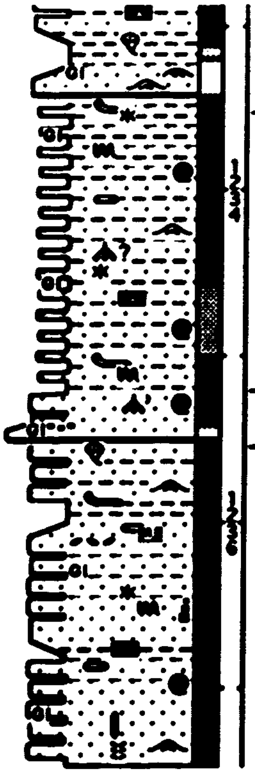
UNIT 4: Poorly Sorted Clast Supported Conglomerate
- appears to fine upwards slightly, some sideritized clasts, chert granules to pebbles (maximum ~3.5cm diameter), mostly all well rounded clasts, matrix is well sorted vf sandstone which is macroscopically identical to the vf sandstone above

U3/U4 Contact

UNIT 3: Interbedded vf Sandstone and Shale Interbedded with Thicker Bedded vfU-fL Low Angle Laminated Sandstone (i.e. Facies Association 2)
- thicker sandstone beds range in thickness from ~5-25cm thick and there are more of them in the basal portion of the unit and the sands get fewer and thinner upwards within the unit, sands are sharp based, low angle parallel laminated with some low angle truncations (HCS or SCS?) and rip-ups, some of which are sideritized, bed tops are generally gradational and/or slightly burrowed (likely waning flow sequences)
- interbedded portions do not have much burrowing except very rarely in thin beds, low trace diversity, possible syneresis cracks near the top, vf sandstones/siltstones are very sharp based and normally grade upwards into organic-rich shales, sandstone beds commonly have hints of oscillation rippled/parallel wavy bedding, traces are rare Chondrites, Helminthopsis, Asterosoma, Planolites/Thalassinoides

Interesting that above here, there is a significant thickness of section with very few substantially thick storm-generated sandstone beds; perhaps "turning off" deposition on an active deltaic lobe?, lobe switching? or perhaps recording some sort of seasonal fluctuation in storm-generated sand deposition?...; this may actually represent a correlatable "event"

U2/U3 Contact



UNIT 2: Burrowed Interbedded Shale and vf Sandstone

- overall, unit sands upwards, one significant sand bed that is oscillation rippled and grading up into angles that suggest some current influence (combined flow rippling)
- according to Tom Saunders, my Dactyloidites are actually Asterosoma and my Asterosoma are actually just thick walled Palaeophycus; NB- the "Dactyloidites" are more likely Asterosoma or ?Phycodes

U1/U2 Contact

UNIT 1: Interbedded moderately to commonly Burrowed vf Sandstone and Shale

- wide trace fossil diversity, looks fully open marine, bedding thicknesses 3-10cm, one sharp based mg sandstone bedbed

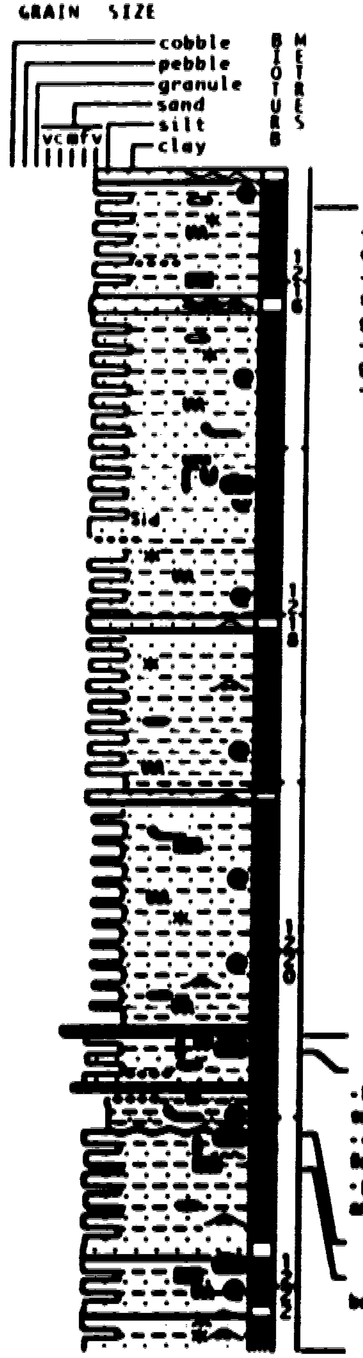
Sundance et al. HUSSAR
16-25-26-20w4

Date logged: July 9, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 907.10 m KB: 911.30 m

Remarks: Core 1; 13 boxes, 3.5" full diameter core; ~1215.3m-1234m (haven't checked depths against well logs yet); photogenic; no box shots; mostly lower, regional Viking cycles cored



UNIT 8: Interbedded Sandstone and Shale
- overall, unit sands upwards with more Chondrites in the lower shale dominated part; upper 3m of unit has some 3-5cm thick jet black mudstones that are rarely burrowed
- possible cryptic bed junction where Arenicolites is but it is probably part of the original softground assemblage; ~40cm below the Arenicolites/Skolithos is a 5cm zone of mg with granules, sand; with sideritisation
- the thicker preserved vf sandstone beds are ~7-10cm thick, sharp based with gradational/burrowed tops and oscillation rippled/wavy parallel bedded (HCS???)
- similar to UNIT 2, but slighty muddier and more thoroughly burrowed

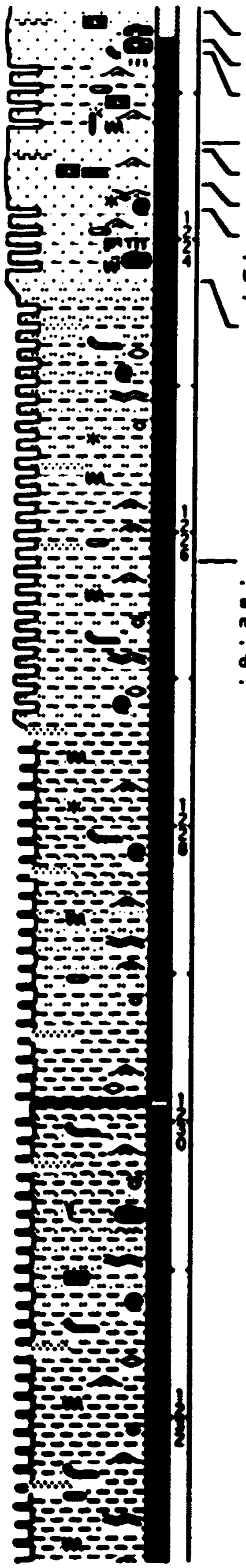
U7/U8 Contact

UNIT 7: Burrowed Interbedded Sandstone and Shale
- basal 50cm is thoroughly churned with scattered pebbles (mostly chert, some lithics, sub-rounded to rounded, maximum ~1cm diameter, average ~3-5mm diameter)
- 4cm thick pebbly lg sandstone unit within that shows hints of small scale current to combined flow ripples
- probable Glossifungites "surface" at unit top (Skolithos, cross cuts softground assemblage and is passively filled with sub-angular salt and pepper sand)

U6/U7 Contact

UNIT 6: same as UNIT2, but with a pair of thicker interbedded oscillation rippled vf sandstone beds

[illegible]



UNIT 5: same as UNIT 3

U4/U5 Contact

UNIT 4: same as UNIT 2

U3/U4 Contact

UNIT 3: Oscillation Rippled vf Sandstone with little Burrowing

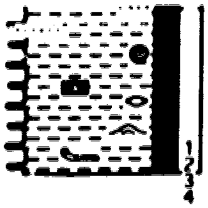
U2/U3 Contact

UNIT 2: Burrowed Interbedded vf Sandstone and Shale
- sands are all sharp based and oscillation rippled; ~5cm thick sand beds, sandier/siltier than UNIT 1; muddy beds are thoroughly burrowed
- possible synaeresis cracks?

U1/U2 Contact

UNIT 1: Interbedded Shale, Siltstone and vf Sandstone
- basal 6.7m of unit has rare Chondrites, Helminthopsis and thinly bedded siltstone/vf sandstones (0.5-3cm thick) that have hints of small scale oscillation to combined flow ripples; more Helminthopsis above as the sequence sands upwards; possible ?Rosselia, ?Trichichnus
- siltstone/sandstone lenses are sharp based, commonly loaded into shale, and mostly discontinuous on the scale of the core due to burrowing
- 4cm thick bentonite within this unit

248



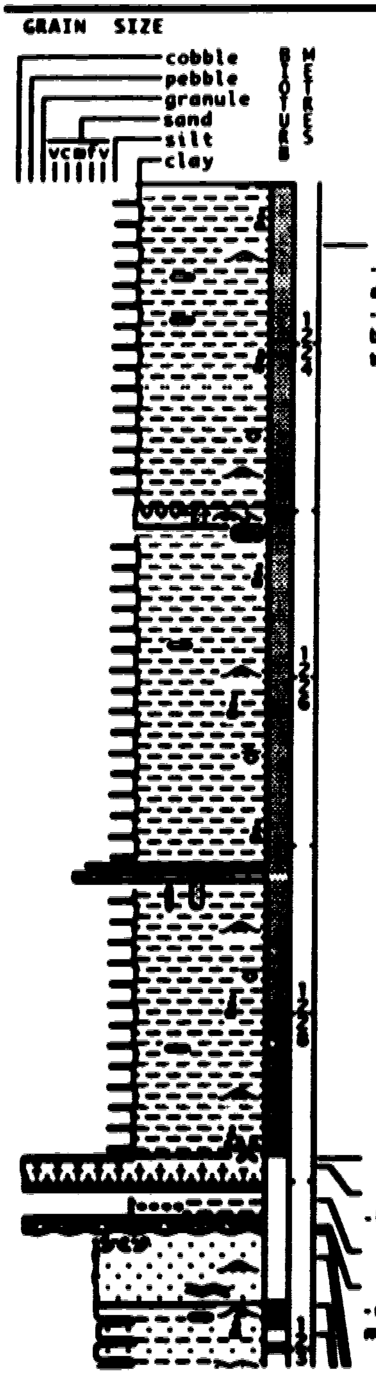
CPOG HUSSAR
7-35-26-20w4

Date logged: July 11, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 922.90 m   KB: 927.20 m

Remarks: Core 1; 9 boxes, 4012'-4054'; 3.5" full diameter core; reasonably photogenic, have box shots and prints



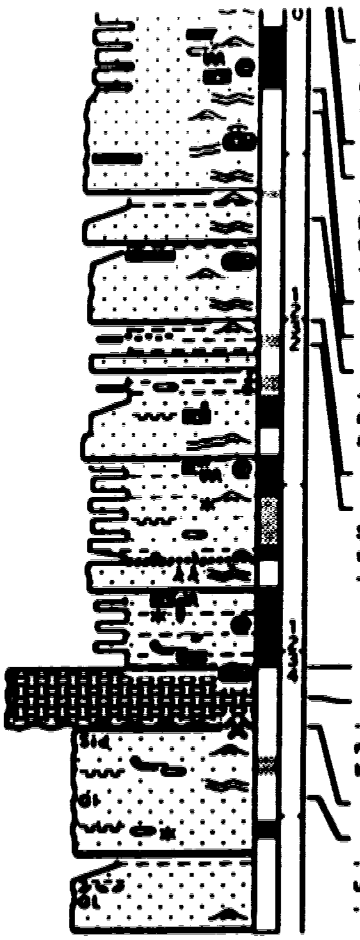
UNIT 10: Interbedded Shale, Siltstone and Sandstone
- mostly shale with very minor sharp based, commonly loaded siltstone/vf sandstone beds that are commonly 1cm or less in thickness
- salt and pepper cross bedded sand unit within as well as a 12cm thick bentonite that is burrowed by Diplocraterion (2 possible Glossifungites "surfaces") and has small scale current to combined flow ripples

U9/U10 Contact

UNIT 9: essentially same as UNIT 7 but with even more shaly matrix
- U7/U8/U9 are all probably transgressive deposits

UNIT 8: Dark Shale with rare pebbles

UNIT 7: Very Poorly Sorted Clast Supported Conglomerate
- matrix is mud to mg sand; pebbles are both chert and lithics; mostly sub-rounded to rounded; maximum pebble ~1.2cm diameter; average ~0.4cm diameter



U6/U7 Contact

UNIT 6. Low angle laminated to combined flow rippled vf Sandstone
- low angle inclined laminations, less than 10-12 degrees, larger bedforms than "small scale ripples"
- upper 15cm is sideritised and contains coaly fragments (possibly ripped up material)

U5/U6 Contact

UNIT 5: Interbedded Sandstone, Siltstone and Mudstone
- normally colour graded beds, more burrowed+more trace diversity lower in this unit which lessens upwards; remnant oscillation ripples that are commonly not continuous on the scale of the core
- interbedding on the order of 1-2cm

U4/U5 Contact

essentially the same as UNIT 4; 9cm of mud below may not be in place

UNIT 4: Combined Flow Rippled vf Sandstone
- parallel wavy bedded, low angle truncation surfaces (~10 degrees): probably combined flow ripples, possibly some current component to these laminations; organic rich laminae accentuate the structure

U3/U4 Contact

UNIT 3: Interbedded Shale and Sandstone that itself is interbedded (i.e punctuated)with Sharp based fg Oscillation Rippled-Wavy Parallel Bedded Sandstone (probably storm-generated sandstone beds)
- decrease in burrowing intensity and diversity upwards in the shalier portions of this unit...

U2/U3 Contact

UNIT 2: Clast Supported Conglomerate
- rounded chert and lithic pebbles; maximum ~5cm diameter, average ~1.5-2cm diameter; matrix is granules(rarely) but mostly very well sorted vf sand which is macroscopically identical to the surrounding sand

U1/U2 Contact: likely "VE3.5" candidate, with increased burrowing intensity above

UNIT 1: fg Oscillation Rippled/Massive appearing Sandstone with rare shaly interbeds
- well sorted, moderately rounded sand, oscillation rippled to apparently massive(or very gently undulating, parallel wavy bedded)
- minor burrowing in shaly interbeds

Sundance et al. WAYNE
6-36-26-20w4

Date logged: February 28, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 909.80 m KB: 914.20 m

Remarks: Core 1; 13 boxes, 1209-1227m (actually 1210.5-1228.5m), Rec. 18.1m; 3.5" full diameter core; photogenic

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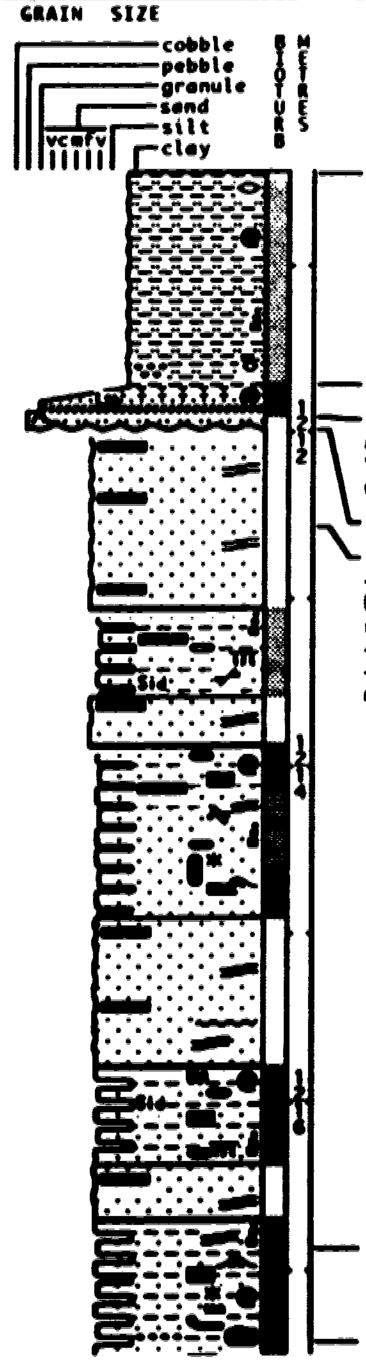


UNIT 6: Dark silty shale with mm-1cm scale discontinuous silt/vf sand beds
- sharp based with remnant oscillation ripples; a few rare scattered pebbles in the basal 10cm of unit

U5/U6 Contact

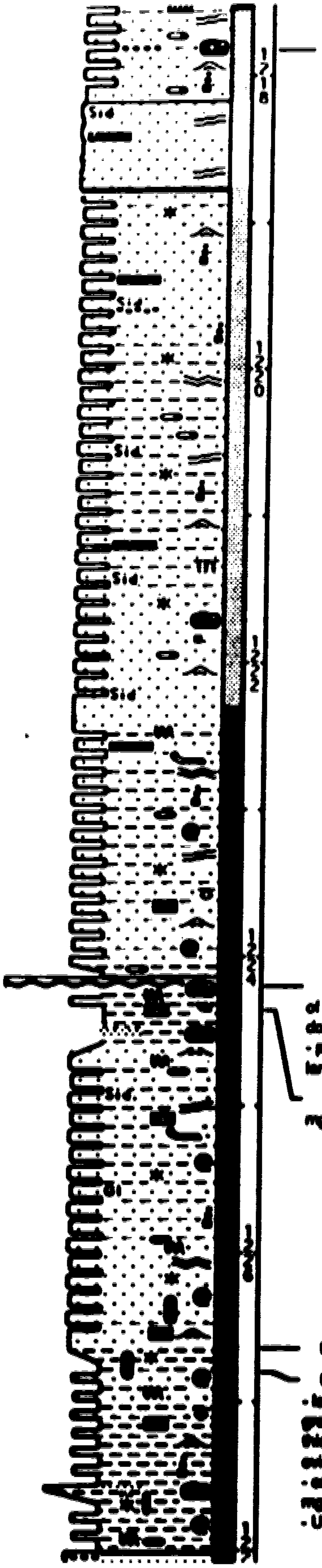
UNIT 5: probable transgressive conglomerate; pebbles generally sub to well rounded; chert and lithics; average 0.5-0.9cm diameter, rare pebbles up to 1.5-2.1cm diameter; matrix is that "salt and pepper" mg sand; goes up into churned sandy shale with scattered pebbles, and then up into similar lithology with many more scattered pebbles (probably reworked biologically)

U4(FA2)/U5(Transgressive Lag) Contact

UNIT 4: typical FA2
- thicker sands upwards; more burrowing near base; overall less burrowing than FA1 but burrowing in FA2 can still be abundant locally with corresponding higher diversity: this is strange!
- traces, bed thicknesses given on litholog profile
- in interbedded portion, the low angle laminated sands are 1-10cm thick with some oscillation ripples as well as very small scale combined flow ripples

cluster of small Terebellinas here: possibly Schaubcylindrichnus?? (does not seem likely)

possible "VE3.5" trace in this well



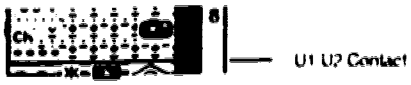
Cheel and Leckie, 1992-type pebbly storm bed

U3/U4(FA2) Contact: lots of pebbles: concentrated in a lens and not continuous on the scale of the core; some of the coarse material ~30cm below here may simply have been burrowed down from this contact; essentially go into FA2-type sediment above here
- pebbles are mostly rounded chert; average 0.3-1.1cm diameter; 2 sideritised clasts the largest of which is 6cm in diameter!!

UNIT 3: basically FA1; 1-10cm thick oscillation to low angle undulatory laminations; scattered mg sand and small pebbles (average 0.4cm diameter)

U2/U3 Contact

UNIT 2: Burrowed interbedded vf sand and shale
- lots of Helminthopsis, Chondrites; pebbles (3 largest=2, 1.8, 1.5cm diameter; average granules to 0.5cm diameter pebbles) scattered (probably by burrowers) through basal ~30cm: this almost certainly represents a flooding surface (parasequence boundary) and this is also evident on the logs
- one thin mg sand bed with very sharp walled Skolithos subtending from it that is filled with mg-cg sand (autocyclic Glossifungites??)
- U3 above is essentially the same but has a higher % sandstone than U2


Ch
8
U1 U2 Contact

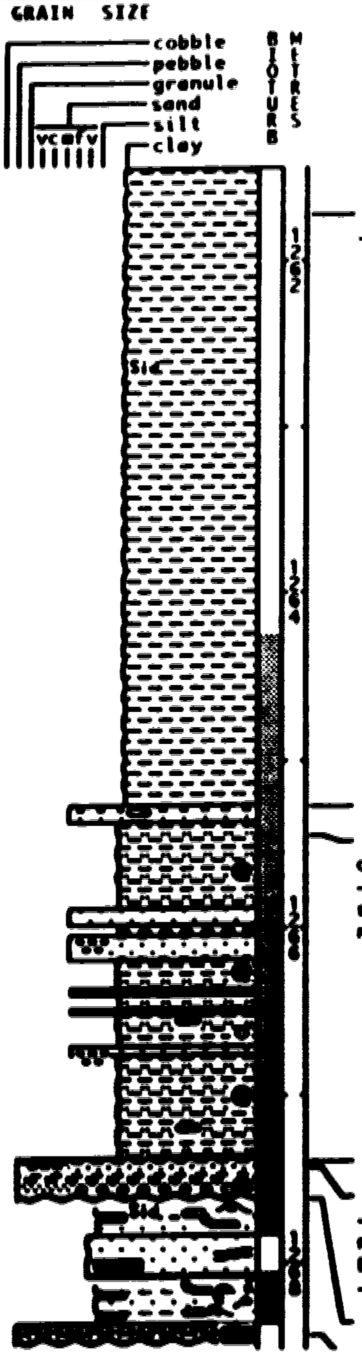
TGT MOBIL OIL CPR N STANDARD 16-1
7-16-26-22w4

Date logged: December 10, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 878.70 m KB: 883.30 m

Remarks: Core1 Boxes 1-12(7-12 logged) 4105-4165' (prob 4138-4167'); Core2
Boxes 1-8 4165-4200' (probably 4167-4202')
reasonably photogenic; actual thicknesses of beds suspect since very
few pieces of the core could be properly put together



UNIT 4: Dark Silty Shale
- very little silt here, and no mg sand in this unit, local zones of sideritisation

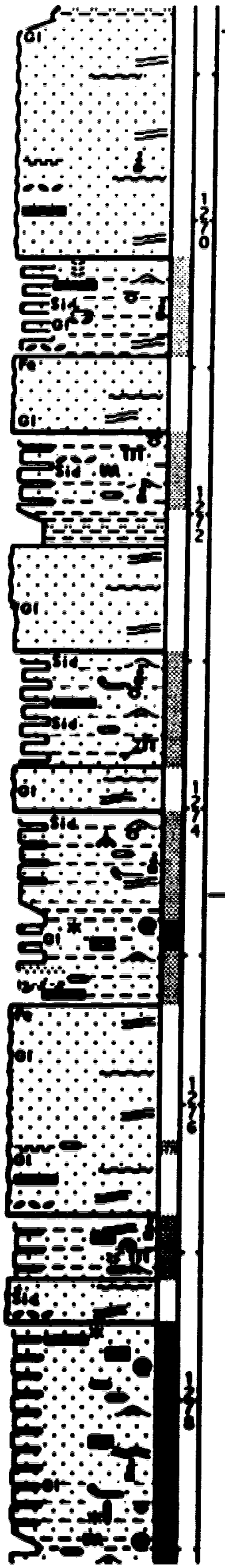
U3/U4 Contact

UNIT 3: Dark Silty Shale with interbeds of churned mg salt and pepper sand beds with dispersed pebbles and granules
- sands are lens-like probably due to burrowing, however only Planolites is recognisable; scattered pebbles(maximum 1cm diameter) and 2-3mm diameter granules are angular to well rounded, chert and lithic fragments

U2/U3 Contact

UNIT 2: Poorly Sorted Churned matrix Supported Conglomerate
- mostly well rounded chert and lithic pebbles, maximum diameter 2cm, matrix is salt and pepper mg sand and extremely friable shale, appears thoroughly burrowed but no discernible trace fossils
- probably a transgressive deposit

U1/U2 Contact

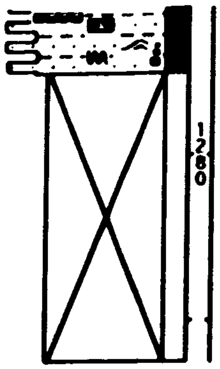


the "anomalous" well sorted conglomerate that generally fines upwards

UNIT 2: basically transitional FA2 into FA2 with the anomalous Sorted fining upwards conglomerate

- thick sands: low angle parallel to undulatory laminations with low angle truncation surfaces, glauconitic, some angular shale and sideritised rip-up clasts, generally vfU-fL, well sorted sands, organic detritus commonly accentuate the laminae
- interbedded portion: less burrowed upwards, sharp based normally graded beds common, loaded bases, waning flow deposits, some definite CFR, oscillation ripples, low angle undulatory laminations, glauconite, some shale rip-up clasts, minor sideritisation, synaeresis cracks increase upwards
- conglomerate: well sorted, fines upwards, clasts generally well rounded, mixture of chert, lithics, sideritised clasts, 4.5cm maximum diameter at base to 2-3mm diameter at top, matrix is same vf sand found throughout the section

some great combined flow ripples and low angle truncation surfaces in the probable HCS bed just above


1280

Maynard Dorothy
10-21-27-17w4

Date logged: December 14, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 815.60 m KB: 819.60 m

Remarks: 3.5" full diameter core; lots of sampling and very few pieces fit together; Core 1, 13 boxes, 3374'-3434' Rec. 57.3'; Core 2, 5 boxes, 3434'-3457' (actually 3439'-3462'), Rec. 21.1'; reasonably photogenic; 6 box shots; top 1.5m of core not shot

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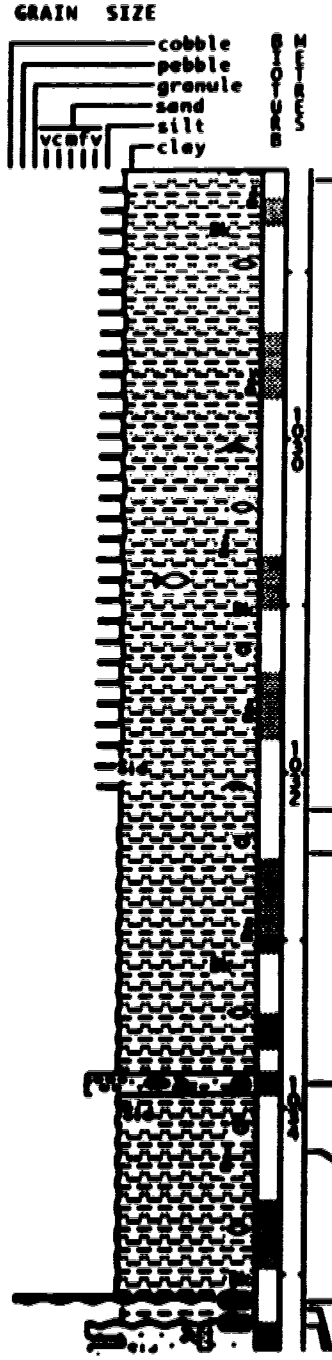


UNIT 20: very similar to U19 but with more (but still rare) wavy parallel to oscillation rippled to combined flow rippled vfL sandstone beds up to 1cm thick; sharp based fining up beds also; local zones of vf grained siderite cemented shales; fish scales visible on bedding planes of shales

