LICENCE TO McMASTER UNIVERSITY

This Thesis has been written
[Thesis, Project Report, etc.]

by Lorraine McIntosh for
[Full Name(s)]
Undergraduate course number 4K6 at McMaster University under the supervision/direction of Dr. R.G. Walker.

In the interest of furthering teaching and research, I/we hereby grant to McMaster University:

1. The ownership of 6 copy(ies) of this work;
2. A non-exclusive licence to make copies of this work, (or any part thereof) the copyright of which is vested in me/us, for the full term of the copyright, or for so long as may be legally permitted. Such copies shall only be made in response to a written request from the Library or any University or similar institution.

I/we further acknowledge that this work (or a surrogate copy thereof) may be consulted without restriction by any interested person.

R.G. Walker
Signature of Witness,
Supervisor

Lorraine McIntosh
Signature of Student

May 1 '95
date

(This Licence to be bound with the work)

THE SEDIMENTOLOGY AND STRATIGRAPHY OF THE LOWER CRETACEOUS (Albian) VIKING FORMATION, JOFFRE/MIKWAN FIELDS, ALBERTA, CANADA

THE SEDIMENTOLOGY AND STRATIGRAPHY OF THE LOWER CRETACEOUS (Albian) VIKING FORMATION, JOFFRE/MIKWAN FIELDS, ALBERTA, CANADA

By

Lorraine McIntosh

A Thesis
in Partial Fulfillment of the Requirements
for the Degree
Bachelors of Science

McMaster University

1995

Bachelors of Science (1995) **McMaster University**
(Geology and Geography) **Hamilton, Ontario**

TITLE: **The Sedimentology and Stratigraphy of the Lower Cretaceous (Albian) Viking Formation, Joffre/Mikwan Fields**

AUTHOR: Lorraine McIntosh

SUPERVISOR: Dr. R.G. Walker

NUMBER OF PAGES: xi, 71

ABSTRACT

The Joffre/Mikwan field (Lower Cretaceous, Viking Formation) is a long narrow sandbody encased in marine mudstones. The sandbody trends northwest-southeast. Four cross-sections of the area were made, perpendicular and parallel to the sandbody. The data consisted of 12 cores and 185 resistivity logs.

Five erosion surfaces are present within the Joffre/Mikwan fields; E1, E2, CM4, CM5 and VE4. Generally, the erosion surfaces drop stratigraphically northward. Northward, the erosion surfaces truncate the surface below or cut into the underlying facies.

There are two erosion surfaces below the main Viking sandstones, E1 and E2. E1 underlies lower shoreface deposits and E2 underlies middle shoreface deposits, the main Viking sandstones. These two erosion surfaces were formed as a result of sea level fluctuations within an overall transgression. The shorefaces prograded during stillstands within the transgression. These surfaces, E1 and E2 were formed during the transgression which followed the relative sea level drop that created the first valley incision at Crystal.

There are two erosion surfaces above the main Viking sandbody, CM4 and CM5. Transgressive surface of erosion CM4 was formed when transgression resumed after deposition of the main Viking sandbody. After this transgression another

relative sea level drop created the second incision at Crystal. The transgressive surface of