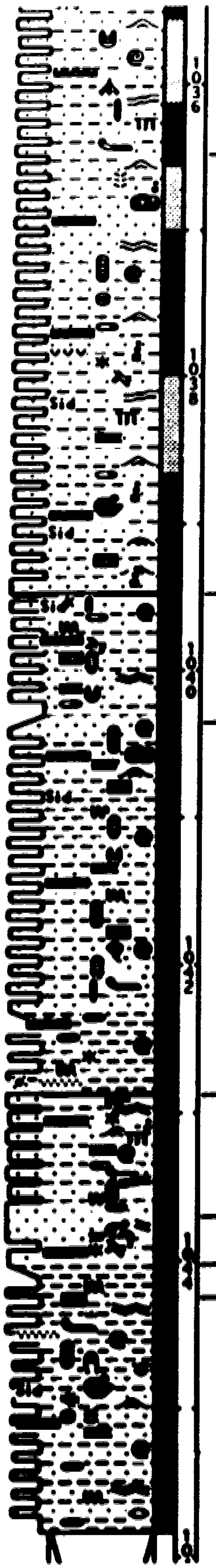
U19/U20 Contact

UNIT 19: similar to U17; loading

UNIT 18: mottled sandy and granuley friable shale; rare Planolites, Terebellina and Thalassinoides (may even be ?Ophiomorpha); dispersed granules subrounded 2-4mm diameter; 2cm lg sandstone bed

UNIT 17: silty friable shale with mm scale sharp based fining up, discontinuous siltstone to vfL sandstone "lenses"; rare zone of vf grained siderite cemented shale near unit top

UNIT 16: conglomerate; rounded to subrounded, mostly chert with minor small lithics, matrix is salt and pepper mg sandstone, more pebbles than the underlying pebbly sandstone, maximum pebble is 1.[illegible]cm diameter



UNIT 15 black friable shale

U13/U14 Contact UNIT 14: 1cm of salt and pepper mL-cL sand with rare pebbles (rounded, maximum 8mm diameter, chert); Glossifungites suite with Thalassinoides

UNIT 13: essentially FA2; sandstone beds 1-13cm thick; different zones within this unit are actually shale dominated but overall unit is sand dominated; traces are quite diverse but are concentrated into thinner intervals, are more sporadically distributed, and there are fewer actual numbers and sizes; local synaeresis cracks, siderite cemented zones; 1.64m from unit base is a very thin bentonitic/smectitic horizon; sandstone beds are dominantly oscillation to combined flow to wavy parallel laminated with lesser low angle inclined stratification

U12/U13 Contact: essentially FA1/FA2 contact

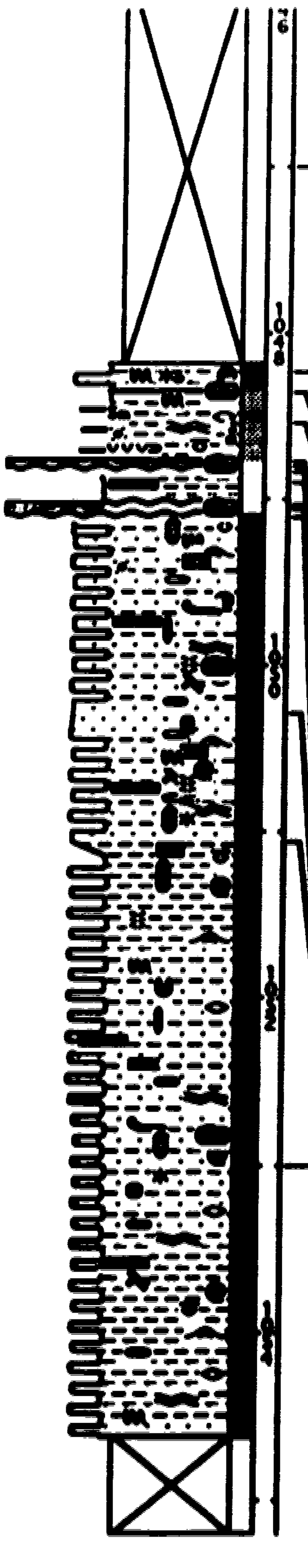
UNIT 12: abundantly burrowed churned/mottled vf sandstone and shale with increasing sandstone content upwards; upper ~1.5cm there are some 2-7cm thick wavy parallel to oscillation rippled sandstone beds with burrowed tops (lam-scram, most commonly with Ophiomorpha nodosa); below the upper 1.5m, there is essentially no bedded sandstone, it is all burrow mottled; essentially like totally equilibrium marine community lower shoreface/interdistributary portion of delta with no freshwater influence (i.e. like an inactive lobe or simply from inactive deltaic sedimentation below to more delta/freshwater influenced deltaic deposition above)

U11/U12 Contact: may represent the basinward expression of the "VE3.5" conglomerate?? (NB: serious increase in burrow intensity above this slight flooding event)

U10/U11 Contact

U9/U10 Contact

UNITS 9-11: one overall sanding upwards cycle with "shredded" appearing mm-3cm thick vfL-vf sandstone beds with remnant wavy parallel and oscillation ripples going up into a similar sandier facies and on up to U11 which has 2-7cm thick low angle inclined/wavy parallel/oscillation ripple laminae; organic detritus throughout with slightly less burrowing intensity upwards; U11/U12 Contact is based on sand % and a marked increase in burrowing above in U12; contact is also marked by scattered mL-cL sand grains around and above the contact; very diverse assemblage of trace fossils that gets less intense and slightly more storm dominated upwards



1046.65m-1048.19m was not actually cored

UNIT 8: commonly burrowed and mottled sandstone and shale; quite churned with many types of trace fossils; maximum 8mm diameter pebble at unit base with scattered granules throughout the unit; rounded to subrounded chert and minor lithic granules/pebbles

U7/U8 Contact

UNIT 7: interbedded shale with minor silt/vfL sand; sand beds are sharp based fining up with rare hints of wavy parallel laminations; sandstone beds commonly discontinuous on the scale of the core due to minor burrowing; sand beds mm-1cm thick; local loaded base; bentonitic horizon just above conglomerate with smectitic clay persisting throughout U7; rare scattered granules

U6/U7 Contact

UNIT 6: clast supported conglomerate; well to subrounded chert pebbles; maximum 2.6cm diameter; average 4-7mm diameter

U5/U6 Contact

UNIT 5: silty shale with minor organic detritus; silt/vf sand bed at top of unit with wvy parallel laminations

U4/U5 Contact

UNIT 4: clast supported conglomerate; well to subrounded chert pebbles/granules; maximum clast 1cm diameter with overwhelming majority of clasts 2-6mm diameter granules; sideritised clasts up to 6.5cm diameter; sandstone below contact is also slightly sideritised (therefore may be rip-up clasts in the conglomerate?); matrix is cg-mg sand; coalified wood rip-up clasts also found

U3/U4 Contact probably "VE3"

U2/U3 Contact

U1/U2 Contact

UNITS 1-3: one overall sanding upwards succession; more sand % upwards; abundant to common burrowing intensity; relatively diverse marine, "equilibrium" trace fossil suite; "shredded" appearance to all these units due to extensive burrowing leaving "lenses" of mm-4cm thick vf sandstone; sand beds with wavy parallel to oscillation ripple laminae

Sundance et al. ROSEDALE
6-9-27-18w4

Date logged: July 17, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 866.80 m KB: 871.20 m

Remarks: Core 1; 13 boxes, 1119m-1137m (probably 1118.3m-1137m), Rec. 18.25m; 3.5" full diameter core, very photogenic; have box shots and prints

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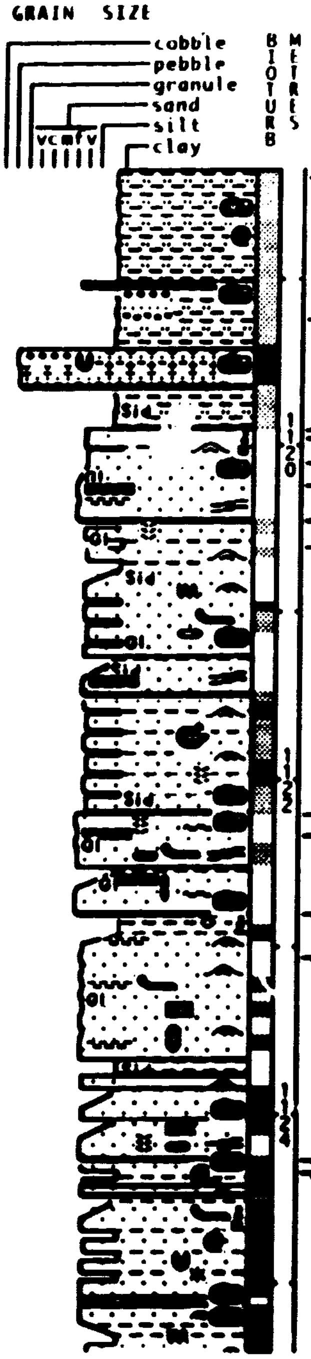


UNIT 12: Dark Shale with mm scale siltstone stringers/laminae that are generally discontinuous on the scale of the core
- gritty pebbly zone with Arenicolites shafts (granules-0.8cm diameter chert and lithic pebbles)
- another pebbly zone above (granules-1.7cm diameter chert pebbles)

zone of some dispersed mg, salt and pepper sand grains

U11/U12 Contact: Transgressive

UNIT 11: Colour Graded Relatively Unburrowed Interbedded Cemented Sandstone and Dark Mudstone (0.5-10cm thick sandstone beds)

U10/U11 Contact

UNIT 10: Low angle laminated to Oscillation rippled vf Sandstone

U9/U10 Contact

UNIT 9: Moderately burrowed Interbedded vf Sandstone and Dark Shale
- sand beds 1-10cm thick are oscillation to combined flow rippled; dark shales with rare Planolites

U8/U9 Contact

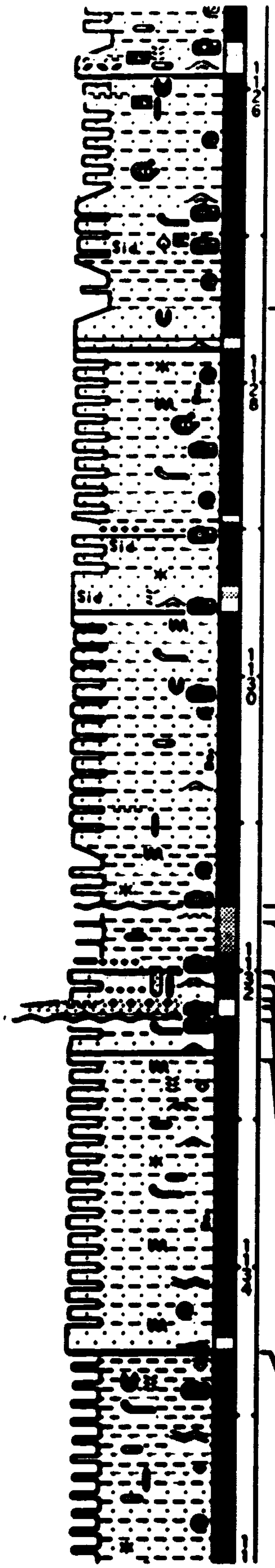
UNIT 8: vf Sandstone with combined flow/Oscillation ripples, and common low angle truncation surfaces
- parts look like they're getting up to high angle trough cross bedding(at least CFR definitely, but likely not cross bedding as the angles are rarely higher than 15 degrees in the core and can simply be accounted for by low angle truncation surfaces created by amalgamated storm sandstones), organic "coffee grounds" accentuate the low angle laminations, rare shalier zones that are slightly burrowed

U7/U8 Contact

UNIT 7: vf Oscillation/combined flow rippled Sandstone v [illegible] re burrowed shaly interbeds (core is very shattered up in this interval)
- some sideritization in shale; local burrowing in the shalier portions; low angle ripple laminations, probably oscillation with small current component as angles are starting to get up to 10-15 degrees

U6/U7 Contact: essentially FA1/FA2 Contact

UNIT 6: Interbedded vf Sandstone and Shale
- some up to fg; wide variety of trace fossils; basal ~2.5m contains most of the Terebellina and above this is really where we get the most Chondrites and Rhizocorallium (other traces: Planolites, Skolithos, Arenicolites, possible small ?Diplocraterion; escape traces, Ophiomorpha, more Rhizocorallium, Palaeophycus in the more continuous sandstone beds, Asterosoma etc...



- more sand beds upwards within the unit, [illegible] near the top
- sand beds 3-12cm thick and burrowed discontinuous ones with possible remnant oscillation ripples and in the thicker more continuous sandstone beds there are wavy parallel laminations (HCS?), combined flow/oscillation ripples, to low angle parallel laminations
- pebble stringer at base of unit(0.5-1.5cm diameter) and siderite overlain by scattered pebbles(0.5-1cm diameter) ~2.4m up from unit base
- also carbonised plant fragment(fern leaf?)

many of the interbedded sandstone and shale intervals above here are totally churned by burrowing organisms (?related to a possible ?"VE 3.5" event)

U5/U6 Contact

UNIT 5: Interbedded Shale and vf Sandstone (with scattered pebbles near the base), (90/10)
- low diversity of traces, possible Glossifungites(Skolithos) "surface" at lower contact, less sand upwards, discontinuous vf sandstone/siltstone lenses with remnant oscillation ripples

U4/U5 Contact

UNIT 4: churned interbedded vf sandstone and shale (60/40)

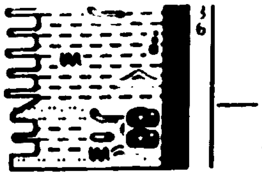
U3/U4 Contact

UNIT 3: Very Poorly Sorted Conglomerate
- mostly chert pebbles(0.5-2.5cm, well rounded) mixed with granules, fg-mg sand and apparently bedded thin dark mudstone wisps(!!)
- a second look reveals that this conglomerate fines upwards from clast supported at the base into a pebbly/granuley mg sandstone above

U2/U3 Contact

UNIT 2: Burrowed and Interbedded vf-fL Sandstone and Shale
- some normally colour graded beds, sandstone beds range from ~3-7cm thick with oscillation to combined flow rippled to parallel wavy bedded, sandstone beds are sharp based and generally have burrowed tops, sandstone beds also contain escape traces as well as the rare Palaeophycus found in this facies
- lots of Helminthopsis
- continuation of sanding upwards sequence

U1/U2 Contact



UNIT 1 Burrowed Interbedded Shale, Siltstone and vf Sandstone
- grades into sandier facies above, churned but little lithologic contrast to discern individual trace types, very small traces, discontinuous vf sand beds with loaded bases

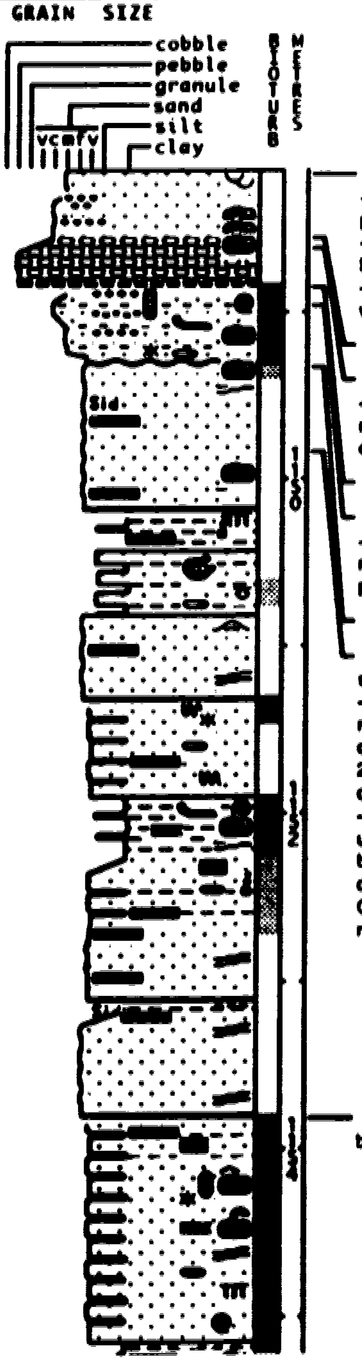
CPOG EW WAYNE
7-1-27-19w4

Date logged: March 1, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 883.90 m KB: 887.30 m

Remarks: Core 1; 9 boxes, 3768'-3808' (~1148.5-1160.7m), ~0n depth (+/-2'); photogenic; box shots and prints



UNIT 5: (Trough??) Cross bedded mg-cg pebbly Sandstones
- pebbles/granules accentuate the high angle cross beds, average 0.4-0.8cm diameter pebbles/granules; sand is mostly mL but can get up to cU, especially near the base of the unit
- cross bed sets minimum 7-10cm, probably not planar tabular cross bedding because no planar horizontal bedding boundaries are observed
- upper part of unit shows little sign of physical structure, although it looks vaguely like slightly wavy parallel bedding

U4/U5 Contact

UNIT 4: Apparently structureless clast supported conglomerate
- most pebbles 0.3-0.8cm diameter and well to sub-rounded; rare pebbles to 1.2cm diameter, mostly chert with minor lithics; hint of some wavy trough like structure near the base but definitely nothing conclusive

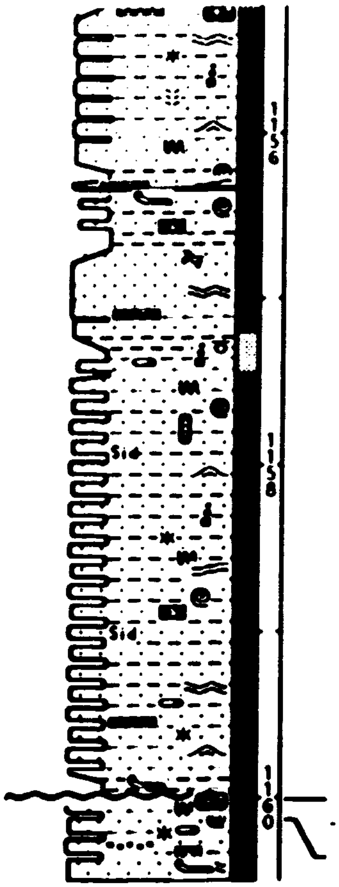
U3/U4 Contact

UNIT 3: Highly mottled mg-cg muddy sandstone with scattered pebbles
- lithics and chert; maximum ~2cm diameter, average ~0.8cm diameter granules, mostly well rounded to subrounded; scattered pebbles probably due to intensive biogenic reworking; more pebbles near base; coaly rip-up near top

U2(FA2)/U3(transgressive mg sand with pebbles) Contact

UNIT 2: transitional FA2 into more definite FA2 (~split at where the first reasonably thick vf sand comes in)
- lower transitional part of FA2: probably basal part of an overall sanding upward package with more and thicker sands upwards; here the sands tend to be 1-10cm thick with remnant oscillation to low angle parallel to undulatory laminations; lots of burrowing although zones up to 20cm thick are virtually unburrowed with sharp bases and normally grade up with awesome oscillation ripples
- "true" FA2 with thick bedded, sharp based vf sand beds that are low angle parallel to low angle undulatory laminated (SCS or HCS type of thing) with organic laminae etc.; between the thick bedded sands are thinner interbeds of vf sand, silt and shale with remnant oscillation ripples, organic laminae, vf sand beds up to 10cm thick; minor traces: *Zoophycos*, *Rhizocorallium*, *Chondrites*, *Helminthopsis*, *Asterosoma*, *Planolites*; minor escape and *Paleophycus* in the more continuous bedded sands

generally, the amount and diversity of burrowing decreases in the interbedded portions between the thicker bedded vf sands of FA2



U1(FA1??)/U2(transitional FA2 to FA2) Contact

- granules and cg-mg sand at base of U2, sharp, undulatory contact

UNIT 1: probably a bit of FA1

LALTA C.P.O.G. WAYNE
11-15-27-19w4

Date logged: February 19, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 882.40 m **KB:** 886.10 m

Remarks: Core 1; 11 boxes, 3818'-3870' (prob. ~3824'-3876'); 3.5" full diameter core; photogenic; have box shots and prints

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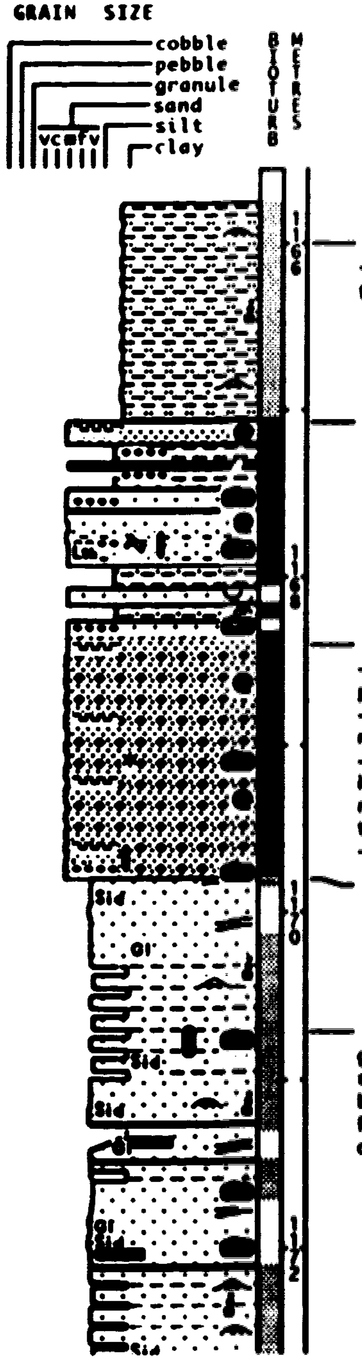


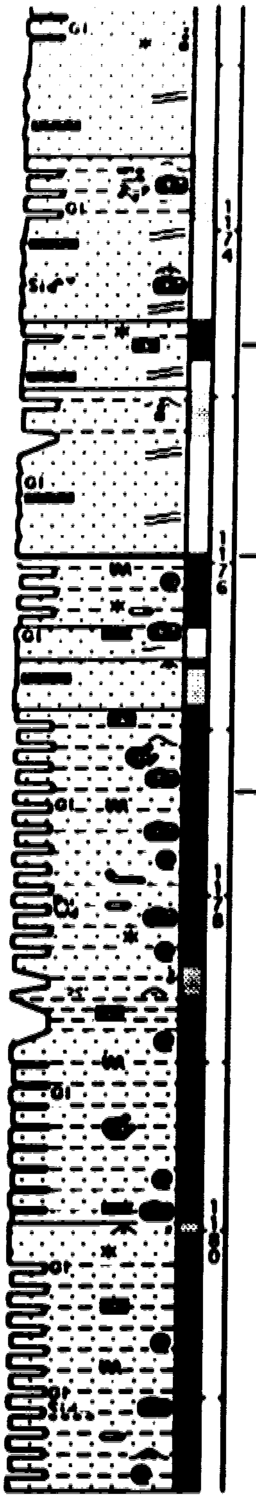
UNIT 4: Silty Shale with Discontinuous siltstone/vf sandstone beds
- minor burrowing (lacks lithologic contrast); remnant oscillation ripples, sharp based colour graded beds; mm to 1cm scale thickness

U3/U4 Contact up into Colorado shale

UNIT 3: Thoroughly Burrowed Muddy Pebbly mg Sandstone
- lithic and chert pebbles dispersed through this unit (on average 0.7cm-1.1cm diameter), probably by the intensive biological reworking of sediment
- contains 2 mg "salt & pepper" sandstone beds that are (trough?) cross bedded, 9-10cm thick, relatively sharp based
- one 13cm thick mg "salt & pepper" sandstone bed that is very sharp based and has pebbles at its base (mostly semi-rounded chert and lithics; average ~ 0.6cm-granules in diameter, maximum chert pebble 1.5cm diameter); this bed appears to be unburrowed and massive in texture
- churned but individual traces difficult to discern: Asterosoma, Thalassinoides??

U2/U3 Contact: above is the "Viking Grit" of the transgressive phase

UNIT 2/FA2: thick bedded low angle laminated vfU-fL sandstones with organic "coffee grounds" accentuating the laminae; in the intervening interbedded rarely burrowed vf sand/mud, there are rare Planolites; even rarer Thalassinoides, very small Terebellina, few branches of Chondrites, very small Asterosoma?, tiny ball like Teichichnus??, Rhizocorallium/Zoophycos??, rare synaeresis cracks; vf sand beds with remnant oscillation/combined flow ripples



Last significant/reasonably abundant occurrence of Chondrites, Asterosoma

FA1/FA2 Contact (U1/U2 Contact)

UNIT 1: FA1

- highly burrowed, good diversity, Asterosoma, Rhizocorallium, Zoophycos, Chondrites, Helminthopsis, Planolites, rare Terebellina, rare escape trace, Zoophycos in normally graded oscillation rippled lg-vf sands/silt
- oscillation/combined flow rippled sands 5-7cm thick
- anomalous little lithics/chert pebble stringer near core base, 2 largest= 1.6-2.2cm diameter, also smaller pebbles; stringer is discontinuous and <1cm thick

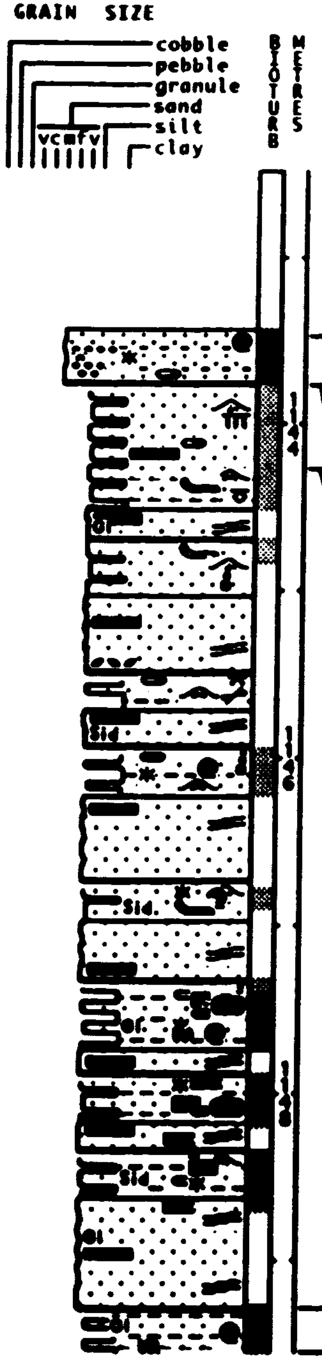
CPOG EW WAYNE
6-29-27-19w4

Date logged: February 22, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 843.40 m   KB: 847.34 m

Remarks: Core 1; 6 boxes, 3750'-3775' (probably 3751.35'-3774.55', or 1143.41-1150.48m); not photogenic (?oil staining? and gouges caused by core barrel); have box shots and prints; BFS 3626' (1105.2m)



UNIT 3: Thoroughly Churned mg "salt & pepper" sand and mud

- scattered granules (average ~3-5mm diameter) and a few pebbles (average ~ 1cm, maximum ~2.1cm diameter) ● base and scattered about within the unit (probably due to intensive biogenic reworking)
- Asterosoma, Teichichnus??, Planolites??, Thalassinoides??
- probably transgressively reworked sediment
- chert and lithic(??) pebbles, or simply multi-coloured chert pebbles

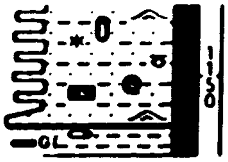
U2(FA2)/U3(Transgressive...) Contact

UNIT 2/FA2: pretty typical FA2

- numbers of traces way down, but diversity is variable; good in places, poor to nil in others
- interbedded portion: sharp based normally colour graded beds with remnant oscillation ripples, rare burrows generally; Chondrites, Asterosoma, rare small Terebellina, rare Zoophycos, Planolites, etc., rare synaeresis, no visible Teichichnus, some loaded based sands, rare micro-faulting/dewatering/soft sediment deformation?
- Thick bedded vf sands: low < undulatory laminations, low < truncations, some waning flow tops into oscillation ripples to silt to mud, some glauconite, lots of organic detritus accentuating the laminae, rare burrowing

U1(FA1)/U2(FA2) Contact

UNIT 1/FA1: typical FA1



[illegible]

- 5-10 cm thick oscillation rippled vf sands (with glauconite) that are sharp based and commonly have burrowed tops
- traces include Ophiomorpha (in sands), Asterosoma, Chondrites, Helminthopsis; may be a trace association with those bulbous branching Asterosoma (that I originally called Dactyloidites, and may actually be small, shallow Teichichnuses) and Chondrites which are the only traces present in some of the lesser burrowed mud dominated portions

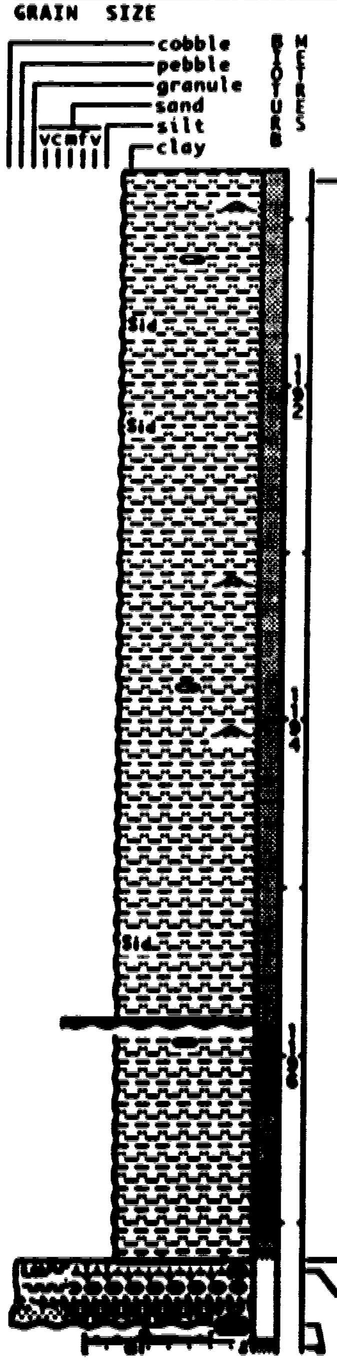
CPOG W WAYNE
7-1-27-20w4

Date logged: July 31, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 892.50 m KB: 895.81 m

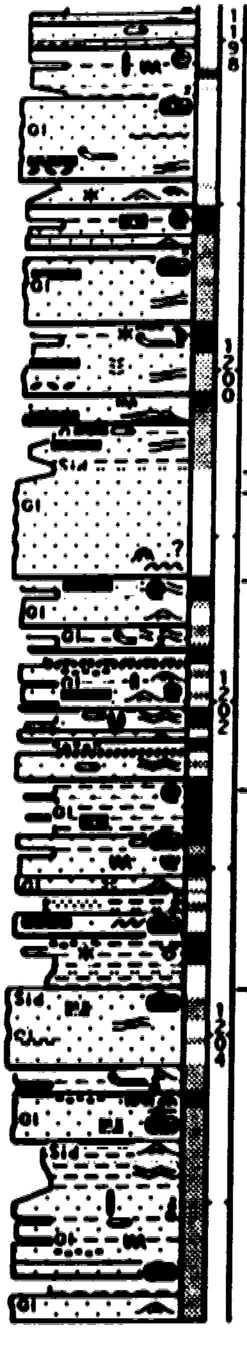
Remarks: Core 1; 11 boxes, 3903'-3954' (core more likely 3906.6'-3955.81' (1190.73m-1205.73m)), Rec. 51' (more like 49.21'); 3.5" full diameter core; fairly photogenic, have box shots and prints; BFS 3811' (1161.59m)



UNIT 5: Dark Shale with mm scale Discontinuous Silty/vf Sand Laminae
- rare burrowing (due to the lack of lithologic contrast, traces are probably difficult to see)
- one salt and pepper mg sandstone bed with undulatory base (no convincing Glossifungites)
- patches are sideritised

U4/U5 Contact

UNIT 4: Poorly Sorted Clast to Matrix Supported Conglomerate to pebbly and sandy mottled shale
- transgressive lag, basal ~15cm has granules to vf sand matrix and upper ~25cm has fewer



pebbles(lithics and chert, maximum ~3.5cm diameter, average ~1cm diameter, mostly well to sub-rounded), and a much shaler matrix with a bit of salt and pepper mg sand

U3/U4 Contact

UNIT 3: Facies Association of Interbedded vf Sandstone/Shale/Siltstone that is "interbedded" with Thickly bedded vf Low angle Laminated/Oscillation Rippled/combined flow Rippled Sandstone

- **different than Facies Association in Unit 1 due to the much more thickly bedded sandstones as well as the dominance of low angle laminations**
- the interbedded portions are only rarely burrowed to any great degree, and in these instances, the trace diversity is good (Terebellina, Chondrites, Helminthopsis, Planolites, Asterosoma), rare escape trace in thicker sandstones
- interbedded portions are commonly sharp based normally colour graded
- Thicker bedded sandstones: 8-45cm thick, laminations from essentially planer parallel to low angle parallel to slumpy/soft sediment deformed, also smaller scale oscillation/combined flow ripples that are probably related to the waning flow portion of some of the thicker bedded sandstones
- looking closely reveals that the "low angle parallel laminations" do in fact undulate slightly and one can see very low angle (1-2 degrees) truncations; HCS??, SCS??

U2/U3 Contact

UNIT 2: Well Sorted vfU Grained Sandstone

- basal 15cm is slumpy/soft sediment deformed and above this is "apparently massive" sandstone although there are hints of "slumpy" laminations, some glauconite, also quite a bit of interstitial clay as visible under the binocular microscope

U1/U2 Contact

UNIT 1: Facies Association really, of Interbedded vf Sandstone and Shale with more continuous and thicker bedded Oscillation/combined flow Rippled vfU-fL Sandstone beds

- "bands" of plentiful Macaronichnus in some of the thicker sands and same rare Palaeophycus, sand beds range from 5-20cm in thickness, average 8-10cm thick, some loaded/chaotic bedding, organic ripped up material, some siderite cemented zones
- interbedded portions are both heavily burrowed and sharp based normally graded beds, Terebellina, Planolites, Chondrites, Asterosoma, Helminthopsis, possible Rosselia, fewer and less traces in the basal interbedded vf sandstone/shale, some vertical trace that starts to "J"(?Arenicolites)

possible flooding equivalent to "VE3.5"?; the shalier zones above here do tend to be more heavily burrowed than anywhere below...; also, the sandstone beds are noticeably thinner for a distance above here

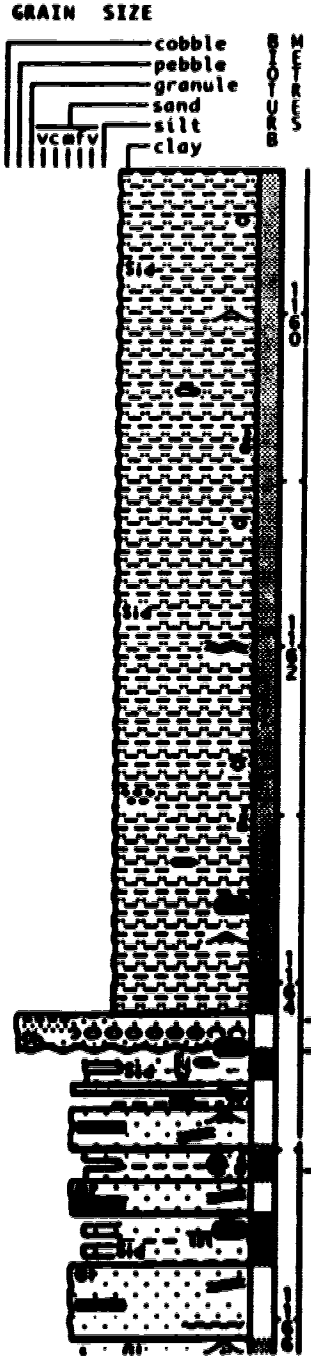
Mobil et. al. WAYNE 10-1MU
10-14-27-20w4

Date logged: July 19, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 852.50 m KB: 856.20 m

Remarks: Core 1; 13 boxes, 3800'-3860' (1158.2m-1176.5m); OK photogenic; have box shots and prints

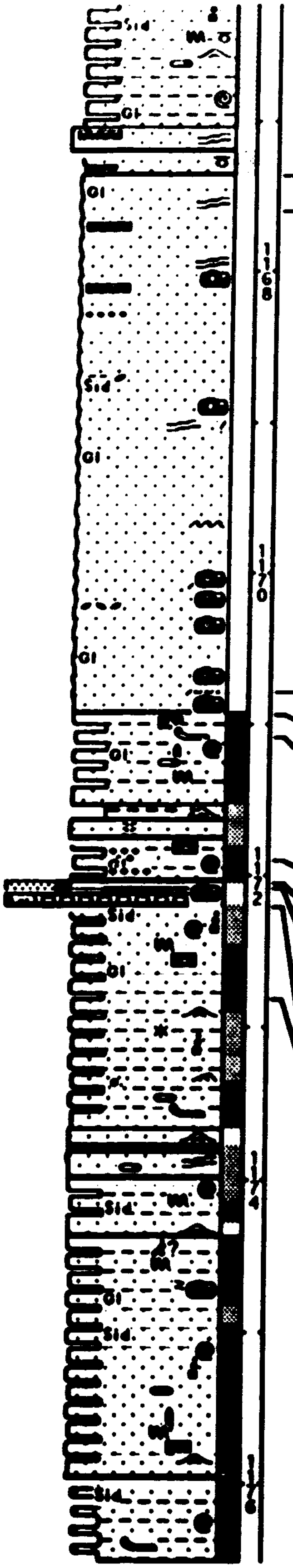


UNIT 7: Dark Silty shale
- rare silt-vf sand beds that are rarely continuous on the scale of the core due to burrowing (commonly 1-2mm thick)
- patchy sideritisation in areas; remnant oscillation ripples
- rare scattered granules

UNIT 6: Poorly Sorted Matrix Supported Conglomerate
- granules to 1.5cm diameter chert and lithic pebbles in a mixed up matrix of shale, siltstone and sandstone; possible Glossifungites "surface" at unit base
- transgressive lag

U5/U6 CONTACT

UNIT 5: Interbedded vf Sandstone and Mudstone interbedded w/vfU-fL Sandstone
- moderately to little burrowing, LOW TRACE DIVERSITY !, possible synaeresis cracks perhaps together indicating brackish water conditions
- areas are sideritised



U4/U5 CONTACT

UNIT 4: vf Grained Well Sorted Sandstone
- apparently trough cross-bedded at base (but likely oversteepened laminations) then into a zone of much soft sediment deformation/ slumping with lots of oversteepened bedding/convolute laminations
- then into a zone of apparently massive sandstone with only vague hints of low angle inclined stratification; above this into a zone with definite low angle parallel laminations and "coffee grounds" type organic laminae that accentuate the low angle parallel laminations
- rare lithic pebbles(~0.8cm diameter) and sideritised mud rip-up clasts (rounded, ~1cm diameter); near base in the soft sediment deformed area is a large, angular ripped up mud clast
- base may be surface of valley incision(???), or this may be a part of an incised valley fill (contact not completely visible)-NB: unlikely, more apt to be quickly deposited, storm-generated, possibly wave liquefied sandstone

oversteepened laminations; looks like cross bedding but likely isn't

U3/U4 CONTACT

UNIT 3: Interbedded vf Sandstone and Mudstone
- more burrowing upwards, none of those big Chondrites(?) as seen below but lotsa' little pinprick Chondrites
- scattered pebbles prob. burrowed up from cgl. below, granules along wavy laminae in oscillation rippled sandstone

scattered up to 2cm diameter pebbles in burrowed shaly zone

U2/U3 CONTACT

UNIT 2: Sorted clast Supported Conglomerate
- most pebbles ~1cm diameter, rounded chert and ?lithics (or possibly just multi-coloured chert pebbles), matrix of shale and fg sandstone
- 2 horizons separated by unburrowed dark shale

U1/U2 CONTACT

UNIT 1: Burrowed Interbedded vf Sandstone and shale (~4.3m)
- traces give that "restricted environment" sort of feel; a few robust Terebellina near base, Helminthopsis, rare Chondrites, Asterosoma(?) or are they those robust Chondrites?? (NB- possibly ?Phycodes): regardless, there are lots of them, rare short vertical shafts, Planolites
- small scale oscillation to combined flow ripples, rare small scale combined flow/current ripples; normally graded beds with oscillation ripples; some more thick and continuous sand beds with oscillation to wavy parallel bedding and Palaeophycus
- patchy sideritisation throughout but significant thickness sideritised at upper contact; rare isolated pocket of chert granules

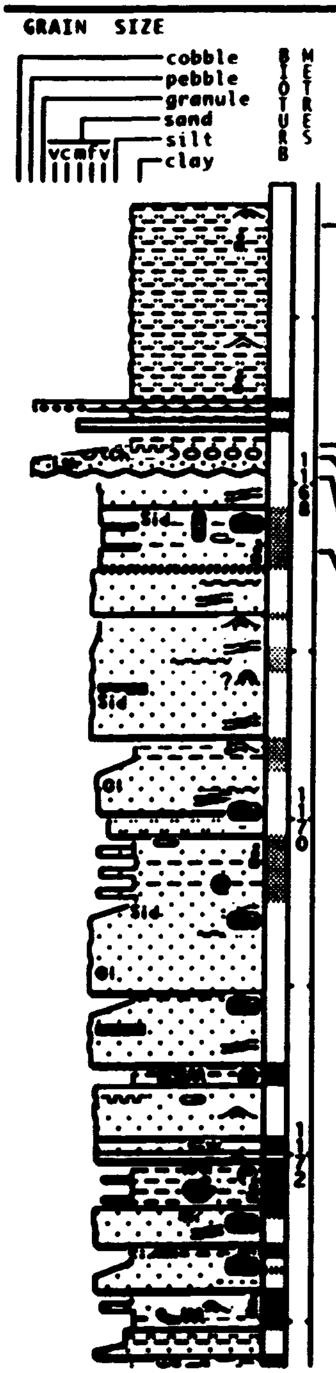
CPOG W HUSSAR
6-18-27-20w4

Date logged: July 26, 1990.

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 830.60 m KB: 833.90 m

Remarks: Core 1; 10 boxes, 3827'-3872', Rec. 45'; 3.5" full diameter core; photogenic; have box shots and prints; occurrence of thick "?VE3.5"-type conglomerate



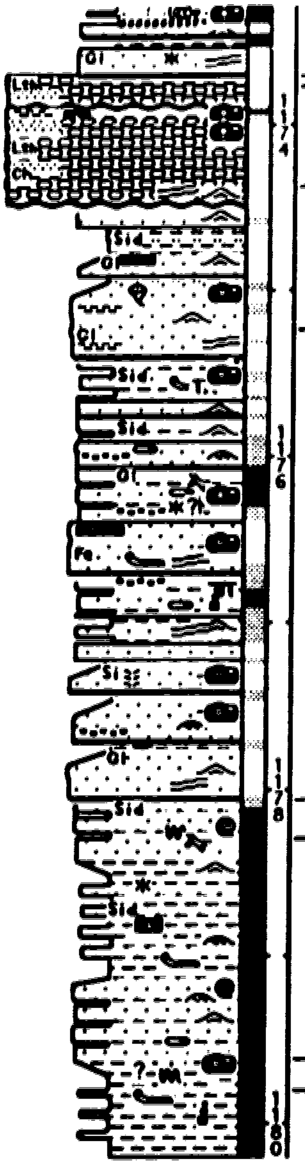
UNIT 7: Dark Shale with rare mm scale silty laminae
- sharp based siltstone/vf sandstone beds, a mg salt and pepper sandstone bed near base, and a burrowed mg sandy/pebbly zone just above, rare hint of very small scale oscillation ripples/combined flow ripples

U6/U7 contact

UNIT 6: Very Poorly Sorted Matrix supported Conglomerate
- transgressive lag, matrix is essentially mudstone, maximum pebble ~1.6cm diameter, average ~0.8-1.0cm diameter

U5/U6 contact

UNIT 5: Interbedded vf Sandstone, Shale and Siltstone that is itself interbedded with much thicker low angle parallel to combined flow to oscillation rippled vf Sandstones
i.e. a facies association of Interbedded vf Sandstone/Siltstone/Shale with thick bedded low angle laminated/combined flow/oscillation rippled vf Sandstone facies
- lower interbedded portion(i.e. below the 2 close thickest bed. sands): strongly burrowed by a wide diversity of traces(Helminthopsis, Terebellina, Chondrites, Teichichnus, Rhizocorallium) as well as locally sharp based, normally graded, oscillation rippled sand beds BUT above the 2 thick sands, the interbedded facies is rarely burrowed with a few scrappy Planolites and most of it is sharp based vf sand beds that grade normally up into silts and muds(rare synaeresis cracks) (perhaps moving from a more open marine setting into a more restricted/stressful environment?)
- thicker bedded sands have low angle parallel, low angle undulatory to possibly locally oversteepened laminations, commonly with small scale ripples (oscillation and current/combined flow rippled) at the top (probably waning flow cycles)
- organic laminae can accentuate laminations, some sideritised areas
- anomalous 15cm thick siltstone bed with no structures other than maybe being 100% bioturbated?, or more likely, dish structures



U4/U5 contact

UNIT 4: Reasonably well sorted Clast supported Conglomerate
- matrix for most of unit consists of vf sand, granules with a bit of mud but a small portion of the unit has pebbles "floating" in a muddy matrix that contains Chondrites!, also the pebbles in the shaly portion look like they've fallen into the shale and deformed laminae within the shale(i.e. shale was unlithified)
- pebbles are both chert and lithics, mostly rounded to sub-rounded, maximum size ~3.5cm diameter, average ~1.5cm diameter

U3/U4 contact

UNIT 3: Interbedded vf Sandstone and Shale interbedded with relatively thickly bedded, low angle laminated/combined flow rippled vf Sandstone
- sand beds: 10-30cm thick, low angle undulatory laminations, low angle parallel laminations, up to small scale combined flow ripples, rare small scale low angle truncations, organic detritus throughout rarely accentuating the low/medium angle laminations
- interbedded vf sand and mud portion: barely burrowed with relatively low diversity and numbers of traces, mostly little scrappy Planolites, possible ?Phycodes, one single very small Rosselia, one small probable Terebellina, disturbed laminations in some sand beds are probably escape traces; localal sideritised areas
- probable synaeresis cracks

U2/U3 contact

UNIT 2: Moderately to Commonly Burrowed Interbedded vf Sandstone and Shale
- oscillation to combined flow rippled sand beds, sand beds are sharp based/burrowed tops, commonly normally colour graded, and 2-5cm thick
- the "Palaeophycus" is probably Macaronichnus (Saunders, pers comm., 1990) and the weird "mega-Chondrites" type thing is probably some weird form of Dactyloidites(Saunders, pers.comm., 1990); NB- it is likely Phycodes
- occasional siderite

U1/U2 Contact

UNIT 1: Burrowed Interbedded Shale and vf Sandstone/Siltstone
- dominated by Helminthopsis, sharp based sandstone beds with burrowed tops, some normally graded beds, sand beds ~1cm thick

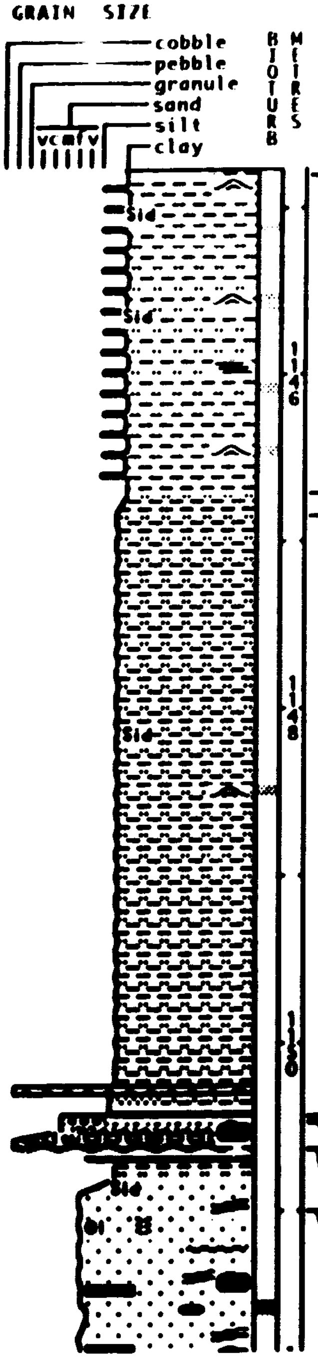
TCRL WAYNE
6-22-27-20w4

Date logged: July 23, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 833.60 m KB: 836.10 m

Remarks: Core 1; 7 boxes, 3759'-3790'; Core 2; 4 boxes, 3791'-3811'; quite photogenic, have box shots and prints; occurrence of non-marine facies and thick ?"VE3.5"-type conglomerate



UNIT 15: Essentially the same as U14 but more and thicker siltstone/vf sandstone beds
- 5-10cm siltstone/sandstone beds, oscillation rippled; local sideritised patches

U14/U15 "Contact"

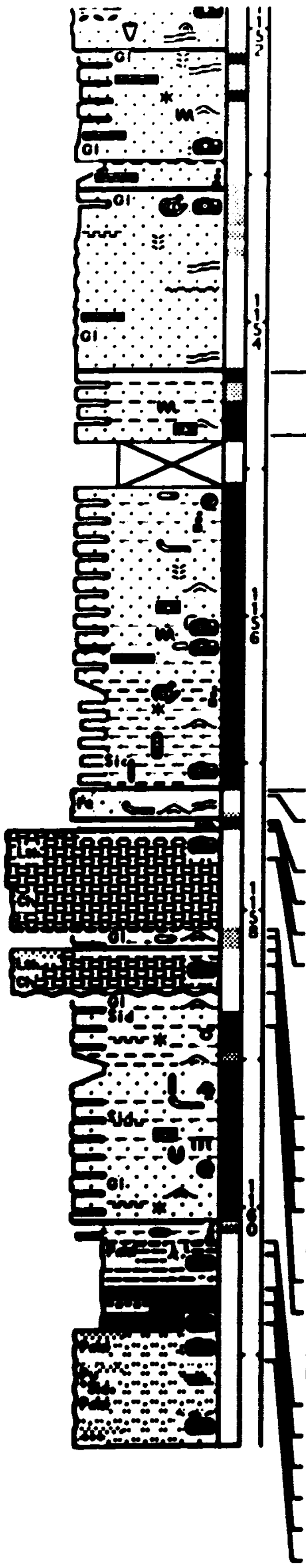
UNIT 14: Dark Shale with Sharp based mm scale to 2cm thick small scale oscillation rippled siltstone/vf sandstone
- near base is another ~4cm thick poorly sorted matrix supported, sandy/pebbly shale; matrix mg salt and pepper sandstone, mud; chert and lithic pebbles, maximum ~1.2cm diameter, average ~0.75cm diameter

U13/U14 Contact

UNIT 13: Poorly Sorted Conglomerate
- basal 11cm is clast supported conglomerate (lithic pebbles and chert; average ~0.7cm, maximum 1.8cm diameter) and above this is essentially mg salt and pepper sub-angular sandstone with pebble stringers that are commonly in discontinuous wisps of mudstone

U12/U13 Contact

UNIT 12: Dominantly Low angle Parallel Laminated to Oscillation Rippled Well Sorted, Glauconitic vfU Sandstone with areas of Slightly Burrowed Interbedded vf Sandstone and Shale (i.e. FA2)



- Rhizocorallium, possible ?Conichnus or is it just an ?escape trace
- one area is chaotically bedded/slumped/soft sediment deformed with rounded ripped up sideritic clasts
- upper part of unit appears massive

U11(~FA1)/U12(~FA2) Contact

UNIT 11: Burrowed Interbedded vf Sandstone and Shale
- stressed out small rare Teichichnuses, Terebellina, mostly Chondrites, Helminthopsis, thicker continuous sandstone beds(5-10cm) contain escape traces, Palaeophycus, Asterosoma, also Rhizocorallium, Planolites, rare Skolithos
- sandstone beds mostly oscillation to wavy/low angle parallel laminated
- it's weird, some areas are thoroughly churned sandstone/shale whereas in other portions of this unit, the sandstone/shale have been interbedded with little or no burrowing in which case the sandstone beds are commonly sharp based and normally grade upwards

U10/U11 Contact

UNIT 10: vf Oscillation Rippled to Apparently Massive Sandstone, possible low angle inclined laminations also

U9/U10 Contact

UNIT 9: Burrowed Interbedded Shale and vf Sandstone

U8/U9 Contact

UNIT 8: Reasonably Sorted Clast Supported Conglomerate
- lithic and chert pebbles, range 0.8cm-2.3cm, average ~1-1.2cm diameter
- basal 31cm is totally broken up and contains some smaller pebbles similar to the size common in UNIT 6; so the actual thicknesses and grain size ranges given may not be completely accurate
- matrix is mud to vf sand that appears almost bedded; coarsens upwards with accompanying increase in interstitial vf sandstone

U7/U8 Contact

UNIT 7: Interbedded vf Sandstone and Shale

U6/U7 Contact

UNIT 6: Well Sorted Clast Supported Conglomerate
- rounded to sub-rounded lithic and chert pebbles in a vf sand matrix; pebble sizes range from 0.2-1.0cm diameter, average ~0.6-0.7cm diameter

U5/U6 Contact

UNIT 5: Interbedded Burrowed Shaly vf Sandstone and Interbedded Colour Graded Shale and Sandstone
- mostly muddy sandstone(vfU); "wispy" mud streaks; sand dominated portions have that bulbous look to their burrowing

U4/U5 Contact

UNIT 4: Mottled Rooted Grey Palaeosol

U3/U4 Contact

UNIT 3: Dark Carbonaceous Mudstone with coal fragments

UNIT 2: Coal

UNIT 1: Sandy Siltstone (palaeosol?) with Sand Filled Desiccation Cracks

- possible desiccation cracks that are filled with fg sandstone
- stringers of curious little round things with cracks in them (spherulitic siderite??, ostracodes??), some parallel laminations

Spruce et al. Hussar
6-23-27-21w4

Date logged: April 19, 1991

Logged by: Indraneel Raychaudhuri

Ground: 796.40 m KB: 800.10 m

Remarks: Core 1; 11 boxes, 3.5" full diameter core, 3780-3830', unsure of depths?? (check well logs), overall unphotogenic, have box shots

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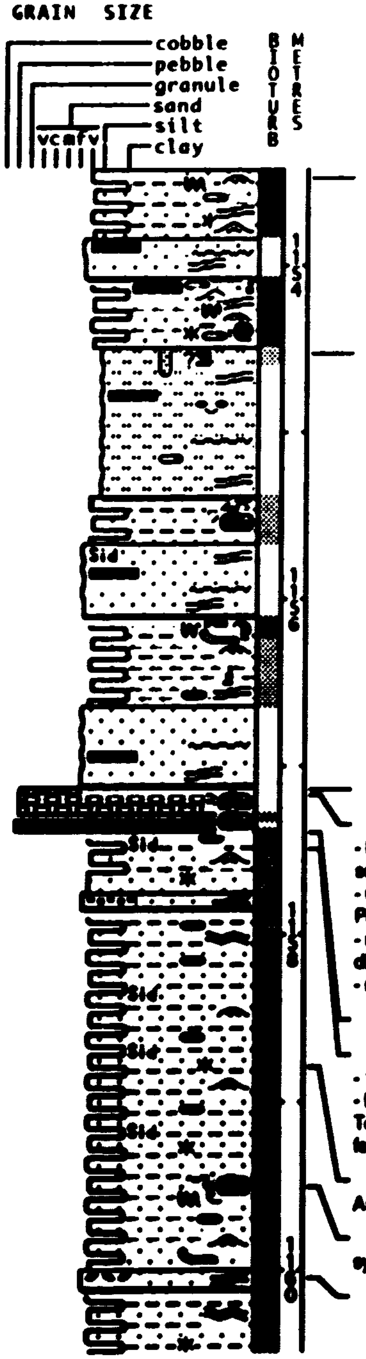


U9: true FA2 with the occurrence of this oddball siltstone

?possible Glossifungites?

U8/U9(FA2) Contact

U8: Sorted Conglomerate bedded with interbedded vf sand and shale
- lower contact is actually undulatory but not in an erosive sense, rather, the conglomerate seems to be draping a small scale oscillation/combined flow ripple
- 6cm conglomerate, then 4cm of vf sand dominated interbedded sand and shale(rare burrow, Planolites), then another 16cm of conglomerate!
- mostly rounded chert pebbles(0.4-0.6cm diameter; maximum 0.9cm diameter); 9.5cm diameter angular siderite clast in lower conglomerate
- matrix is vf sand; upper conglomerate appears to be low angle wavy laminated at the base

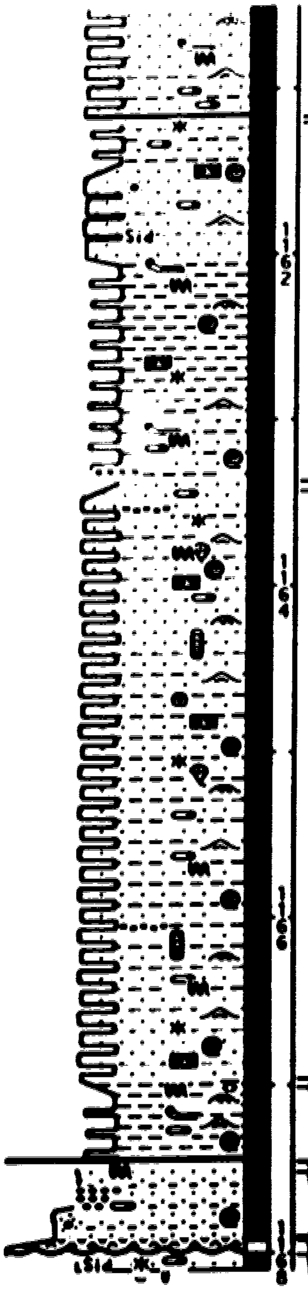
U7(Transitional FA1-FA2/FA2)/U8(Sorted Conglomerate) Contact

U7: Transitional FA1-FA2/FA2
- 1-10cm thick oscillation/combined flow rippling/low angle parallel laminations
- burrowing decreases upwards; basal 2.41m: Planolites, Asterosoma, Palaeophycus, Terebellina(Schaubcylindrichnus?), Helminthopsis(rare- only seen up to the "guttercast" feature); top 1.37cm: Planolites, Asterosoma, Palaeophycus

for ~20cm beneath the siderite is a zone thoroughly burrowed by those very small ball-like Asterosoma

loading structure? or erosional guttercast?(Bhattacharya, pers.comm., 1991); also synaeresis? or dewatering structures?

angular shale rip-up clasts



U6/U7(FA1-FA2 Transitional/FA2) Contact

U6: Shale dominated Burrowed Interbedded shale and vf sand
- 1-2cm thick sharp based sands with remnant oscillation/combined flow ripples; coaly rip-ups and chert grits/granules(vc sand) at unit base
- Chondrites, Helminthopsis, Asterosoma, Terebellina, Planolites, Palaeophycus, silt-haloed "Helminthopsis"
- 42cm from unit top are two 0.5cm diameter chert pebbles
- sharp upper contact; 1.5m from base of unit is the base of a 2cm thick sideritised zone

U5/U6 Contact; granules just above here are in a burrow fill (?Thalassinoides)

U5: vf Sand dominated Interbedded sand and shale (60/40); oscillation to combined flow rippled vf sandstone; sandstone beds 1-7cm thick; coaly fragments; Planolites, Chondrites, Asterosoma, Siphonichnus, Teichichnus, Helminthopsis, Palaeophycus, Rosselia

U4/U5 Contact: gradational; overall sanding upwards sequence

U4: "typical" regional Viking, shale dominated, Helminthopsis dominated
- thin sharp based vf sands with remnant oscillation/CF ripples
- base of unit has a 1-2cm thick poorly sorted conglomerate made up mostly of rounded to subrounded chert pebbles less than 0.5cm diameter

U3/U4 Contact: "NB: everything below here is shattered up and only small portions could be reconstructed, therefore all the underlying thicknesses and order are only the best approximation to the original order"

U3: Thoroughly burrowed shaly sandstone with scattered granules and small pebbles(chert); Planolites, Helminthopsis

U2/U3 Contact

U2: poorly sorted conglomerate with a mg-vc sand matrix

U1/U2 Contact: sharp) and probably erosive; may represent a flooding surface(E/T type surface); rounded chert pebbles, maximum 5-6cm diameter), average 2cm diameter, matrix is anywhere down to mg sand; could this be VE3?(Davies, 1990); possible Glossifungites "surface" with Skolithos(?); U1: burrowed muddy sandstone

PCP Redland
10-1-27-22w4

Date logged: April 18, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 830.60 m KB: 834.30 m

Remarks: Core 1; 17 boxes, 4" full diameter core, 1215-1233m, Recovered 18.3m, probably ~1215.3-1233.8m

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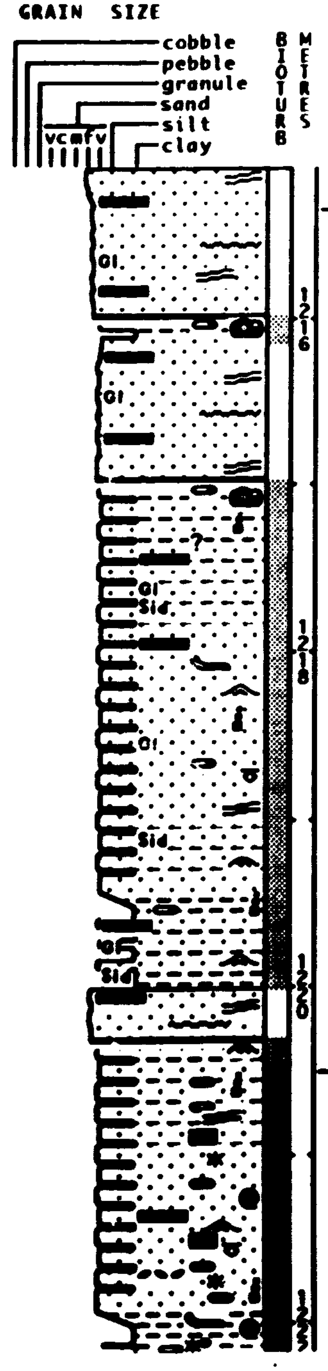


U10: essentially FA2
- there are only Planolites and extremely rare Terebellina(in the sands) (Schaubcylindrichnus?) in the interbedded portions; NO Chondrites or Asterosoma, all traces rare and small, some synaeresis cracks/ dewatering loading structures
- thick sands low angle laminated with low angle truncations etc

above here is where "true" FA2 is encountered

U9/U10 "Contact" into transitional FA1/FA2 above

U9: thick bedded low angle parallel/undulatory laminated vf sandstone with organic material accentuating the laminae, minor glauconite and low angle truncation surfaces(part of FA2)

U8/U9 Contact: actually, the U8/U9 association is very similar to FA2 but U8 and U9 have been split out as different units in this well due to the sharp change to a very shaly facies that overlies U9

U8: this is much like the transitional FA1/FA2 facies commonly seen as a gradational facies between FA1 and FA2
- change in the nature of burrowing from totally Helminthopsis dominated /rare minor Chondrites in U7, to Chondrites and small ball-like Asterosoma domination/minor and rare Helminthopsis in U8; intensity of burrowing is also less with more preservation of sharp based, 1-7cm thick normally graded oscillation/low angle laminated/combined flow rippled vf sand(like FA1)

angular wispy shale rip-up clasts

U7/U8 Contact: part of overall sanding upwards sequence, more and thicker vf sandstone above

U7: essentially the same as U5, but with more preserved 1-4cm thick vf sands with remnant oscillation/CF rippling, sharp or burrowed bases and generally burrowed tops
- traces: totally dominated by Helminthopsis, also minor Chondrites, Asterosoma, Planolites, Palaeophycus in the sands, Terebellina; some of the wispy black pseudo-vertical trace that is probably some form of Helminthopsis or Chondrites

U6/U7 Contact: sharp undulatory contact with a 2cm thick discontinuous lens of conglomerate overlying it(all granules 0.3-0.5cm diameter); also granules are dispersed for ~7cm above the contact (probably by burrowing organisms) NB this may be VE3 of Davies(1990)

U5/U6 Contact: part of overall gradational sanding upwards sequence

U5

U4/U5 Contact: possible flooding surface/parasequence boundary; scattered fg-mg sand, a few rounded chert pebbles maximum diameter 0.5cm and granules dispersed for ~5cm above

U4: similar to U2; part of overall sanding upwards sequence
- traces include Planolites, Asterosoma, Helminthopsis, probable Zoophycos and Rosselia near the top
- 1-4cm thick in general with 1 22cm thick vf sand at the top; mostly with low angle parallel laminations and CF rippling; the 1 thick sand bed is low angle parallel laminated at the base and is oscillation to CF rippled at the top(and sideritised), with organic detritus and glauconite; sands generally sharp based and/or with loaded bases

U3/U4 Contact: part of overall sanding upwards sequence

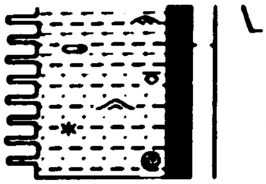
U3: same as U1 of this well except
- only Planolites, and rare Chondrites, one escape trace in a vf sand bed
- more loaded bed bases, rare load cast ripple, mostly very small CF ripples with some apparent starved ripples

U2/U3 Contact: flooding surface?

U2: vf sand dominated burrowed interbedded sandstone and shale
- remnant 1-7cm thick sand beds(average 3cm) with oscillation/CF rippling to low angle parallel laminae; sharp based, commonly with loaded base, commonly discontinuous beds on the scale of the core due to burrowing, large pebble found within this unit...
- traces include: Helminthopsis, Asterosoma, Planolites, rare Chondrites, Thalassinoides, possible Ophiomorpha in one of the thicker(i.e. 7cm) sands
-"NB similar to U2 of 14-36-28-20w4"

a single 1.2cm diameter chert pebble here with the pointed part of its apparent C-axis pointing down and deforming laminae of a thin discontinuous vf sand bed
-"NB the overlying shales are also draped around this pebble(although this may simply represent a post depositional compactional relief)- similar to the situation the "anomalous" thick conglomerates rarely found in the "upper" Viking are found in"

U1/U2 Contact: part of overall sanding upwards sequence



U1 shale dominated Burrowed Interbedded shale and vf sandstone
- traces: Planolites, Asterosoma, Terebellina, probably are more but there is generally very little lithologic contrast
- 1-2cm thick sharp based oscillation/CF rippled to low angle parallel laminations, tops of beds are generally burrowed
-"similar to U1 of 14-35-26-20w4"

PCP REDLAND
14-22-27-22w4

Date logged: December 10, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 871.30 m KB: 875.00 m

Remarks: Core 1; Boxes 1-15, 1268-1286m, (probabl, ~1274-1292m) not particularly photogenic; lots of broken up core; 4" full diameter unslabbed core; have box shots

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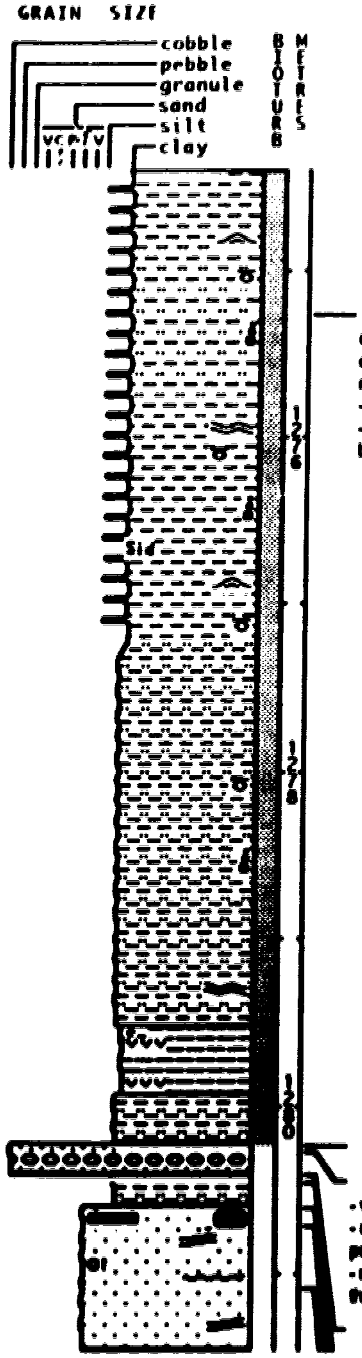
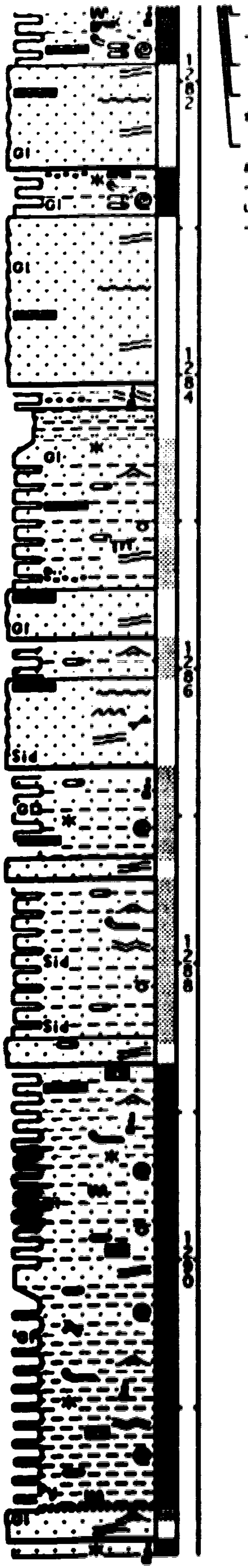


UNIT 4: Dark Silty Shale with mm scale sharp based, normally graded silt beds that passes upwards into a slightly siltier facies with more and thicker(1-2cm with sand starved oscillation/combined flow ripples: definite small scale foreset laminae with an overall oscillation ripple form) sharp based vf-silt beds preserved
- local sideritisation
- 41cm thick bentonite near base of unit (may actually be thinner but the core is extremely broken up in this area)

U3/U4 Contact

UNIT 3: Poorly Sorted Matrix Supported Conglomerate
- very very similar to uppermost transgressive conglomerate in 15-16-28-22w4
- most of matrix is very friable shale, two 2cm thick zones where most of matrix is salt and pepper mg sand
- maximum pebble is 3cm diameter, pebbles average 1cm diameter, are well rounded except for the odd subrounded pebble, mostly multi-coloured chert pebbles

U2/U3 Contact



UNIT 2: Dark Silty Shale
- may actually just be part of U1 FA2

U1(=FA2)/U2 Contact

great example of low angle parallel/slightly undulatory laminations with low angle truncation surfaces passing up into small scale oscillatory combined flow ripples

UNIT 1: Essentially transitional FA2 (i.e. sand beds average only 2-10cm but trace assemblage more like FA2) sanding and coarsening upwards into true FA2
- thick possible HCS sands have low angle truncations (5-10 degrees) of low angle parallel to undulatory laminae
- lower in unit totally dominated by Chondrites and Asterosoma

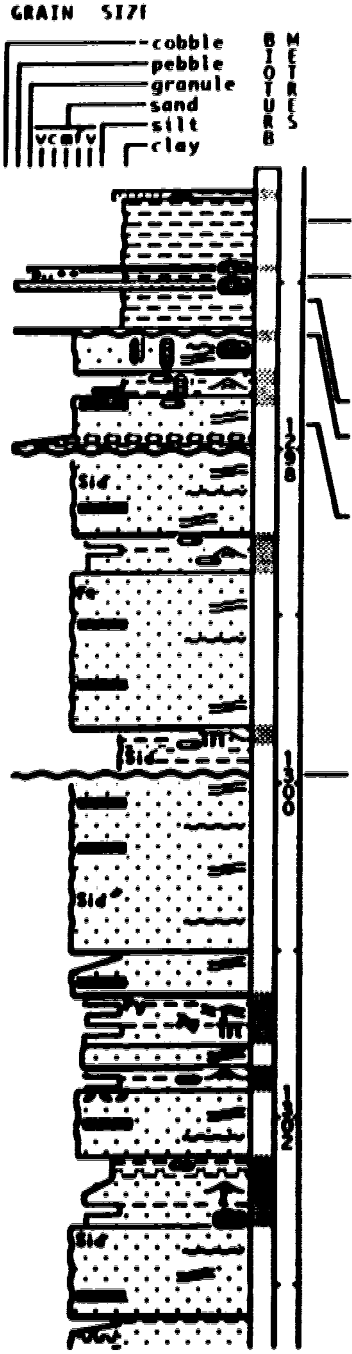
Canpet LM CPOG Redland
6-15-27-23w4

Date logged: March 31, 1992

Logged by:

Ground: 847.00 m KB: 850.40 m

Remarks: 3.5" whole diameter core; quite photogenic; have box shots
Core 1, 11 boxes; full recovery
4253'-4305' and well is on depth within 6"



Dark Shale

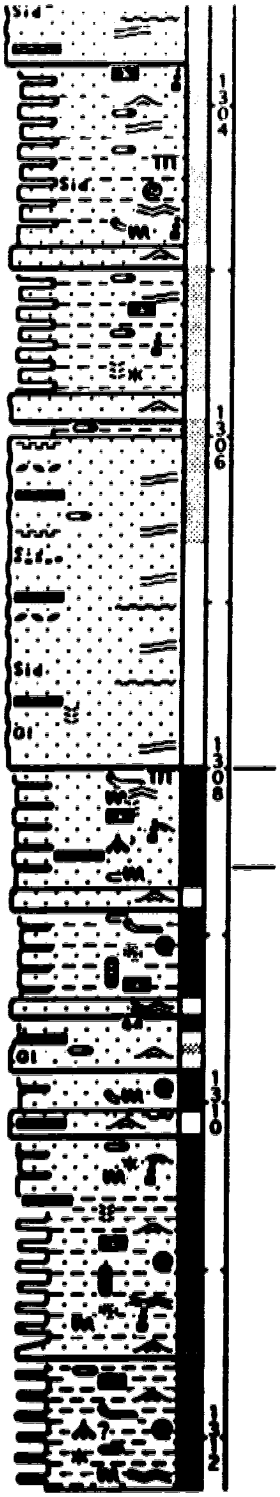
3 gritty zones:
1) basal zone is mg sand with plentiful rounded pebbles up to 2.4cm diameter
2) middle zone is mg-cg sand with rarer up to 1cm diameter subrounded to rounded granules and pebbles, some lithics
3) uppermost gritty zone is burrowed mg mud into dark shale (Planolites)

Dark Shale

FA2/Transgressive contact
- maximum pebble 1cm diameter; maybe Glossifungites surface at bottom contact into the sandstone below

typical FA2 with thick sandstones separated by slightly burrowed shalier zones
- local sideritized bands, rip-up clasts, 2 zones of clast supported conglomerate, lower pebbly zone has 2.7cm maximum pebble diameter (well rounded), upper thicker conglomerate has well rounded pebbles average 1cm diameter and maximum 3cm diameter
- sparse burrowing, synaeresis cracks in the mud etc.

lower, thinner zone of clast supported conglomerate



FA1/FA2 Contact

FA1: sandier upwards, less burrowed upwards; ?Phycodes

Oak Ridge et al. WILLOW
11-21-28-17w4

Date logged: November 19, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 875.40 m KB: 879.70 m

Remarks: Core 3; 13 boxes 3590-3650'+(actually 3583-3643.5'), Core 4; 6 boxes 3650-3675'(actually 3643.5-3668.5'); 3.5" full diameter core, heavily sampled and broken up, unphotogenic; no box shots

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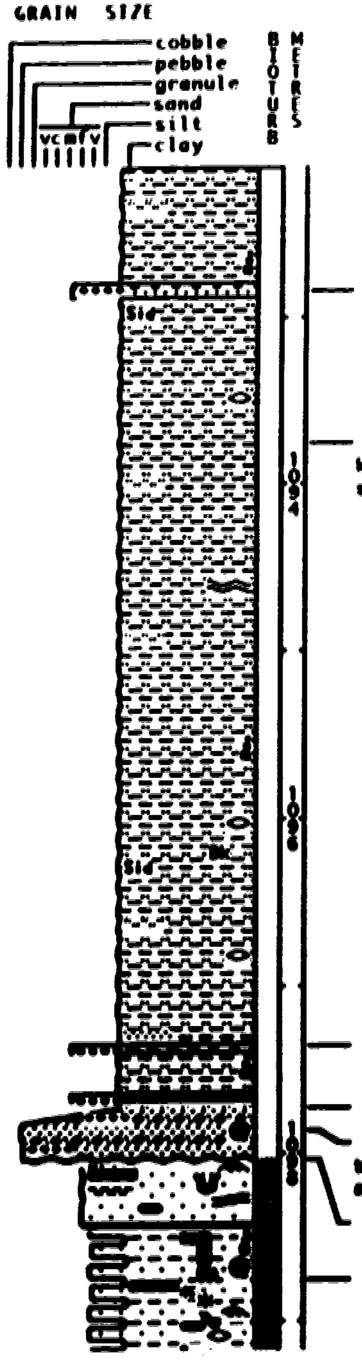


more thin mg salt and pepper sandstone with ~1cm diameter rare pebble

UNIT 8: silty shale with local lenses of coarser sand/pebbly sand; local sideritised zones; lens-like sharp based fining up silt/vfL sandstone beds that are commonly discontinuous on the scale of the core

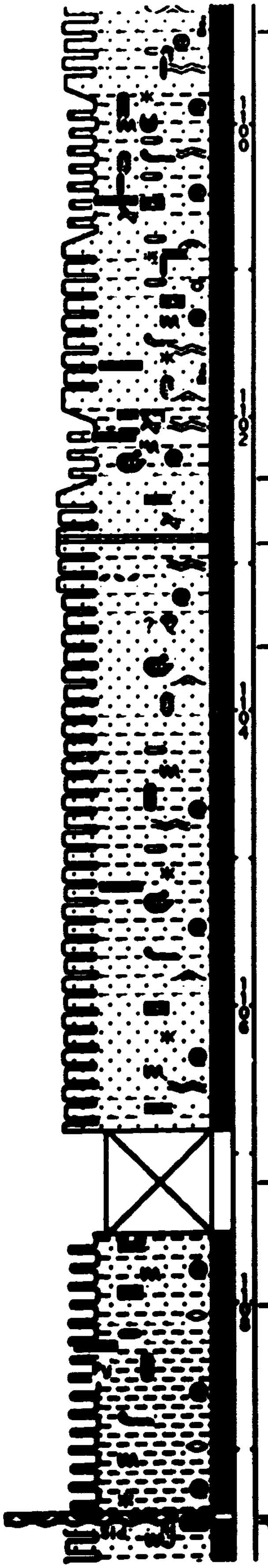
2 thin zones with mottled mg sand (salt and pepper) with rare rounded ~1cm diameter pebbles

U7/U8 Contact

UNIT 7: pebbly mg sandstone; also lots of shale and much of unit is broken up and therefore true unit thickness is tough to discern; churned; maximum pebble is 3cm diameter; mostly chert and well rounded to subrounded; some rare volcanic pebbles

U6/U7 Contact: "VE4"; erosional transgressive surface

High diversity but locally sporadic burrowing by all the tracemakers



UNIT 6: a very muddy, burrowed version of FA2 with only local portions of the unit having the characteristic sharp based rippled beds capped by organic-rich shales, no visible syneresis cracks; perhaps losing salinity stress due to much further basinward setting, moderately to commonly burrowed, one reasonably thick storm sandstone bed at top of unit

U5/U6 Contact: "FA1/FA2" Contact??

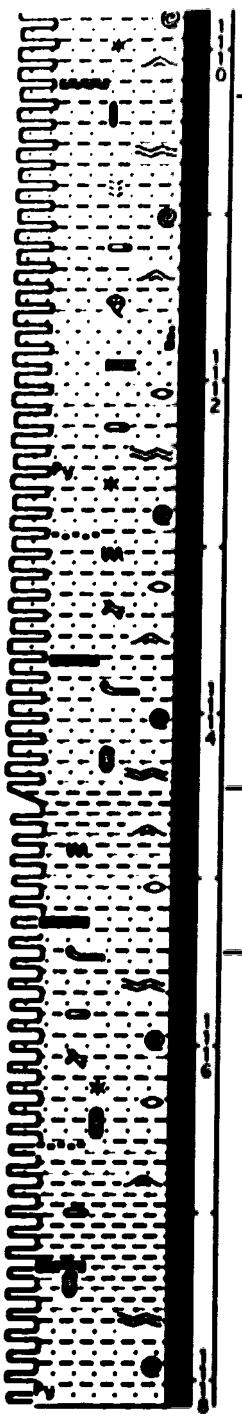
base of 4cm sideritised zone that may be basinward expression of the "VE3.5" surface characterised by the huge, up to 6cm pebble conglomerate found in thin beds to the west; or "VE3.5" could be at U5/U6 contact

UNIT 5: sandier version of U4; some 1-5cm preserved sandstone beds with wavy parallel to oscillation ripple laminae; highly burrowed with many types of trace fossils visible on the strip log

this missing core represents the 70cm discrepancy between the core and well log where the missing 70cm has been sampled throughout U4

UNIT 4: totally churned/burrowed vf sand and shale; dominated totally by Helminthopsis; no good physical sedimentary structures preserved

UNIT 3: clast supported, poorly sorted conglomerate; quite porous and permeable; maximum pebble is 2.8cm diameter; rounded to subrounded, dominantly chert pebbles; "matrix" is mostly subrounded granules [illegible] diameter



U2/U3 Contact. Transgressive; probably "VF3"

UNIT 2: sanding upwards continuation of U1; 1-6cm thick wavy parallel to oscillation rippled sandstone beds near top of unit; upper 9cm of unit is sideritised with possible Glossifungites surface ("VF3"); commonly burrowed with many types of traces shown in the litholog

U1/U2 Contact

UNIT 1: upper offshore to lower shoreface transition; rare 1-2cm scale vfL sandstone beds with loaded bases, commonly discontinuous on the scale of the core; common burrowing intensity; minor pyrite; grades/sands upwards into U2 (overall sanding upward cycle)

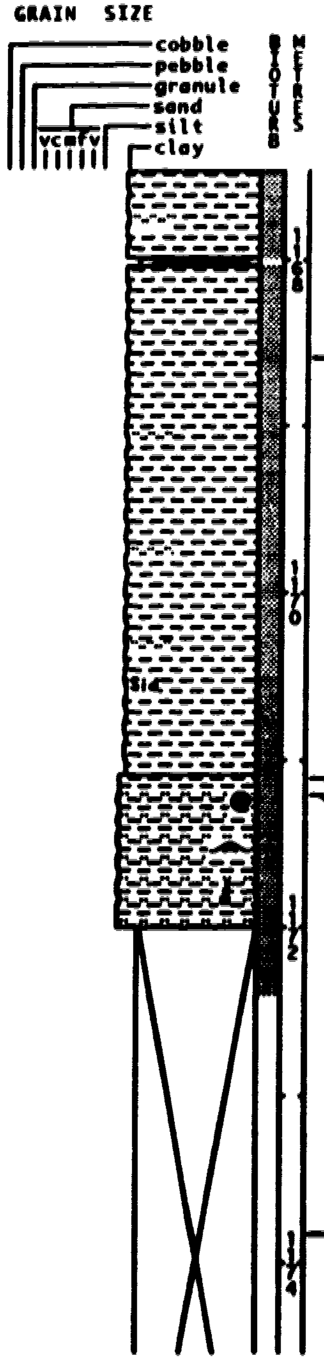
Anglo Socony Drumheller #1
9-29-28-20w4

Date logged: February 25, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 841.60 m   KB: 845.20 m

Remarks: 1" wireline drill core with some unrecovered; well is hard to hang on logs; ~3840'-3970' (1170.4-1210m); no box photos or other photos

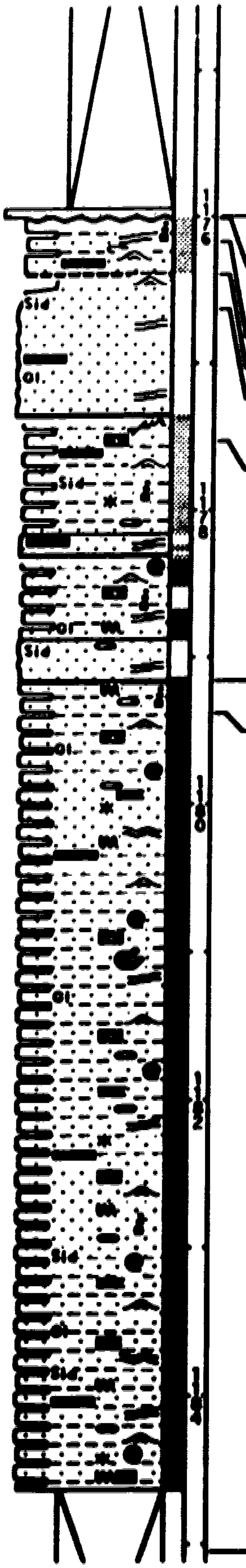


UNIT 10: Black Shale
- with rare lenses(mm scale) of silty material; U9 and U10 probably burrowed but difficult to tell due to lack of lithologic contrast

U9/U10 "Contact"

UNIT 9: Dark Silty Shale
- rare mm-1cm scale sharp based vf sandstone/siltstone beds with remnant oscillation ripples
- mostly rubble of which some of it contains shattered up bits of mg sand

"may want to pull this core again to box shoot the lower sequences" (if necessary)



UNIT 8: reasonably sorted mg "salt and pepper" sandstone
- no apparent structures

U7(FA2)/U8(prob. transgressive sand) Contact
- actual observed thickness of U8 is only 2-3cm but has been made slightly thicker on the litholog so that it can be more easily seen

probably a continuation of U7 (FA2)

UNIT 7: unknown upper contact due to missing core at top? at bottom?

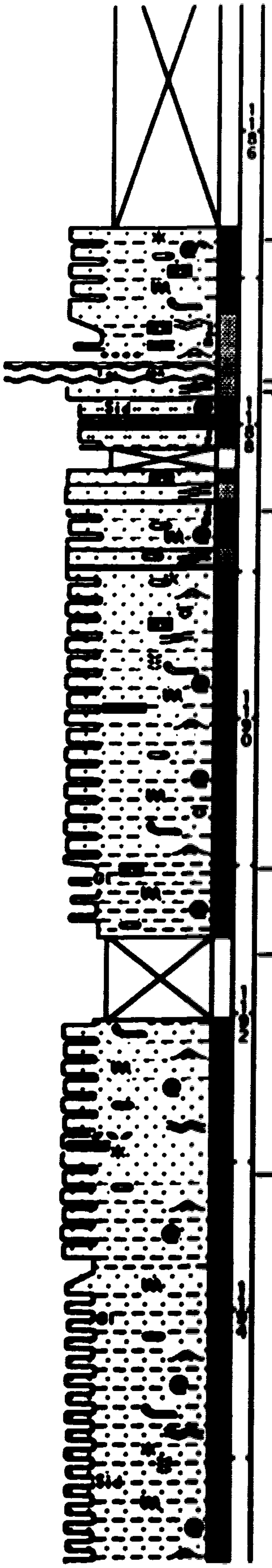
UNIT 7(FA2): thickest sand bed ~75cm thick
- Chondrites, Planolites, Asterosoma dominated assemblage, rare Helminthopsis near the base of the unit

~last occurrence of Chondrites with last occurrence of Asterosoma a few 10's of cm below

U6(FA1)/U7(FA2) Contact: kind of transitional over ~1m below this actual placement of the contact

UNIT 6/FA1: vf sandstone beds oscillation/wavy parallel bedded, to low angle undulatory/parallel laminations, glauconite, minor organic detritus accentuating laminae; sands sharp based, commonly burrowed tops, 5-10cm thick sands which tend to be normally graded (similar to what is more likely found in FA2)
- traces include Zoophycos, Rhizocorallium, lots of Chondrites, some Helminthopsis, and those bulbous Asterosoma

this last core represents the missing core between [illegible]



UNIT 5: Interbedded relatively rarely burrowed vf sandstone and shale
- sharp based, normally colour graded sandstones/siltstones; remnant oscillation/wavy parallel laminations
- very few numbers of traces: Helminthopsis, Zoophycos?, rare Chondrites
- 2cm pebbly sand at base: maximum pebble ~2.6cm diameter, chert and lithics, sub to well rounded, average ~0.7cm diameter, 2cm pebble stringer near unit base with very irregular and sharp base (average ~0.7cm diameter, chert and lithics); matrix= coarse sand and granules, some pebbles scattered about by burrowing
- upper portion of unit is much sandier, far more churned with only 1 sand "bed" with remnant combined flow ripple laminations; more diverse but still not many traces

probably U4/U5 Contact

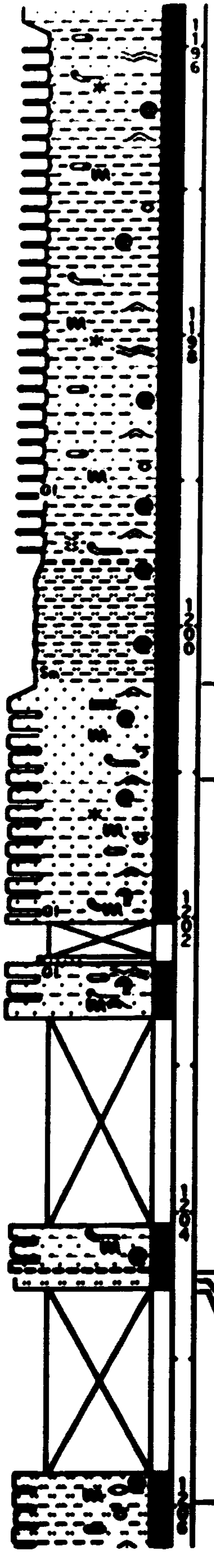
probably a continuation of U4 (similar to the lower part of FA2 stuff...)

probably a continuation of U4: ~ upper 60cm we start getting thicker sharp based vf sands with low angle laminations/wavy parallel laminations (10-12cm thick) and the sands are relatively commonly burrowed with Palaeophycus and Teichichnus
- intervening thinner interbedded vf sand and shale is less burrowed than anywhere below ("kind of similar to lower part of FA2")
- Helminthopsis, Terebellina, first appearance of Chondrites, Asterosoma, Planolites

The first convincing Chondrites I've seen in this core

This interval of lost core represents the missing core in Core 17: 3913-15
Core 16: 3908-13'; Core 15: 3903-08'; Core 14: 3901-03' Rec. 1.5'; Core 13: 3900-01' Rec. 11"; Core 12: 3898-3900' Rec. 2.5'; Core 11: 3896-98' NO RECOVERY; Core 10: 3891-96' Rec. 0.5'; Core 9: 3886-91'; Core 8: 3881-86' Rec. 5.1'; Core 7: 3876-81' Rec. 5.2'; Core 6: 3871-76' Rec. 5.2'; Core 5: 3866-71' Rec. 6.3'; Core 4: 3861-66' Rec. 1.5', 6.3' drilling mud; Core 3: 3852-61' Rec. 3.3'; Core 2: 3842-52'; Core 1: 3840-42' Rec. 1.85'

UNIT 4: Interbedded vf sandstone and shale
- churned thoroughly but still different from the churned interbedded vf sandstone and shale below because in U4, the sands tend to more bedded (and therefore concentrated in)1-7cm thick oscillation rippled vf sandstone beds with glauconite, rare organic detritus, sharp bases and commonly burrowed tops; the Palaeophycus and escape traces noted were restricted to the thicker continuous sands in this unit
- between the sandy "event" beds, the sand and shale are generally well churned and commonly shale dominated
- unit generally sands upwards with thicker, more frequent and more continuous sands as we go up in the unit
- one sand bed with rounded shale rip-up clasts



U3/U4 Contact: possible parasequence boundary

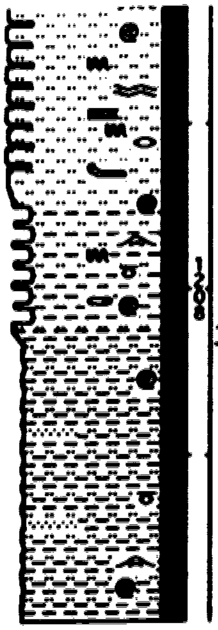
UNIT 3: Churned interbedded vf sandstone and shale (sand dominated)
- continuation of sanding upwards sequence
- rare preserved sand beds 1-3cm thick; sharp based with gradational to burrowed tops; some glauconite; remnant oscillation ripples/wavy parallel bedding
- lots of Helminthopsis, some Planolites, small Terebellina, Asterosoma?
- shale overlying upper contact (possible parasequence boundary??) is highly smectitic

U2/U3 "Contact": at a core break where there is no apparent loss of core

probably continuation of U2

Core 31: 4120-4121; Core 30: 3866-3870' Rec. 4'; Core 29: 61-66' R. 5' Core 28: 3860-61'; Core 27: 3855-60' R. 0.5'; Core 26: 3854-55'; Core 25: 3848-54' R. ~1.5'; Core 24: 3841-46' R. 0.1'; Core 23: 3836-41'; Core 22: 3833-36'; Core 21: 3832-33'; Core 20: 3827-32'; Core 19: 3821-27'; Core 18: 3815-21'; Core 17: 3813-15' R. 2'; Core 16: 3808-13'

UNIT 2: Churned interbedded vf sandstone and shale
- typical regional Viking shale full of Helminthopsis, rare Terebellina, Zoophycos??
- sands/silts rarely continuous on the scale of the core(1"?), but where they are, they are up to



1cm thick and have remnant oscillation ripple to wavy parallel laminations

U1/U2 Contact

UNIT 1: Dark Silty/vf Sand Shale
- core is almost totally shattered
- burrowed but individual traces difficult to discern probably due to lack of lithologic contrast
- gradational upper "contact"...

CPOG WAYNE
9-14-28-21w4

Date logged: August 8, 1990

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 854.00 m   KB: 858.00 m

Remarks: Core 1; 11 boxes, 3952'-4004'; 3.5" full diameter core; photogenic but is stained, have box shots and prints

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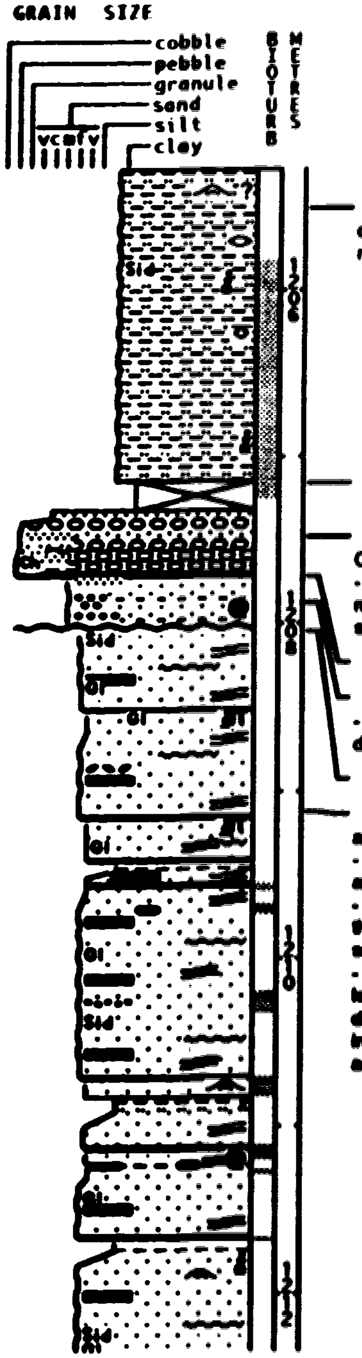


UNIT 7: Dark Shale with mm scale discontinuous siltstone/vf sandstone lenses; no discernible traces due to lack of lithologic contrast, rare sideritised patches, hint of oscillation rippling in the thin siltstone/vf sandstone lenses?, lower contact is missing

U6/U7 Contact (core missing: sampled for fracture test)

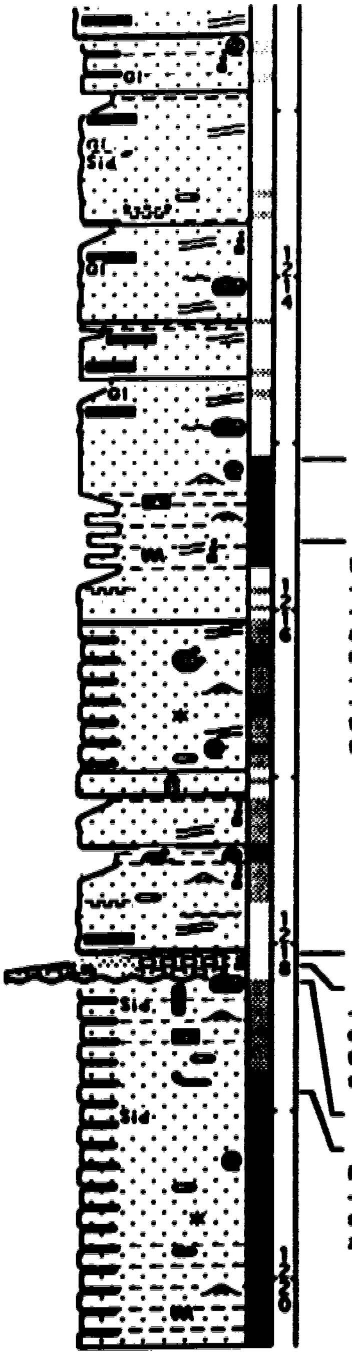
UNIT 6: Poorly Sorted Clast supported conglomerate that goes up into a Matrix Supported Conglomerate, that goes up into pebbly sandstone
- probable transgressive lag, maximum pebble ~2.1cm diameter, average ~0.7-1.0cm diameter, mostly sub to well rounded, chert and lithics, unit fines upwards with fewer pebbles and more salt and pepper matrix sand

U5/U6 Contact

UNIT 5: Mottled, Poorly Sorted Shaly Sandstone with scattered Pebbles
- pebble "lag" at unit base that overlies sideritised portion of U4, maximum pebble ~1cm diameter, mostly chert and lithic, rounded to sub-rounded granules; sand is fg-mL

U4/U5 Contact

UNIT 4: Facies Association 2: Interbedded vf Sandstone and Shale with Thickly bedded Low angle Undulatory Laminations
- true facies association 2, thickly bedded sandstone beds that are very well sorted with almost all grains vfU
- Interbedded portion: commonly the apparent waning flow part of the flows that produced the thick sandstone beds, rarely burrowed (Planolites), commonly normally colour graded from sandstone to siltstone to shale, rare synaeresis cracks
- Thick Sandstone beds: common low angle truncations which are mostly ~5 degrees or less; less frequently 10-15 degrees, laminations are low angle parallel to slightly undulatory, domination of low angle stratification and sorting suggest a high degree of wave action involved in the sorting and deposition of the sand, some combined flow ripples, organic material accentuate laminae, rare (sideritised) ripped up material, glauconite



U3/U4 Contact

UNIT 3: Facies Association 2: Interbedded Slightly Burrowed vf Sandstone/Shale with thicker Low angle Undulatory laminated vf Sandstone beds
- sandstone beds have some organic laminae accentuating the low angle inclined laminations
- moderately burrowed interbedded vf sandstone/shale but not many traces, not very diverse assemblage (Rhizocorallium, rare ?Ophiomorpha, Planolites, Chondrites, rare Helminthopsis, rare ?Asterosoma)
- physical sedimentary structures are difficult to see well due to staining
- this unit is really a transitional facies association between U1 and U4 where U4 is really the true Facies Association 2 with much thicker bedded sandstone beds and far less burrowing in the interbedded portions

U2/U3 Contact

UNIT 2: Quite Well Sorted Clast Supported Conglomerate
- unit fines upwards from average ~2-3cm diameter pebbles near base to average ~0.8-1.2cm diameter towards the top although the smaller size dominates and does extend locally down to the base of the unit; pebbles are chert and lithics, all are sub to well rounded, not imbricated, vf sand in interstitial pore spaces; gradational upper contact is overlain by siltstone and shale

U1/U2 Contact

UNIT 1: Facies Association 1: Burrowed Interbedded vf Sandstone/Shale with Oscillation Rippled vf Sandstone (very sandy)
- physical sedimentary and biogenic structures are very difficult to discern properly due to staining of core, mostly burrowed with only rare sandstone beds >5cm thick; local sideritised zones

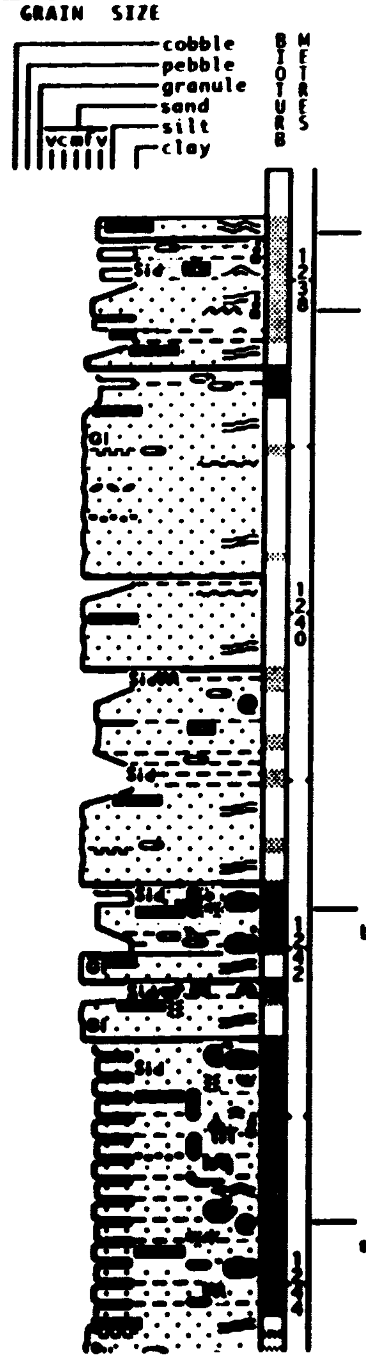
CPOG WAYNE
11-22-28-21w4

Date logged: April 2, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 866.90 m KB: 870.20 m

Remarks: 3.5" whole diameter core; quite photogenic
Core 4, 7 boxes; 4060'-4089' (don't have the log to check depths); have box shots (not including basal ~30cm of core)

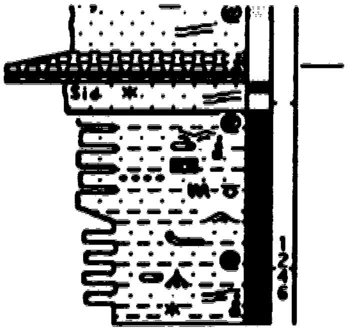


entire well is gradational from FA1/FA2 transitional into FA2 above

intraformational sandstone clast

looks like transitional FA2 with thinly interbedded sharp based sandstone beds and dark black shale beds with lots of Chondrites, Rhizocorallium etc.

lots of Rhizocorallium in this well; in both the dark muds as the lone trace and in the thin storm sandstones



thicker of 2 clast supported conglomerate beds that are separated by a very thin shale bed

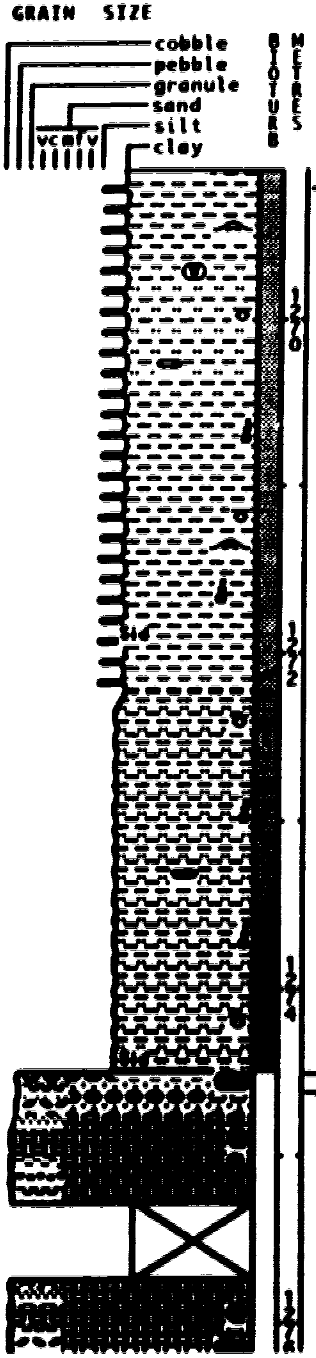
PCP REDLAND
15-16-28-22w4

Date logged: December 9, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 858.30 m KB: 862.50 m

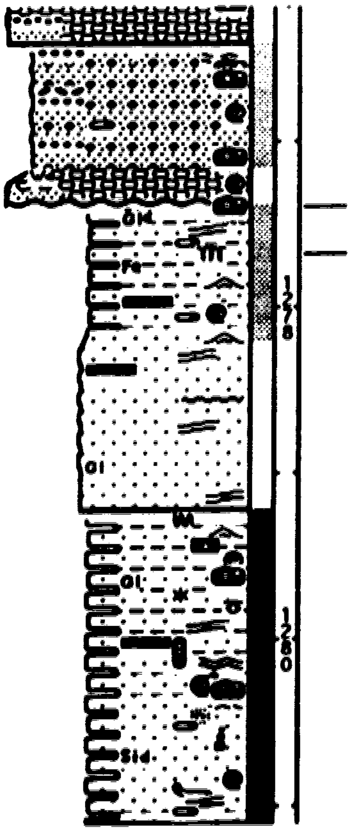
Remarks: Core 1; Boxes 1-5, 1268-1273.6m Rec. 5.6m (1269.1-1274.7m)
Core 2; 1 Box, 1273.6-1274.6m Rec. 0.60m (1274.7-1275.7)
Core 3; Boxes 1-5, 1274.6-1280m Rec. 5.4m (1275.7-1281.1m)
reasonably photogenic, have box shots of ~3.2-7.4m of core



UNIT 3: Dark Silty Shale passing up into Shale Dominated Interbedded Shale and Siltstone
- lower portion is basically Dark Silty Shale with rare mm scale sharp based silty "beds"
- upper portion: more sharp based silt beds preserved (maximum 2cm thick) with remnant oscillation to wavy parallel laminations
- both units have minor burrowing (probably due to lack of lithologic contrast), and local sideritisation

U2/U3 Contact

UNIT 2: Poorly Sorted, Churned Clast Supported Conglomerate with sand, silt and muddy matrix, together with associated Pebbly Burrowed mg Sandstone
- all probably highly burrowed but individual trace types are very difficult to discern
- pebbly sandstone: hints of parallel wavy laminations, rare preserved 1cm thick shale laminae with Planolites, sand dominantly mL but may be mud to granules also
- clast supported conglomerates: very poorly sorted, thoroughly churned, matrix from mud to cg sand with a tendency towards more and more muddy matrix upwards within the unit (possibly a function of more and more influence of a marine transgression)
- pebbles throughout are generally well rounded, mostly chert pebbles, average 1cm diameter, maximum approximately 4.5cm diameter



U1/U2 Contact

UNIT 1: transitional to true FA2

- below the thick sand: more burrowing by more trace types, some Arcoonichnus horizontalis colonising the oscillation to CF rippled tops of probable waning flow storm beds; some clusters of small Terebellina- could be Schaubcylindrichnus?; sand beds sharp based, commonly fine upwards, 5-10cm thick, can have burrowed tops or waning flow features and capped by dark shale which is commonly burrowed strongly with Chondrites
- thick sand with low angle parallel laminae that have low angle truncation surfaces
- above thick sand: mostly 5-10cm thick sand beds with organic detritus accentuating the low angle parallel bedding and oscillatio to combined flow ripples, less intense burrowing with only Planolites and Palaeophycus visible

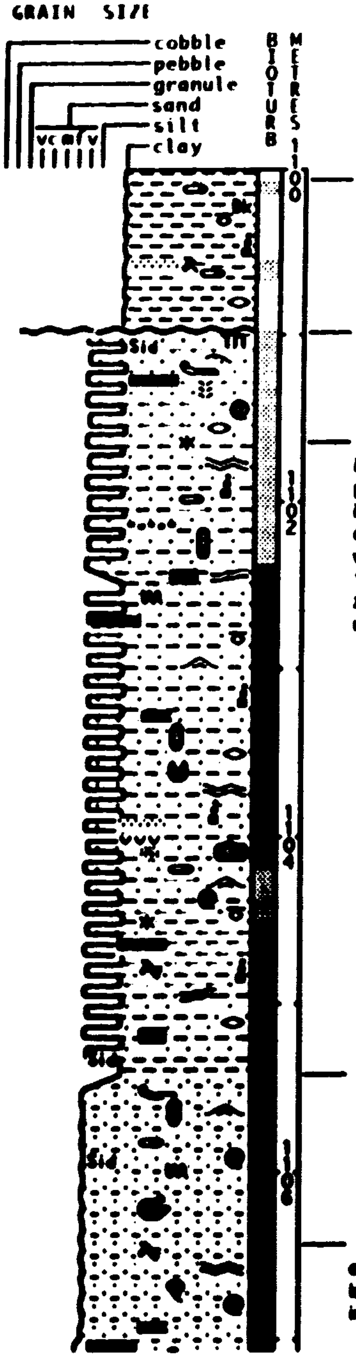
Petromark et al. AERIAL
11-17-29-18w4

Date logged: November 16, 1992

Logged by:

Ground: 840.90 m KB: 844.60 m

Remarks: Core 1; 13 boxes, 1098-1116.25m (actually ~1100-1117.35m); Recovery 17.7m (actually ~17.35m), 3.5" full diameter core, reasonably photogenic but much of core is crumbled up in the boxes; have box shots; wells logged quickly in the interest of time...



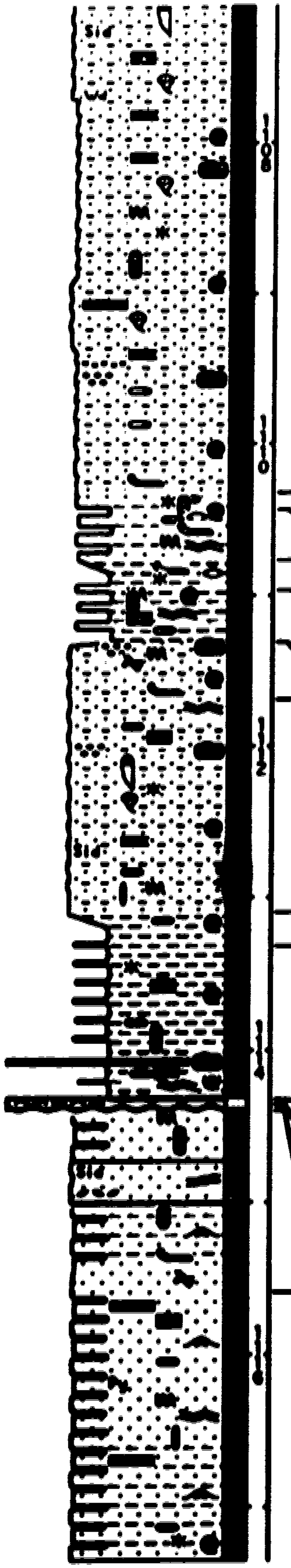
UNIT 10: black shale with rare mm scale discontinuous loaded based silt beds; 30cm from unit base is base of 10cm zone with dispersed fg-mg sandstone; Planolites and possible Thalassinoides

UNIT 9: transgressive pebbly mg sandstone lag; pebbles rounded chert up to 1.5cm diameter

UNIT 8: essentially like FA2, but a little bit more burrowed, with Planolites-Chondrites common in organic-rich shales, Teichichnus, Asterosoma, Helminthopsis, Zoophycos, Diplocraterion, possible Siphonichnus, also Ophiomorpha, fugichnia, Palaeophycus and Anconichnus (mostly in the silty portions of sharp based fining up beds) colonising tops of storm beds; structures dominantly oscillation to combined flow rippled with organic detritus, some low angle parallel to wavy parallel laminations; sharp/loaded based, normally graded fining up sandstone beds 1-3cm near base and up to 10cm thick upwards (with less burrowing); rare siderite (10cm thick zone just below upper contact), rare synaeresis cracks; organic-rich shales commonly unburrowed

U7/U8 Contact

UNIT 7: Thoroughly churned shaly sandstone akin to sandy burrowed FA1; highly burrowed equilibrium trace suite lower shoreface; rare thin sandstone beds with remnant wavy parallel laminations; possible Schaubcylindrichnus and Subphyllochorda; transitional/gradational up into more FA2-type restricted stuff



U6/U7 Contact

UNIT 6: similar to U5 but more sand content

U5/U6 Contact

UNIT 5: mottled sandy shale; vf sand; locally discontinuous 1-2cm lenses with rare remnant wavy parallel laminations; traces: mostly Helminthopsis, also Terebellina, Teichichnus, Asterosoma, Planolites etc.

U4/U5 Contact: possible flooding surface

UNIT 4: totally burrowed shaly fL sandstone (only logged as shaly sand since the degree of burrowing is so dominant that only two 3cm thick lg sand beds (locally with mg at their bases) with remnant wavy parallel laminations are preserved) "equilibrium suite" of marine burrows, probably in the lower shoreface (much like PBS at Chigwell); traces: Zoophycos, Teichichnus, Asterosoma, Planolites, Thalassinoides, rare Chondrites, superabundant robust Helminthopsis, robust Terebellina, Rosselia, Cylindrichnus, rare Skolithos etc.; ~3cm zone of scattered large rounded chert pebbles (maximum minimum diameter of 1.7cm) much like I've seen in this facies in T28 and T29;R19w4; scattered granules (up to 0.5cm diameter subrounded chert pebbles) in upper 10cm at a possible flooding surface

U3/U4 Contact

UNIT 3: shale dominated interbedded shale and vf sandstone; sand beds 1-4cm thick with wavy parallel and oscillation ripple laminae; near unit base is a 2cm thick pebbly/conglomeratic zone with pebbles up to 1.7cm diameter, but mostly rounded to subrounded 0.5-1cm diameter granules; zone between conglomerates is mostly shale with some dispersed pebbles; some discontinuous "lenses" of sand; commonly burrowed with Helminthopsis, Chondrites, Palaeophycus, Teichichnus, Planolites, Asterosoma; wavy parallel laminations with lots of coffe grounds organic material "drape" the underlying transgressive conglomerate

U2/U3 Contact

UNIT 2: clast supported conglomerate; chert pebbles well rounded (maximum 2.5cm diameter) but mostly 0.5-1cm rounded to subrounded granules; whitish clay material in interstices; overall quite porous(?); sharp upper contact

U1/U2 Contact: Flooding surface/parasequence boundary (clearly seen on gamma ray well log)

UNIT 1: vfU sand dominated interbedded sandstone and shale; moderately burrowed with Planolites, Chondrites, Terebellina, Asterosoma, Helminthopsis, Teichichnus, Ophiomorpha, Thalassinoides, Palaeophycus, rare small Skolithos; sand beds average 3-5cm near base with some 10-30cm thick sand beds towards top of unit, sands with oscillation ripple laminae to low angle inclined laminations; organic detritus; minor pyrite; some 1-2cm thick shale beds; sharp upper contact

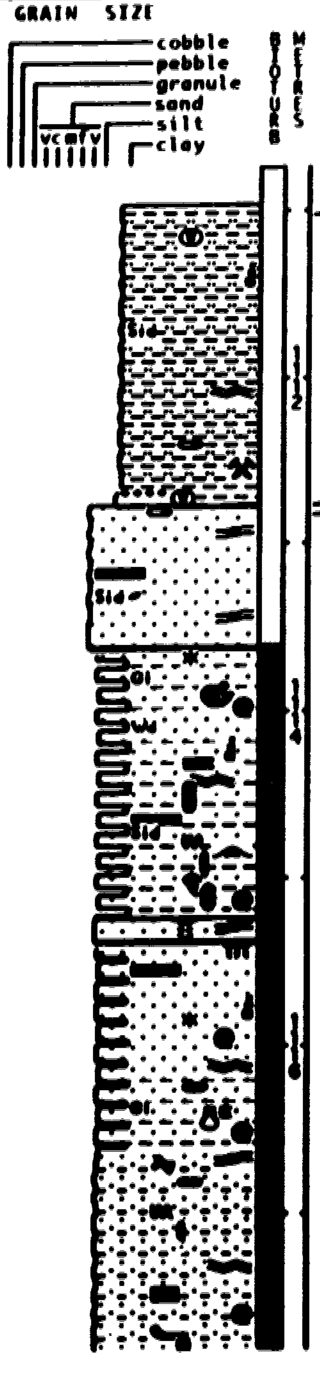
Oak Ridge et al. DRUM
7-1-29-19w4

Date logged: December 5, 1991

Logged by: Indraneel Raychaudhuri

Ground: 843.70 m KB: 847.95 m

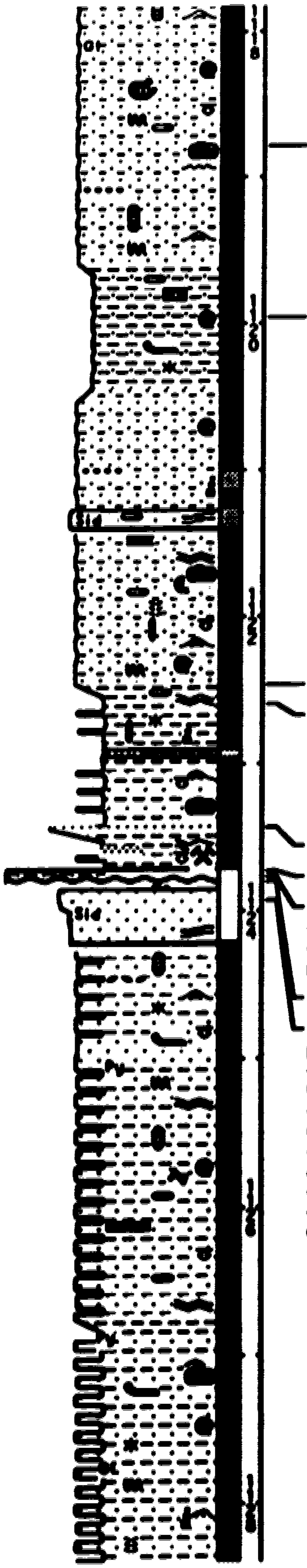
Remarks: ~on depth; 3.5" full diameter core, Core 3; Boxes 1-13, 3645-3705'(1111-1129.28m), full rec., Core 4; Boxes 1-13, 3705-3765'(actually 3706.5-3766.5' or 1129.74-1148.03m), full rec.; photogenic; rechecked some units from box photos (units jibe with logs)



UNIT 8: Dark Shale with mm Scale sharp based fining upwards normally graded vfL/silt to mud beds with vague wavy parallel laminations
- some fish scales

U7/U8 Contact

UNIT 7: Interbedded vf sand with Highly burrowed/churned vf sand and shale (aspects of FA1 which changes upwards into more like FA2)
- extremely plentiful and diverse assemblage of trace fossils
- above where unit becomes totally sand dominated (80%), low angle laminated wavy parallel bedded sands are more plentiful and thicker (hence the burrowing intensity decreases) up to 10-13cm thick
- thick sand at top is probably HCS
- some "psycho" Rhizocorallium in oscillation/CFR rippled sand; Chondrites tend to either reburrow pre-existing wall linings or colonise the dark muds that cap the thicker preserved sand beds



above here the unit is totally sand dominated, much of it similar to what I called Facies 4 (Pale Burrowed Sandstone) at Chigwell

only slightly shalier here; borderline sandy shale/shaly sandstone

U6/U7 Contact: sharp due to marked change in degree of burrowing

UNIT 6: Interbedded vf sand and shale
- sharp based, normally graded sands with hints of oscillation rippled to wavy parallel bedding
- sands 1-2cm thick
- interval is moderately burrowed with two pebble stringers; maximum pebble 1cm diameter, well rounded, in a matrix of mg salt and pepper sand
- very thin mud-lined Skolithos

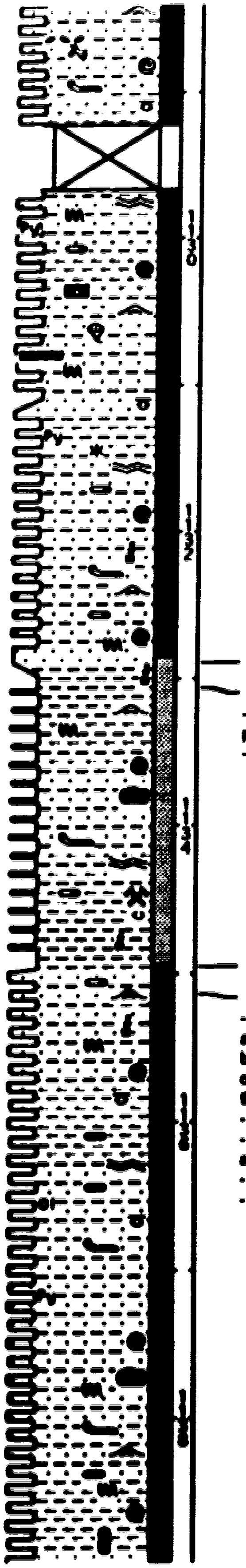
may represent a second "surface"; mostly mg sand with rounded chert granules

U5/U6 Contact

UNIT 5: Poorly Sorted Clast Supported Conglomerate
- probably transgressive lag at a flooding surface/parasequence boundary
- maximum pebbles 2cm diameter, average 1cm diameter, well rounded with a mg salt and pepper sand in the matrix

U4/U5 Contact

UNIT 4: essentially the same as unit 2 with a few more types of trace fossils and a > percentage of sand (vfL)
- one case of definite small scale current ripples , otherwise oscillation/CFR ripples dominate in the sands
- sand beds maximum 8cm thick, average 3cm with sharp bases/loaded bases that may fine upwards
- ichnofossils: small rare Rosselia, rare pinprick Chondrites, Ophiomorpha and Palaeophycus and escape traces more common in the thicker bedded continuous sand beds
- pyritized burrows
- uppermost vfL sand has low angle inclined laminae with some sideritization and minor wispy organic rip-ups

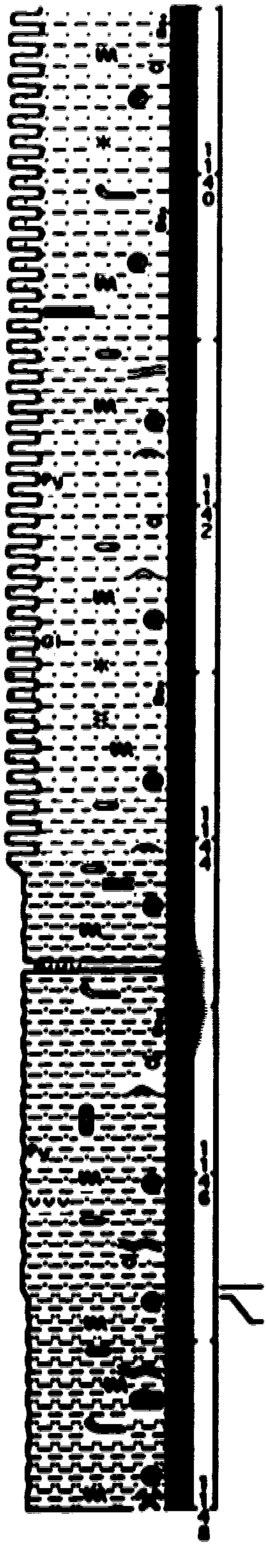


U3/U4 Contact

UNIT 3: Rarely Burrowed Shale Dominated Interbedded vf Sandstone and Shale
- maximum 1-2cm thick sharp based vf sands with commonly loaded bases and hints of possible remnant oscillation/CFR to wavy parallel bedding
- basal 50cm is bentonitic (picked up on logs)

U2/U3 Contact

UNIT 2: Highly Burrowed Interbedded vf sand and shale
- higher sand percentage than U1; rare preserved vfL sand beds which average 2cm thick with a maximum thickness of 7cm and these sands are sharp based(also commonly with loaded bases), fining upwards (normally colour graded)with burrowed tops and rare preservation of oscillation to CFR to wavy parallel bedding; also some organic laminae and some glauconite in the sands
- overall the majority of this unit is similar to U1 but with more sand
- good diversity of trace fossils, most of which are abundant; escape traces and Palaeophycus are basically restricted to the preserved sand beds; all burrows are quite small
- minor pyrite which may be nucleated around burrows
- basal portion is actually totally homogenized shaly sandstone



U1/U2 Contact

UNIT 1: Highly Burrowed Silty Shale
- typical background regional Viking with Helminthopsis abundant and minor Terebellina and Planolites
- rare <1cm thick preserved discontinuous vfL sand/silt beds with remnant wavy laminations

PANALTA EMPIRE ST. WAYNE
10-16-29-20w4

Date logged: December 13, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 790.70 m KB: 794.61 m

Remarks: 3.5" unslabbed full diameter core, Core 1 Boxes 1-11, 3725-3774.5', core appears to be approximately on depth, reasonably photogenic if cleaned up, entire core lies under the main Viking interval, as of Jan. '93 no photos for this well

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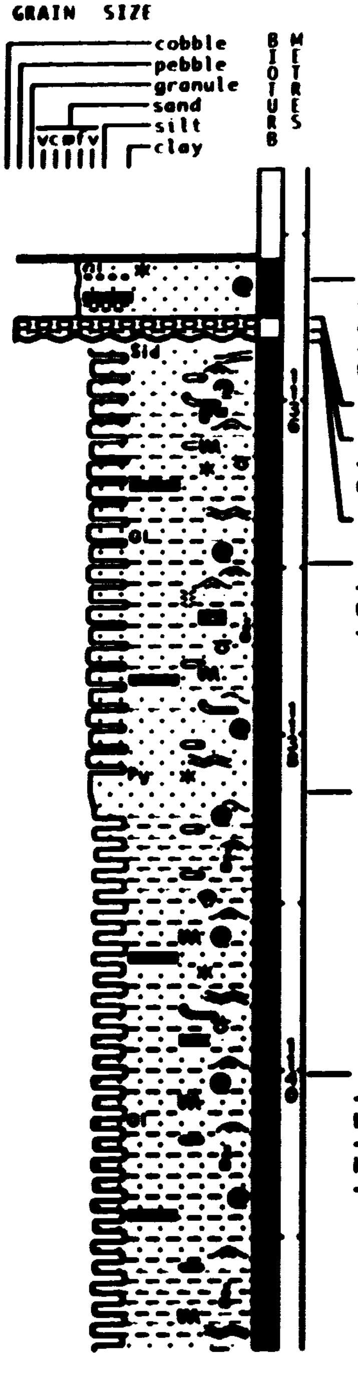


UNIT 5: Burrowed fg Sand with wispy mud streaks
- scattered granules/pebbles throughout; a 2cm pebbly zone at unit top (well rounded, and average 6mm diameter)
- parts of this unit may be slightly out of order since this area was difficult to piece back together

U4/U5 Contact

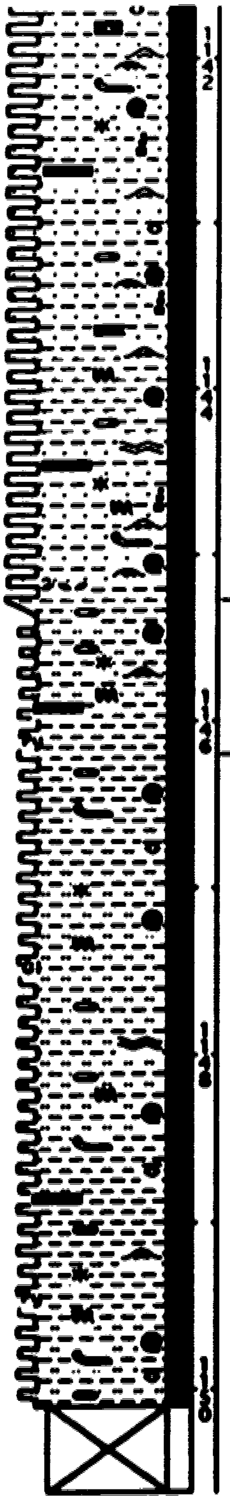
UNIT 4: Poorly Sorted Clast Supported Conglomerate
- maximum pebble 1.2cm diameter, average 0.7cm diameter, matrix is mostly mg and cg sand, most pebbles are well rounded, dominantly chert pebbles but some lithic rock fragments also

U3/U4 Contact

UNIT 3: Thoroughly Burrowed Interbedded vf Sand and Shale
- more like FA2, with higher sand content than U2 plus thicker preserved sands(average 4-5cm thick, maximum 10cm thick) with oscillation/CFR to low angle parallel/wavy parallel bedding
- continuation of overall sanding upwards succession

U2/U3 Contact

UNIT 2: Thoroughly Burrowed Interbedded vf Sand and Shale
- similar to underlying unit but with a higher sand content and more continuous 1-3cm thick sand beds preserved with some definite oscillation to combined flow ripples
- higher trace diversity than U1 may be a function of greater sand percentage, and hence increased lithologic contrast
- Rosselia and Chondrites are very rare; possible Zoophycos



U1/U2 Contact

UNIT 1: Thoroughly Burrowed Interbedded Shale and vf Sand/Silt

- much like the regional background Viking facies, shale dominated and dominating trace is Helminthopsis
- some1-2cm thick, commonly discontinuous(due to extensive burrowing), sharp/loaded based vfL sand-silt beds with remnant traces of oscillation ripples
- basal part of an overall sanding upwards succession

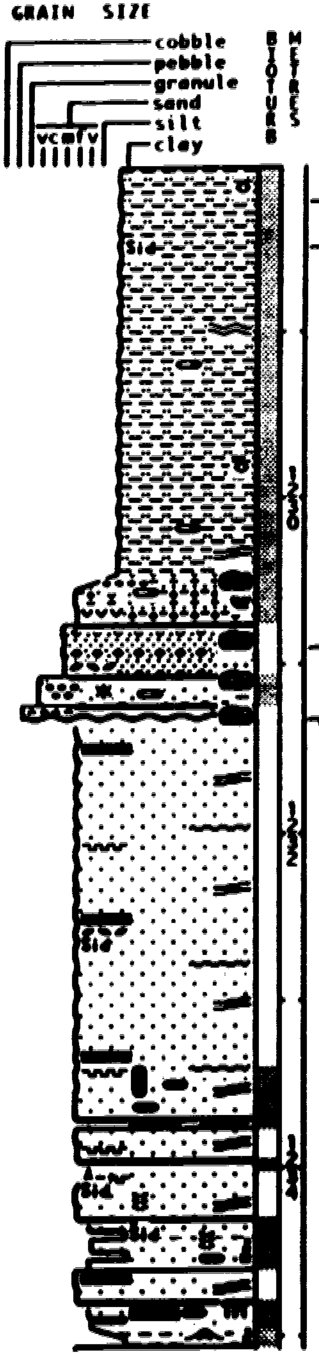
CPOG ZAPATA CARBON
7-1-29-22w4

Date logged: April 1, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 827.50 m   KB: 831.50 m

Remarks: quite photogenic; 4 conglomeratic "lenses" and good development of the coarse transgressive facies (i.e. the Viking grit); 3.5" whole diameter core; have box shots
Core 1; 11 boxes, 4022-4072'(probably 4028-4079' or 1227.73-1243.28m)

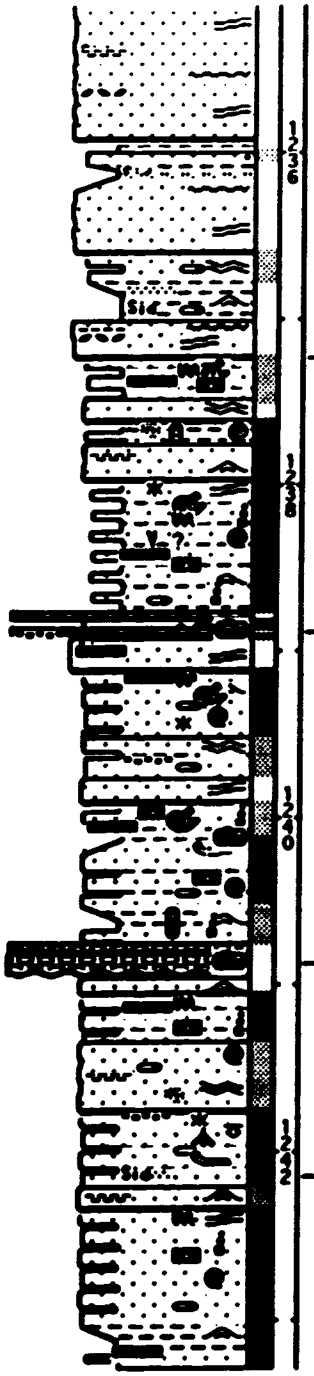


Dark Silty Shale with rare mm to 1cm thick loaded based vf sandstone lenses with remnant wavy parallel laminations

base of 10cm thick sideritised zone

Transgressive deposits:
1) Basal granule/vc sandstone with scattered pebbles up to 1cm diameter
2) Pebbly and Shaly mg sandstone with some cg and vc/granules sand, maximum pebble 3cm diameter
3) Cross bedded pebbly mg sandstone
4) Mottled sandy shale with lenses of mg to cg sand, up to 3cm diameter pebbles
- pebbles in all 4 transgressive units are subangular to well rounded chert and lithic fragments

FA2/Transgressive contact



FA1-FA2 Transitional/true FA2 Contact

actually a lens of pebbly material that doesn't quite go around the entire core diameter; both thin conglomerates are poorly sorted, clast supported, sub to well rounded chert and lithics with mg to cg/granule matrix

2 thin beds of essentially inverse graded conglomerate with maximum pebble diameter ~2cm; pebbles sub to well rounded lithics and chert

mm scale mg sand "stringer"

CWNG Carbon
7-4-29-22w4

Date logged: May 10, 1993

Logged by: ©1993 Indraneel Raychaudhuri

Remarks: Core 1; 9 boxes; 4080'-4120', Rec.40' (actual recovery 41.5' or 12.2m); Core 2; 6 boxes; 4135'-4165', Rec.28' (actual recovery 28.8' or 8.8m); photogenic; have box shots

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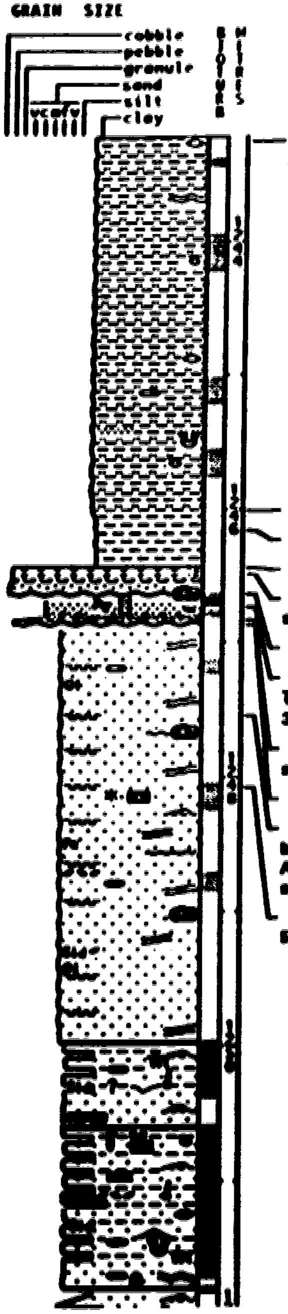


UNIT 12: dark shale with mm scale sharp based commonly discontinuous siltstone stringers with vague wavy parallel laminations; one 4cm thick vf sandstone bed with guttercast-like base; only *Planolites* visible

U11/U12 Contact

UNIT 11: unburrowed black shale

U10/U11 Contact: maximum flooding surface

UNIT 10: basal portion has 3-3.5cm rounded chert pebbles in a matrix of 3-5mm diameter granules/pebbles and mg sandstone; and this matrix gradationally passes upwards into silty shale and shale (but pebbles remain ~3cm diameter)

U9/U10 Contact: with Glossifungites surface (BGP agrees)

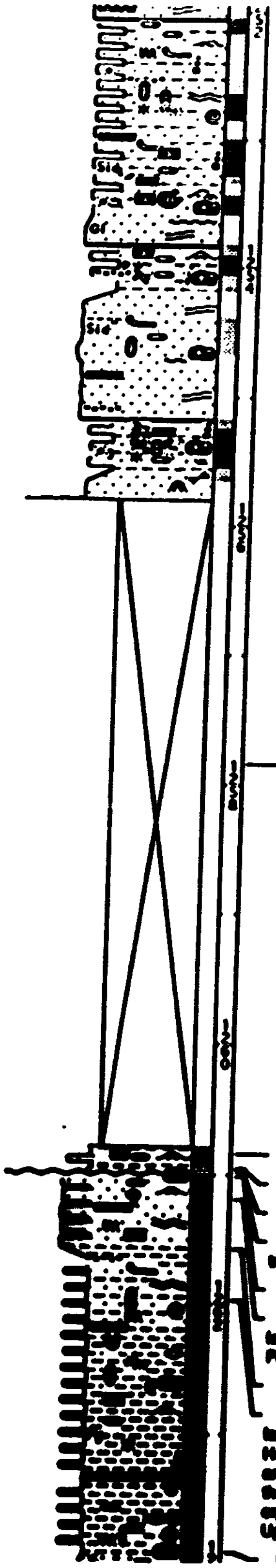
pebbly mg sandstone that is biogenically mottled but few trace fossils visible; Glossifungites at top which is a Thalassinoides; some scattered maximum 8mm rounded pebbles near base, then mostly sandstone with a few large 3-3.5cm diameter rounded pebbles burrowed down from above

basal bit is clast supported conglomerate with good sorting and made up of granules/pebbles averaging 3-5mm; some sideritized rip-ups and muddy rip-ups; mostly subrounded, some subangular

U8/U9 Contact: initial TSE

UNIT 8: basically FA2, with thicker and more amalgamated storm-generated sandstone beds upwards, as well as less burrowed shales upwards; burrowing is sporadic, and basically restricted to small Chondrites, Planolites; rare Asterosoma...; Storm Dominated Delta Front; one sediment gravity flow bed right at base; upper contact has been sampled therefore it is somewhat uncertain

each of these shale laminae symbols represents either the organic-rich muds that cap the sandy storm beds OR thin 5-10cm zones of interbedded oscillation rippled sandstone and shale



not missing core, rather UNCORED, represents Core 1/Core 2 break

UNIT 9: shale dominated interbedded shale and vfL sandstone

U8/U9 Contact

UNIT 8: silty shale; a few dispersed granules

UNIT 7: 5cm thick lense of conglomerate with maximum 6mm diameter rounded pebbles/granules; ?maybe transgressive lag

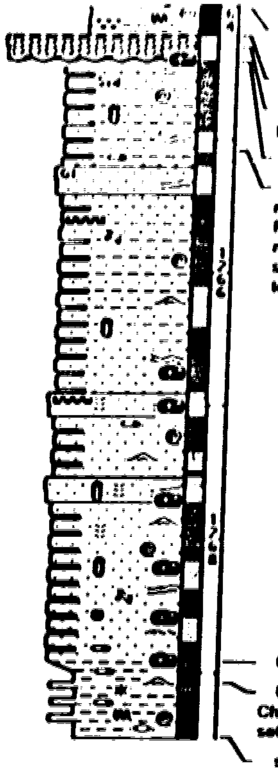
U6/U7 Contact: ?TSE

UNIT 6: sand dominated interbedded vf sandstone and shale; 5-10cm sandstone beds with wavy parallel laminations accentuated by finely comminuted organic detritus; traces: Chondrites in muds, Helminthopsis, Rosselia, Palaeophycus, Planolites; Lower Shoreface

U5/U6 Contact: gradational sanding upwards

UNIT 5: excellent example of FA5"regional" Viking; 1-4cm thick sharp based wavy parallel to oscillation ripple laminated vfL sandstones; some lenticular type bedding; common burrowing intensity with wide diversity: Helminthopsis, Chondrites, Planolites, Thalassinoides, Ophiomorpha, Asterosoma, Zoophycos, small Diplocraterion and Skolithos, Terebellina, Palaeophycus, Teichichnus, Arenicolites etc.; 4cm thick bentonite near unit base and there is essentially no burrowing for 10cm above this bentonite; Chondrites-Planolites association in some organic-rich shale zones; minor pyrite blebs; rare granules at the base of the thin storm-generated sandstone beds; Upper Offshore to Distal Lower Shoreface Setting; well oxygenated, nutrient-rich...

U4/U5 Contact



UNIT 4: mottled silty shale, scattered pebbles and granules in basal 8cm, Helminthopsis galore, also Planolites, some pyrite. Offshore setting below storm-weather wave base

U3/U4 Contact: ?maximum flooding surface

UNIT 3: Clast supported chert pebble conglomerate with minor shale and sand in interstices; maximum visible pebble is ~2cm diameter, all seem well to sub-rounded, likely Transgressive Lag

U2/U3 Contact: TSE

UNIT 2: sand dominated interbedded vf sandstone and shale; traces: totally dominated by Ophiomorpha which are robust 3-5cm diameter (all but one of the visible Ophiomorphas are irregulare, with only one nodosa), also Palaeophycus, Planolites, lots of escape traces, one Siphonichnus, and one small cluster of ?Asterosoma; oscillation rippled to wavy parallel bedded sandstone and some sharp based low angle inclined laminated & storm generated sandstone beds with burrowed tops ("lam-scram"); minor siderite, especially at top of unit near upper contact; appears to represent a classic moderately storm dominated Lower Shoreface succession

U1/U2 Contact

UNIT 1: shale dominated interbedded shale and vfL sandstone; traces: dominated by Helminthopsis, also, Planolites, Chondrites, Palaeophycus; oscillation ripples; lenticular bedding; Upper Offshore transitional to lower shoreface setting

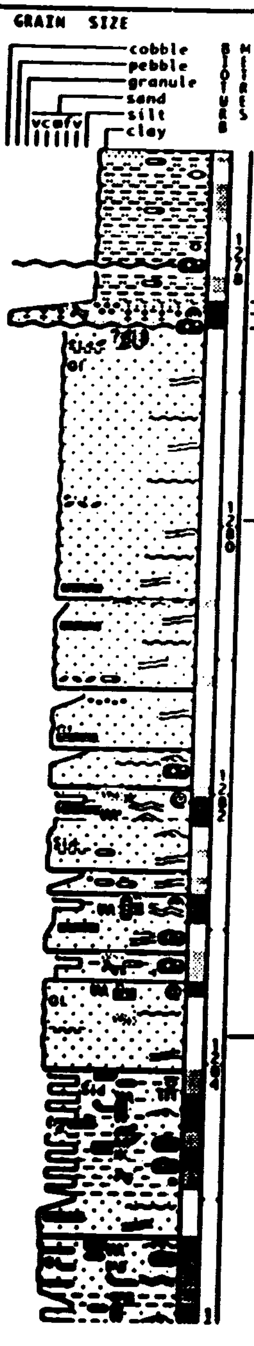
should be 35cm lost recovery at base of core

CWNG et al Carbon
7-7-29-22w4

Date logged: May 12, 1993

Logged by: Indraneel Raychaudhuri ©1993

Remarks: Core 1; 10 boxes, 4190'-4230', Cut 40', Rec. 33.5' (measured 34.1') (1277.1-1289.3m, Cut 12.2m, Rec. 10.4m); 4" full diameter core; photogenic; have box shot the well



UNIT 3: essentially silty shale but with rare vf sand stringers with loaded bases and appearing discontinuous on the scale of the core; rare burrowing visible; one 2-3cm thick bed/lens of pebbly mg salt and pepper sandstone with the pebbles (like U2) are well to subrounded chert pebbles with a maximum clast size of ~1cm diameter

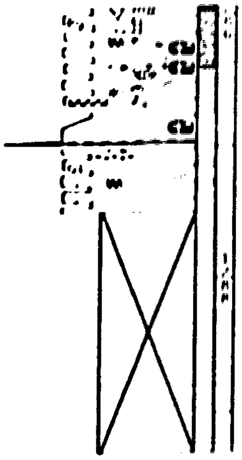
U2/U3 Contact

UNIT 2: pebbly and mg salt and pepper sandy friable shale, mottled but traces are difficult to discern

U1/U2 Contact: Initial TSE

UNIT 1: essentially the entire core is transitional f A1/f A2 into true f A2, burrowing intensity isn't always very high, but the diversity lower down in the core is really quite amazing

this is a 5cm thick zone of 1 large ripped up clast of finely interbedded vf sandstone and shale with even some small microfaulting



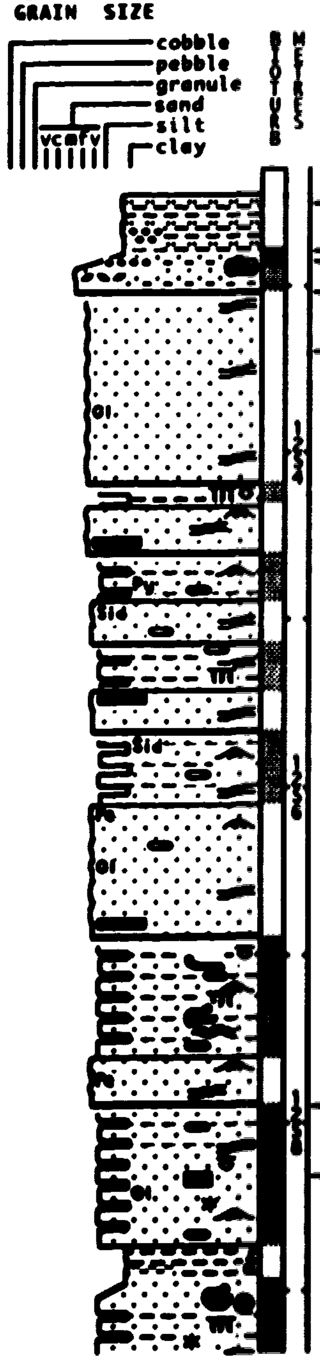
CWNG RES CARBON
6-9-29-22w4

Date logged: December 6, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 826.90 m KB: 830.90 m

Remarks: Core 1 Boxes 1-14: 1251.2-1266.4m Rec. 14.25m
Core 2 Boxes 1-7: 1266.4-1274m Rec. 7.55m
4" full diameter unslabbed core; photogenic
depths on AppleCore boxes may still be out by ~1m



UNIT 11: Dark Silty Shale with mm scale sharp based silt/vfL sand streaks
- some dispersed chert pebbles (maximum 2cm diameter)
- lower contact is gradational probably due to the intensive burrowing

U10/U11 Contact

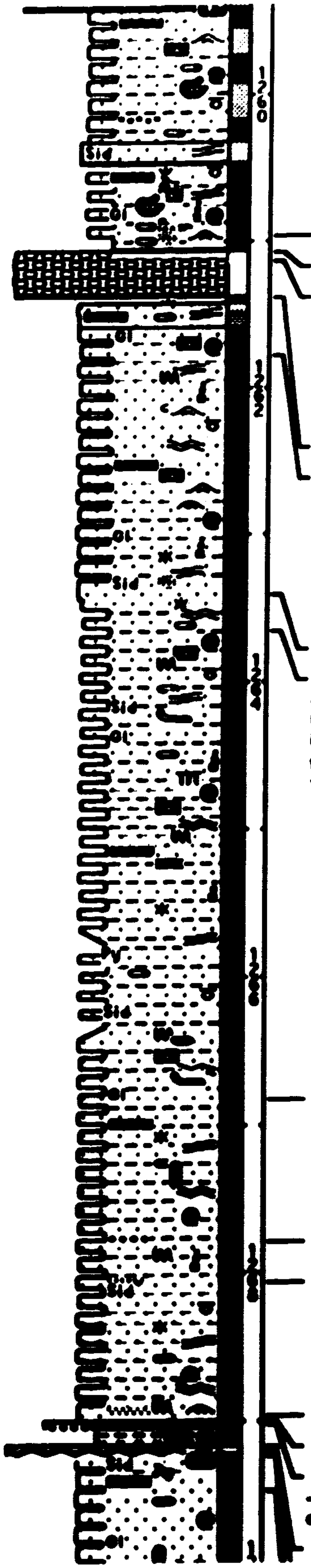
UNIT 10: Churned mg salt and pepper sandstone with dispersed rounded to angular pebbles(maximum 2.5cm diameter)
- probable transgressive lag
- shale is extremely friable, especially when wet

U9/U10 Contact

UNIT 9: Transitional FA2 into FA2
- lose more and more ichnogenera upwards; where burrowed, domination by Chondrites, Asterosoma, Rhizocorallium lower down, basically only Planolites and indistinct burrowing in upper portion of unit
- thicker bedded sands have low angle inclined laminations and organic detritus/Fe staining accentuating the laminae; also low angle truncation surfaces (HCS?); waning flow into oscillation/CFR rippling at tops of sands, fining upwards commonly into dark shales

true FA2 above here

last definite occurrence of Chondrites



actually Anconichnus horizontalis colonising the top of a probable storm deposited vf sand

U8/U9 Contact

UNIT 8: Sorted Clast Supported Conglomerate with a vf sand matrix

- seems to fine upwards with maximum 4-5cm diameter well rounded pebbles at base fining upwards into average 0.8-1cm diameter well rounded pebbles, all of which "float" in a matrix of vf sand identical to the sands around the conglomerate
- lower contact is lithologically sharp, but does not appear erosive at all
- dominantly multi-coloured chert pebbles
- thickness of unit could be (probably is) incorrect due to extensive sampling

U7/U8 Contact

UNIT 7: transitional FA1/FA2

- bedding thicknesses of sand similar to FA1 but burrowing similar to FA2
- sharp based sands that fine upwards into muds (waning storm flow deposits); sands have organic detritus accentuating CFR to low angle inclined laminae with low angle truncation surfaces
- burrowing dominated by Asterosoma and Chondrites, also Planolites and rare Helminthopsis that are able to rework the silty portions of these waning flow sequences; also probable Anconichnus horizontalis in shales at unit base

U6/U7 Contact

UNIT 6: basically FA1 with maximum sand bed 7cm thick

- less Helminthopsis and more Chondrites upwards(although Chondrites still rare, they can be found commonly as the only burrow in dark muds that cap waning flow sequences); burrowing intensity decreases upwards with a corresponding increase in preserved sharp based, normally graded fining upwards wavy parallel laminated 1-3cm thick vf sand beds
- Palaeophycus tend to be restricted to the thicker bedded sands

break between Core 1 and Core 2 is approximately here

lens of salt and pepper cL-cU sand with largest clast an angular 0.5cm diameter shale rip-up

zone of bentonitic/smectitic swelling clays

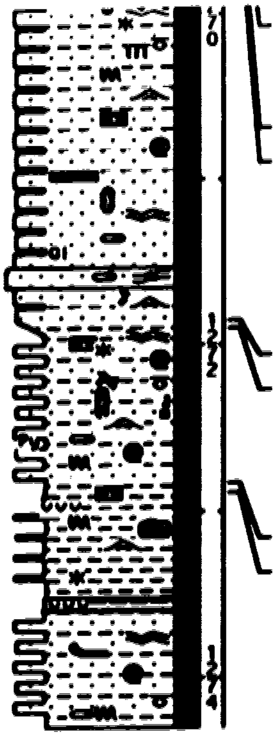
mg sand incorporated into small scale CF ripple

U5/U6 Contact

UNIT 5: Burrowed Silty Shale with mU-cL-pebbly interbed

- coarsening upwards 3cm thick mU-cL sand bed with pebbles up to 2cm diameter, well rounded chert

U4/U5 Contact



UNIT 4: Poorly Sorted Clast Supported Conglomerate
- probable transgressive lag at a flooding surface/parasequence boundary
- pebbles are all well rounded chert pebbles, some sideritised clasts (maximum 2.5cm diameter), pebbles average 1cm diameter

U3/U4 Contact: probable parasequence boundary; sharp and undulatory

UNIT 3: vf Sand Dominated Burrowed Interbedded Sand and Shale
- reasonable trace diversity, but portions of unit are only rarely burrowed by a few trace types(hence a "pinstripe" appearance to some of this unit)
- Chondrites and Helminthopsis very rare, Asterosoma rare, domination of Planolites, Thalassinoides and Ophiomorpha (at least 2 types: Ophiomorpha nodosa and Ophiomorpha irregulare)
- sands are glauconitic and have laminae commonly accentuated by organic rich material, possible synaeresis cracks, sideritisation near top of unit

U2/U3 Contact: continuation of overall sanding upwards succession

UNIT 2: Interbedded vf sand and Shale
- burrowing intensity decreases upwards while sand percentage increases upwards
- very rare Chondrites in low abundances
- some oscillation/CFR to wavy parallel bedding of the sands with rare occurrences of sharp based silt beds that normally grade upwards
- patchy pyritisation which appears to develop around pre-existing burrows

U1/U2 Contact: gradual; part of overall sanding upwards sequence

UNIT 1: Thoroughly Burrowed Interbedded Shale and vf Sand
- typical regional background Viking facies with lenses of 1-2cm thick vf sands with remnant oscillation to wavy parallel laminations
- plentiful Helminthopsis (even in the bentonitic horizon), rarer Chondrites, Planolites, and small Asterosoma

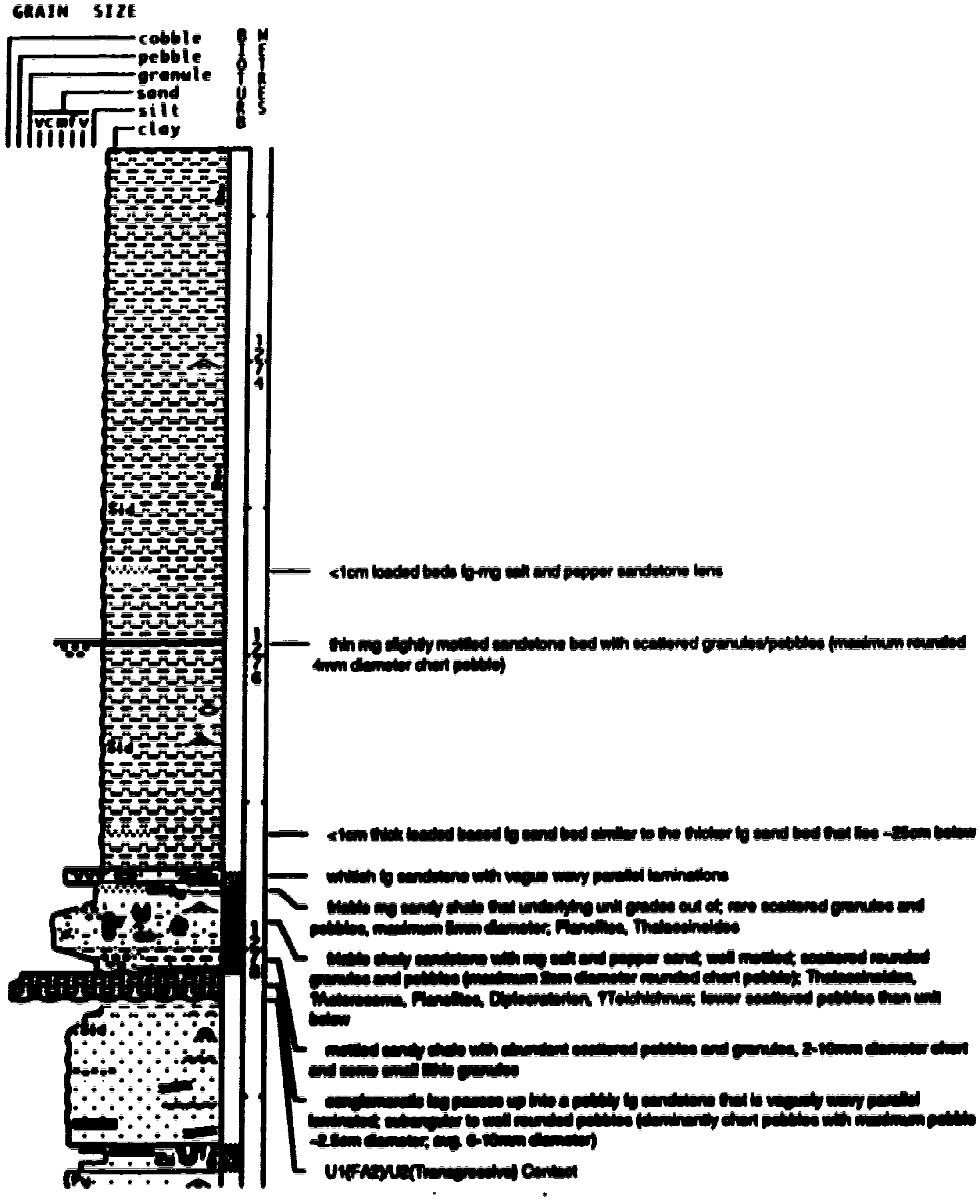
CWNG CARBON
6-19-29-22w4

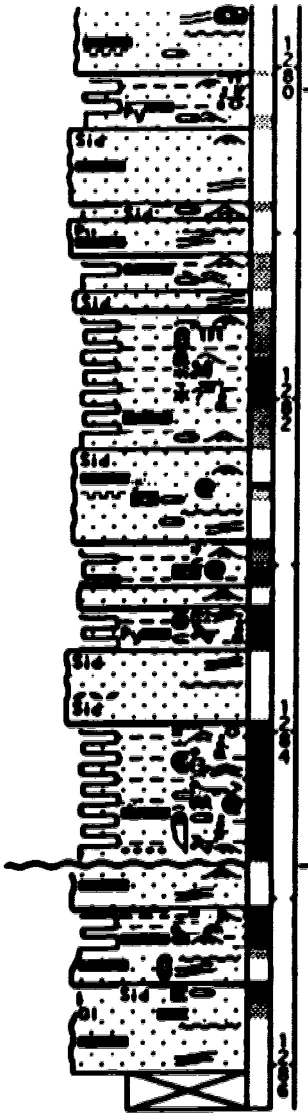
Date logged: December 15, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 829.70 m KB: 833.60 m

Remarks: Core 1, 10 boxes; 3.5" full diameter core; 4175'-4220'; Cut 45', Rec. 43.5'; core heavily sampled therefore only marginally photogenic; can't check depths because I don't have the logs with me; 2 box shots, didn't shoot basal box or top 3 boxes





basically all is like FA2, both above and below the "VE 3.5" conglomerate; the interbedded portions are dominantly moderately-rarely burrowed with sand beds generally 1-3cm thick, synaeresis cracks more prevalent upwards etc.; sandstone beds are dominantly storm-generated with low angle inclined stratification and low angle truncation surfaces that commonly pass up into combined flow or oscillation ripples and are then capped by essentially unburrowed organic-rich shales and the tops of the sands and into the organic-rich shales may be cemented with a very fine grained siderite cement

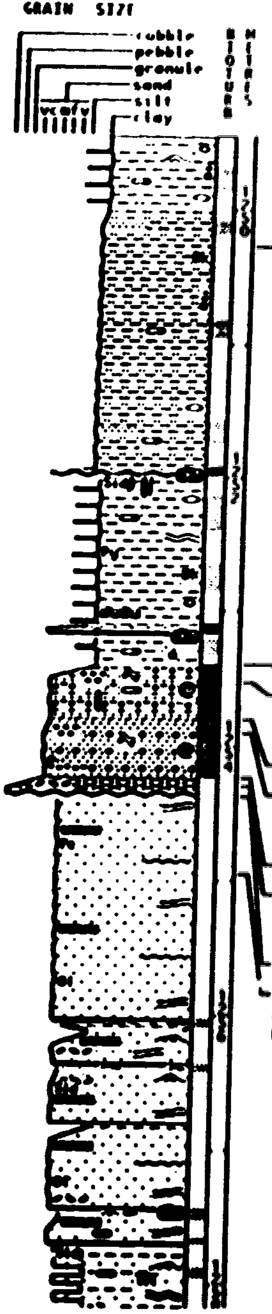
possible "VE3.5"-type surface with "transitional FA2" with moderate burrowing, but tonnes of Chondrites and scattered granules above (i.e. slightly higher burrowing intensity above conglomerate going above it into true FA2

CWNG Carbon
6-21-29-22w4

Date logged: May 12, 1993

Logged by: ©1993 Indraneel Raychaudhuri

Remarks: Core 1; 14 boxes; 4100'-4150', Rec. 50' (1249.7-1264.9m, Rec. 15.2m, actual recovery 15.55m); 4" full diameter core; photogenic; box shots of the basal 12 boxes (i.e. boxes 3-14)



UNIT 6: essentially dark silty shale or shale interbedded with minor vfL sandstone, with the sandstone bases sharp, loaded; oscillation rippling/wavy parallel laminations/CFR; a few gritty mg mottled horizons that may represent phases of renewed transgression; uppermost one is marked with a Glossifungites ichnofacies with small thin Arenicolites and is likely overlain by the maximum flooding surface

U5/U6 Contact

UNIT 5: similar to below and grades out of U4; "matrix" is dark shale with lenses of mg salt and pepper sand and scattered granules and up to 1cm diameter subangular to subrounded pebbles (fewer scattered pebbles than below in U4)

U4/U5 Contact

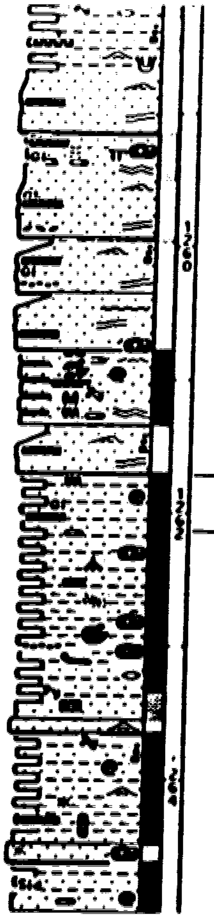
UNIT 4: pebbly mg sandstone; maximum pebble diameter is 2cm; well rounded scattered pebbles, locally in lenses; looks fairly burrowed but traces are difficult to distinguish; looks to be quite a few lithic pebbles; sand is that typical mg, gritty "salt and pepper" sand

U3/U4 Contact

UNIT 3: clast supported conglomerate; maximum pebble 1.5cm diameter, average 5-8mm diameter, well rounded chert and lithic pebbles; some matrix is granular to cg and mg sand; some sandstone and shale rip-ups; some sideritized rip-ups

U2 (FA2)/U3 (Transgressive stuff) Contact

UNIT 2: FA2 with thick HCS beds with waning flow reworked rippled tops grading into dark shales; upwards into amalgamated SCS sandstone; little burrowing, syneresis cracks, sideritization; sandstone bed laminae accentuated by finely comminuted organic detritus etc.



U1/U2 (FA2) Contact

UNIT 1: Transitional FA1/FA2: This is a very distinctive facies with a very unique burrowing style, totally dominated by Chondrites, Thalassinoides, Zoophycos, Rhizocorallium with quite a bit of ?Phycodes also, Thalass, Rhiz, Plano-Chond assemblages common in the dark, friable organic-rich shales, burrowing diversity and intensity is good, scattered granules and pebbles are also common in this facies; this facies may represent transgressive deposits that flood cycle 1 and then is overlain by a later LSE which causes the abrupt basinward shift in facies that characterizes the sharp based true FA2 (which is locally conglomeratic); some sharp based storm generated sandstone beds with oscillation to combined flow rippling; siderite, pyrite, glauconite in sand, ~50/50 vf sandstone and shale, thickest sandstone bed is 14cm thick

CWNG et al. CARBON
7-27-29-22w4

Date logged: December 12, 1991

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 825.10 m   KB: 829.06 m

Remarks: Core 1; Boxes 1-16, 4080'-4140' Rec. 59' (prob. 4087-4147')
Core 2; Boxes 1-4, 4140'-4155' Rec. 13.5' (prob. 4147-4162')
excellent recovery, well is quite photogenic but no box shots!; 4" full diameter unslabbed core

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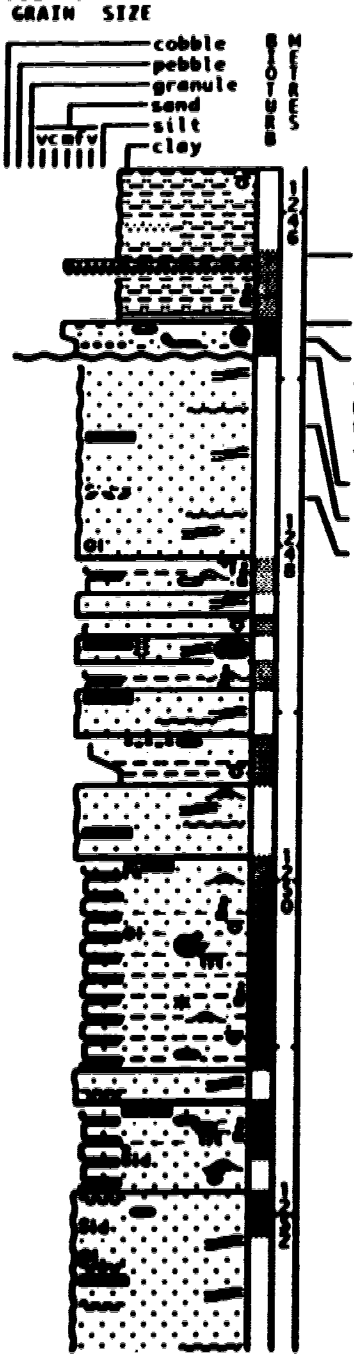


UNIT 9: Dark Silty Shale with mm scale sharp based silt beds with commonly loaded bases
- two zones of burrowed dispersed mg salt and pepper sand

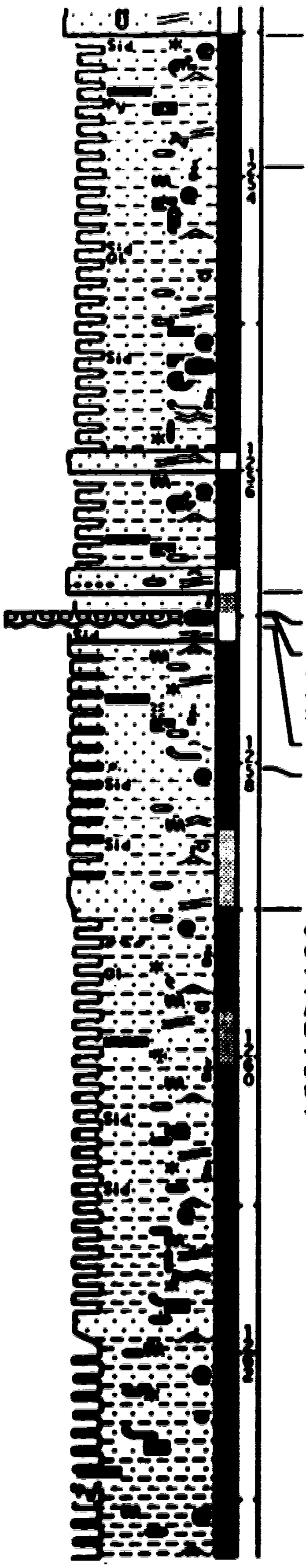
U8/U9 Contact

UNIT 8: Thoroughly Burrowed Shaly fg-mg salt and pepper Sand
- basal 2cm is pebbly with maximum pebble 1.5cm diameter, average 0.8cm diameter, pebbles/granules are subangular to well rounded, dominantly chert pebbles but some lithic fragments also
- up into burrowed shaly sand that goes from fg to mg salt and pepper sand

U7/U8 Contact (Colorado Transgression); appears erosive

UNIT 7: basically FA2 with thicker preserved sands upwards

3.8cm diameter well rounded siderite rip-up clast



U6/U7(FA2) Contact

UNIT 6: Thoroughly Burrowed Interbedded vf Sand and Shale
- extremely wide diversity of trace fossils, but in this unit, Chondrites is totally dominating and Rhizocorallium is also very common; the rest of the traces are found in lesser abundances
- local sideritisation, glauconitic sand locally, sharp based sands that are normally graded when unburrowed

two 3cm diameter well rounded chert pebbles at the base of this sand bed

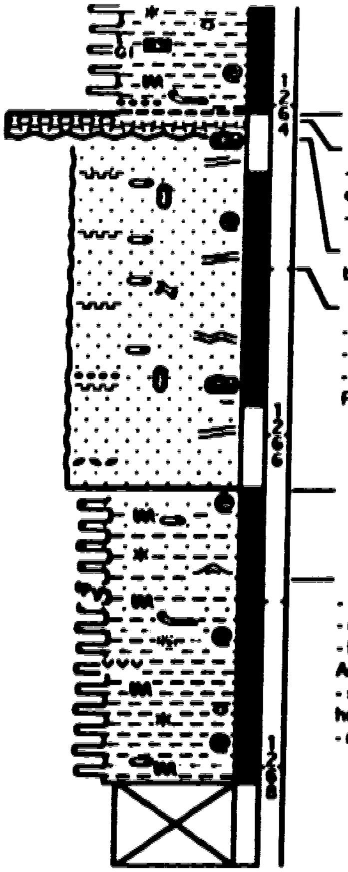
U5/U6 Contact

UNIT 5: Sorted Clast Supported Conglomerate with a matrix of vf sand identical to the surrounding units
- erosive base; pebbles are generally well rounded chert and some sideritised clasts, maximum 3.5cm diameter, average 1.2cm diameter

U4/U5 Contact

single 3mm diameter rounded chert pebble

UNIT 4: basically FA1 at base upwards into transitional FA2 where the abundances of traces decreases and there is an increase in the number and thickness of preserved sharp based, normally graded sand beds
- overall the unit sands and coarsens upwards slightly
- basal 2.21m is totally Helminthopsis dominated but above this, unit becomes dominated by Asterosoma and Planolites; Terebellina and Palaeophycus tend to be restricted to the thicker bedded sands for the most part
- sands increase in thickness upwards from 1-2cm thick to 5-10cm thick above; sands can normally grade upwards in waning flow sequences where there is rare burrowing or the tops of the beds could be thoroughly burrowed
- scattered granules to small pebbles at unit base



top of Core 2 and U3/U4 "Contact"

UNIT 3. Poorly Sorted Clast Supported Conglomerate
- sub to well rounded pebbles, maximum ~2.5cm diameter, average 1cm diameter; dominantly chert pebbles but a minor lithic pebble/granule component also exists
- matrix is dominantly cg sand to granules

U2/U3 Contact: erosive; probable transgressive pebble lag at parasequence boundary/flooding surface

UNIT 2: Moderately Burrowed Pale Sandstone with thin Shale wisps/drapes
- some low angle parallel laminations
- some shale wisps and mm scale drapes or beds
- burrows include Ophiomorpha (maybe irregulare variety also), Planolites, Thalassinoides, and Palaeophycus

U1/U2 Contact

UNIT 1: Thoroughly Burrowed Interbedded vf sand and shale
- typical regional background Viking but with a bit higher sand content
- rare 1-2cm thick loaded based sands with remnant oscillation ripples
- burrowing totally dominated by Helminthopsis, some more robust ones may actually be Anconichnus horizontalis
- smectitic/bentonitic zone is also thoroughly burrowed by Helminthopsis and/or Anconichnus horizontalis
- much like FA1 type facies

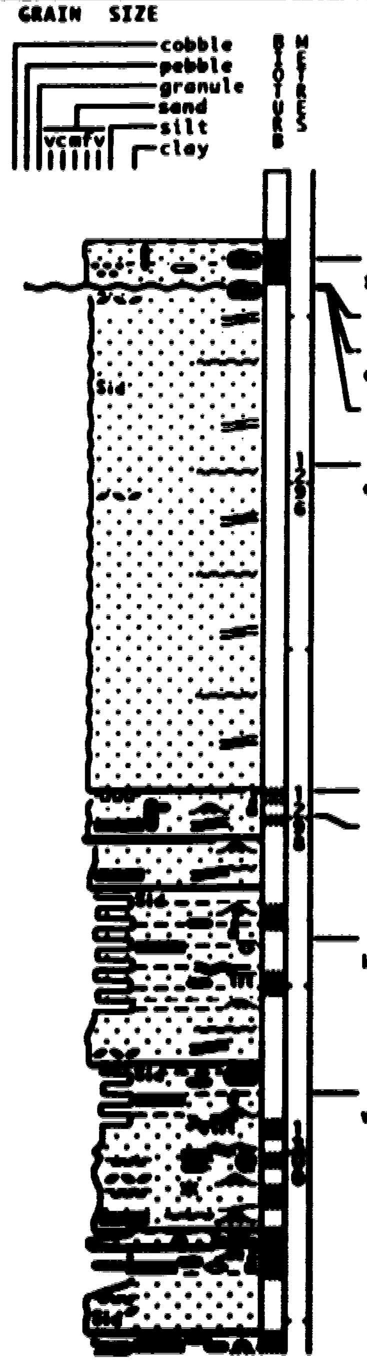
CWNG CARBON
6-25-29-23w4

Date logged: November 17, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 840.30 m KB: 844.00 m

Remarks: Core 1;10 boxes, 1295.8-1307.2m, cut 11.4m, rec. 11.2m; Core 2;8 boxes, 1307.2-1315m, cut 7.8m, rec. 7.5m; Core 3;8 boxes, 1315-1323.8m, cut 9.8m, rec. 8.8m; 4" full diameter core, very photogenic, good recovery, box shots; depths on litholog are correct



UNIT 23: totally churned shaly fU sandstone; totally burrowed, sand is "salt and pepper"; Skolithos, Teichichnus, Planolites; rare scattered ~1cm diameter pebble near base

U22/U23 Contact

UNIT 22: very thin conglomeratic lag (actually a smearing or veneer of maximum 1cm diameter pebbles on transgressive surface); sideritised clasts rounded and up to 6cm diameter

U21/U22 Contact: Transgressive surface ("VE4")

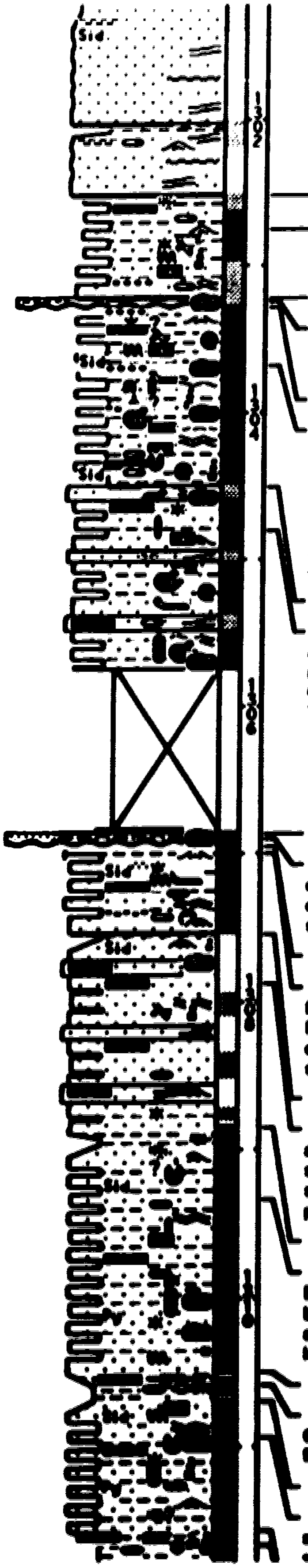
UNIT 21: amalgamated storm beds of the lower to middle shoreface (probably SCS); still part of FA2

U20/U21 Contact

UNIT 20: essentially FA2

subunit b: like subunit a, but with 3-8cm thick oscillation to combined flow to wavy parallel laminated sandstone beds

subunit a: "pinstripey" facies with 1-4cm sharp based fining up storm sands to silts to mud with extremely rare burrowing intensity, sideritised blebs; synaeresis cracks etc.



U19/U20 Contact

UNIT 19: essentially the same as U17; lesser degree of burrowing near base; same traces as U17, add Anconichnus, subtract visible Terebellina; Transitional FA2

U18/U19 Contact

UNIT 18: clast supported conglomerate; largest pebble 1.3cm diameter but overwhelming majority 6-8mm diameter; matrix is granules to vc sand; thin streak of shale in the middle with Chondrites and Planolites

U17/U18 Contact

UNIT 17: moderately burrowed thinly interbedded vf sandstone and shale; this unit is a dead ringer for what I referred to as transitional FA2 in SEPM short course #17; traces include: superabundant Chondrites, Planolites, Rhizocorallium, Skolithos, Zoophycos, Terebellina, Thalassinoides, Arenicolites, rare Helminthopsis, Teichichnus, silty ?Asterosoma or ?Phycodes etc.; rare coaly rip-up fragments; lots of friable, organic-rich shale; woody fragments; local pyrite; common sideritization; <1cm thick pebble layer in unit (pebbles mostly 2-4mm diameter and are sub to well rounded); sandstone beds 1-4cm thick with wavy parallel to oscillation ripple laminae; sandstone beds are sharp based, fining up

U16/U17 Contact

UNIT 16: interbedded vf sandstone and shale; some 8-10cm thick storm sandstones with low angle inclined stratification and opportunistic grazers burrowing the tops of the beds; overall moderate to common burrowing with local churned/mottled bedding; traces: Helminthopsis, Chondrites, Planolites, Asterosoma, Rhizocorallium, Zoophycos, Palaeophycus, small Thalassinoides, Skolithos, Teichichnus etc.

U15/U16 Contact

UNIT 15: clast supported conglomerate with a lot of very large clasts; maximum diameter observed is 3.8cm; dominantly quite well rounded chert pebbles with some possible volcanic clasts; dominantly 1-3cm diameter pebbles with a "matrix" of 0.5cm pebbles, granules and vf sand similar to the surrounding vf sandstone; possibly up to 6cm diameter pebbles!

U14/U15 Contact

UNIT 14: 60/40 thinly interbedded vf sandstone and shale; organic detritus; coaly rip-up fragments; moderate burrowing intensity with only small Planolites, Asterosoma, Palaeophycus, Helminthopsis, Terebellina; 1-3cm thick sandstone beds with small scale oscillation to combined flow ripple laminations, some wavy parallel laminations also; local fL sand

U13/U14 Contact

UNIT 13: similar to underlying unit but much sandier with some thick beds (10-12cm) with low angle inclined laminations that locally pass up into oscillation to combined flow ripples (waning storm flows) and capped by thin unburrowed black, organic-rich shales, sharp based fining up storm beds also; local siderite; rare to nil burrowing; much like thin bedded FA2; traces where present include Planolites, Asterosoma etc. (see litholog)

U12/U13 Contact

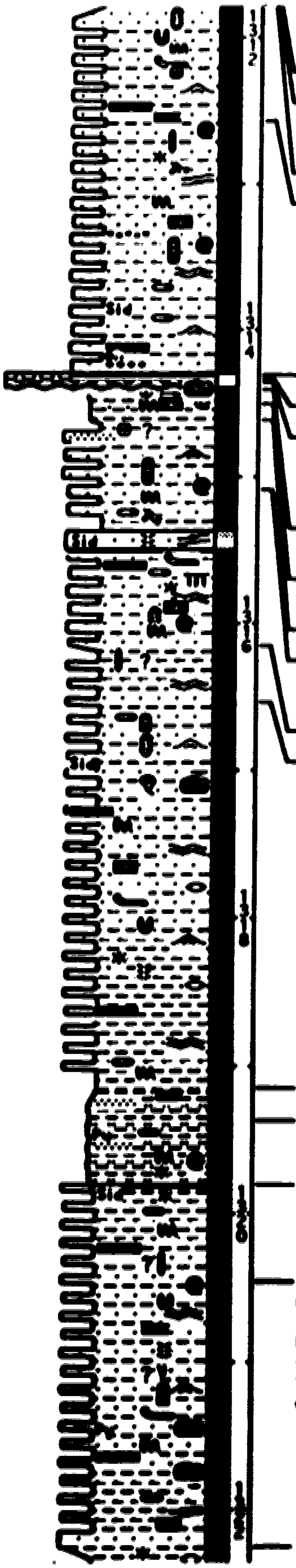
UNIT 12: similar to U12; traces: Asterosoma, Helminthopsis, Arenicolites, Teichichnus, Diplocraterion, Chondrites, Planolites, Siphonichnus, ?Phycodes etc.; sandstone beds sharp based fining up, 1-4cm thick, wavy parallel to oscillation ripple laminated, laminations accentuated by organic detritus, minor sideritization and pyrite; small traces; moderate to locally rare burrowing intensity; shaly zone near top of unit

U11/U12 Contact

UNIT 11: dark, organic-rich silty shale; rare to almost nil burrowing with only rare Planolites, Chondrites, and Helminthopsis; discontinuous silty lenses with loaded bases, sharp based fining up silt beds

U10/U11 Contact

UNIT 10: moderately burrowed interbedded vf sandstone and shale (50/50); sandstone beds sharp based, fining up with common wavy parallel and oscillation rippling, 1-4cm thick; minor sideritization of organic-rich shales; organic detritus accentuate laminations; [illegible]



Planolites, Palaeophycus, Asterosoma, Helminthopsis, rare Chondrites, rare Teichichnus, rare Diplocraterion, all traces small, also possible Anconichnus, looks like transitional FA.-1 A.

U9/U10 Contact

UNIT 9: rarely burrowed organic-rich shale with mm-1cm thick silt/vfL sand beds that are commonly discontinuous on the scale of the core, loaded based, sharp based fining up sandstone beds, rare remnant wavy parallel laminations, traces Planolites, Zoophycos

U8/U9 Contact

UNIT 8: similar to U5; 1-4.5cm thick vfU-fL sandstone beds; lots of traces, minor siderite and pyrite; pebble stringer near base with same grain size of pebbles as U7

U7/U8 Contact

Core 3/Core 2 break is here: probably little or no core missing

UNIT 7: grain supported conglomerate; dominantly rounded to subrounded pebbles, granules and vc sand; appears to fine upwards slightly; maximum pebble diameter is 1.7cm; dominated by average 4-8mm diameter grains; appears to be quite porous and permeable (almost no stuff in matrix pore spaces)

U6/U7 Contact: Transgressive surface of erosion with pebbly lag over top; may be VE 3 of Boreen and Walker, 1990 (Hadley, perscomm., 1992)

UNIT 6: totally churned/burrowed vfL sandy shale with lots of Helminthopsis, also Planolites, Chondrites, Asterosoma

U5/U6 Contact

UNIT 5: essentially same as U4 but with a little bit more sandstone content; one 13cm thick storm sandstone bed with low angle parallel inclined laminations with escape traces, Palaeophycus at top ("lam-scram")

U4/U5 Contact

UNIT 4: similar to U2; 1-4cm sandstone beds with wavy parallel and oscillation ripple laminae, sandstone beds commonly discontinuous on the scale of the core, minor loaded bases to the sandstone beds; common burrowing with Terebellina, Planolites, Asterosoma, Helminthopsis, Palaeophycus, muddy ?Skolithos/(Trichichnus-like stuff), Arenicolites, Ophiomorpha, escape traces, small Rosselia, rare Chondrites, rare Teichichnus, minor pyrite, siderite 80cm down from top of U4

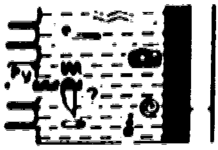
U3/U4 Contact

UNIT 3: regional Viking silty/vfL sandy shale; abundant burrowing with Helminthopsis, Planolites, small Asterosoma, Zoophycos; minor pyrite

U2/U3 Contact: flooding surface

UNIT 2: similar to U1 but sandier (60sh/40sand), sand vfL-vfU, 1-7cm thick sandstone beds, low angle parallel/wavy parallel/oscillation ripple laminae; common burrowing intensity with: Helminthopsis!, Terebellina, Planolites, Zoophycos, Arenicolites, escape traces in sandstone beds, rare Teichichnus, very rare Chondrites (commonly as only trace in dark, organic-rich shales), small ?Skolithos or ??Polykladichnus (those wispy "Trichichnus-like" traces), ?Subphyllochorda; pyrite; organic detritus accentuating laminae and dispersed; siderite at top of unit

U1/U2 Contact



UNIT 1 interbedded shale/vfL sandstone (80/20), 1-2cm sandstone beds, commonly discontinuous on the scale of the core, wavy parallel laminations, moderate burrowing intensity with Planolites, Helminthopsis, Terebellina, Asterosoma, small ?Cylindrichnus; gradational upper contact

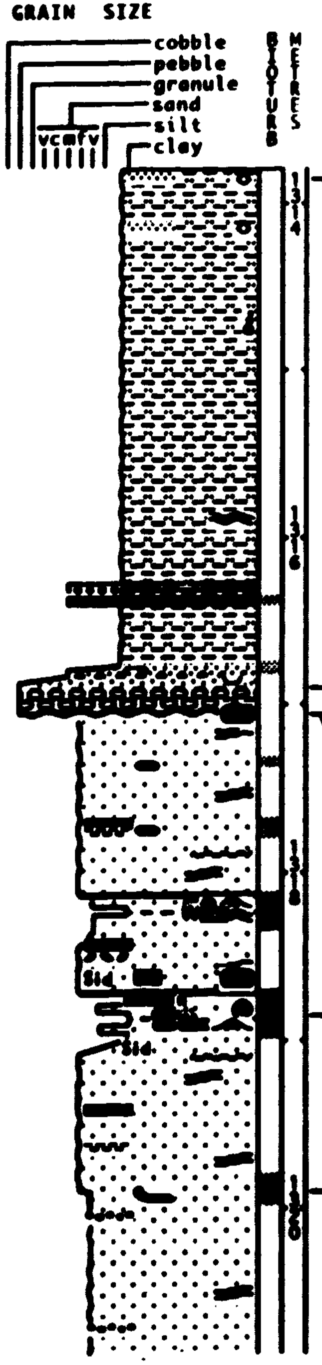
LOC UNION ENTICE
10-14-29-24w4

Date logged: April 1, 1992

Logged by: ©1993 Indraneel Raychaudhuri

Ground: 816.30 m   KB: 820.20 m

Remarks: 3.5" full diameter core, Core 1; 10 boxes
4300'-4346' (actually 4310'-4358' or 1313.69m-1328.32m)
quite photogenic; have box shots starting ~1.23m above base of core



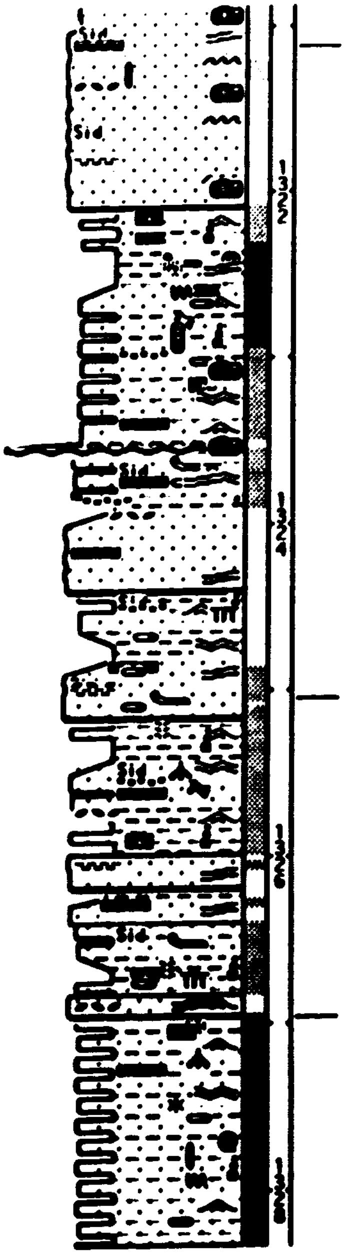
Dark silty shale with mm scale sharp based vf sand stringers with possible wavy parallel laminae, two 1cm sharp loaded based vf sand beds near top

pebbles subangular to well rounded chert and lithics with matrix of mg sand to granules, poorly sorted, maximum pebble 1.5cm diameter, average 8mm diameter, fewer pebbles upwards, some angular shale rip-up clasts also

FA2/Transgressive Contact
- upper part of this clast supported conglomerate has more mg "salt and Pepper" sand matrix and shows hints of cross bedding and seems to grade up into the shaly sand above

also Anconichnus(?) and those wispy black traces

top of the apparently structureless sand/silt



no obvious slumping/soft sediment deformation features above here; an 8cm zone of low angle planar sand above here which is overlain by finer grained, organic-rich apparently structureless sand/silt (vague hints of some low angle parallel laminations)

"psycho" walled Terebellina

FA1/FA2 Contact

Bumper Enron Swalwell
7-1-29-25w4

Date logged: May 11, 1993

Logged by: ©1993 Indraneel Raychaudhuri

Remarks: Core 1; 5 boxes; 1451-1457.55m, Rec. 6.55m; not logged since it is all innocuous Colorado Shale; Core 2; 14 boxes; 1457.55-1476.25m, Rec. 18.7m; 3" slabbed core, but not very photogenic with lots of pieces moved around; no box shots

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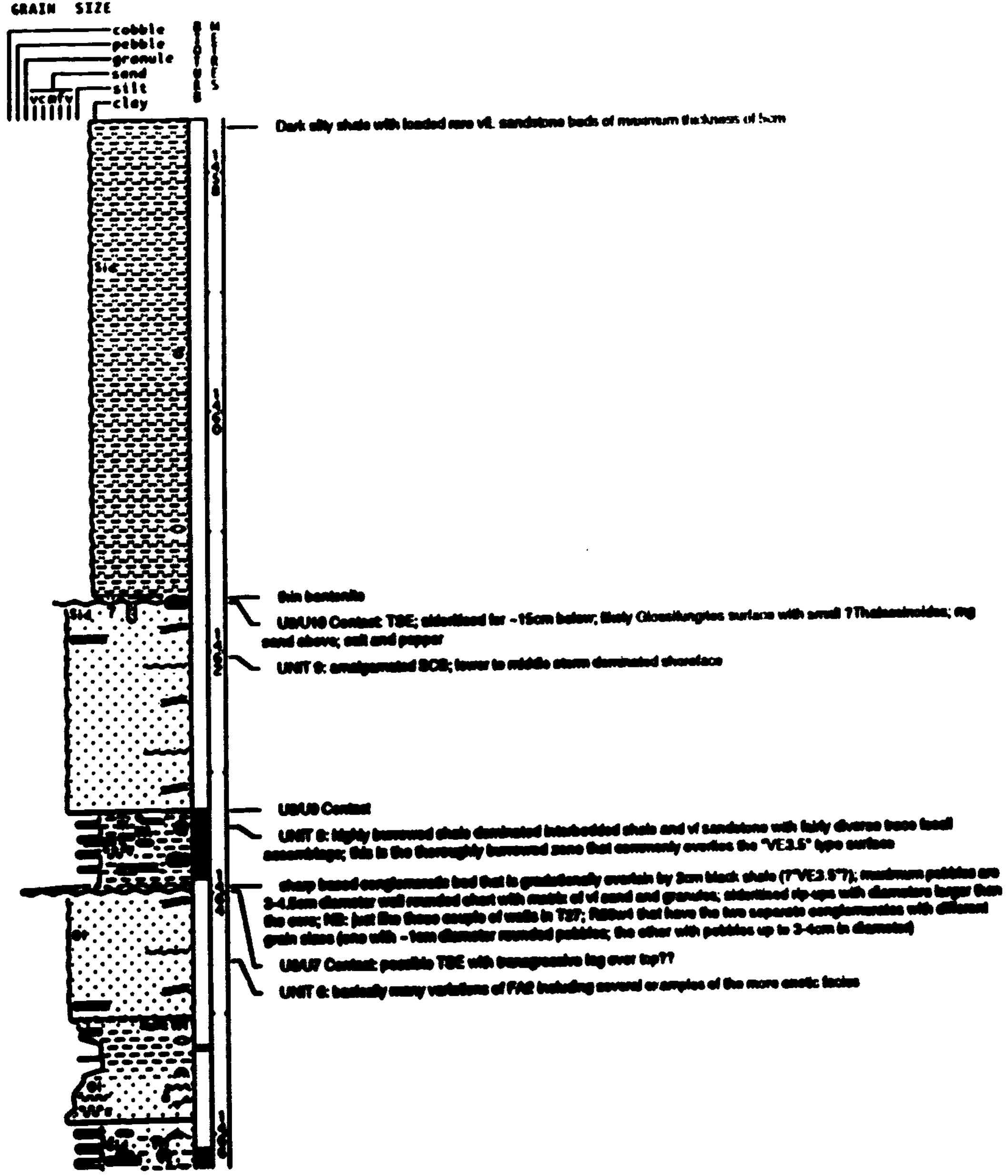

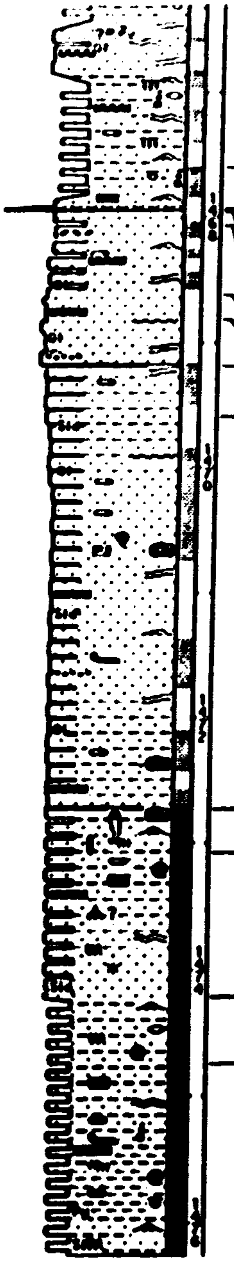

5mm lens of mg sandstone with scattered rounded pebbles, maximum 5mm diameter

clast supported conglomerate at base of storm bed, not particularly erosive looking base, maximum well rounded pebble diameter is 2cm; average is 5-10mm

U5/U6 Contact

UNIT 5: similar grain size to below but medium bedded (~10cm) sandstone beds separated by shalier zones

U4/U5 Contact

UNIT 4: fg-ml. SCS sandstone; organic detritus, Fe staining near base due to breakdown of organics

U3/U4 Contact

UNIT 3: Thickly bedded HCS/SCS sandstone with thin shaly interbeds; shales with Planolites; sandstone with Palaeophycus, local dense zones of Macaronichnus simplicatus, rare small truncated Rosselia, some tiny Terebellina (possibly detrital at the base of a storm bed, SGP says); sandstone beds 5-40cm thick; grain size above here gets locally up to ml., indicating possible middle shoreface SCS type stuff

U2/U3 Contact

UNIT 2: essentially just sandier FA1

U1/U2 Contact: sanding upwards

UNIT 1: essentially FA1 but not super diverse trace fossil assemblage although there is total domination by Helminthopsis and to a lesser extent Anconichnus; 1-5cm thick sharp based sandstone beds with oscillation to wavy parallel laminations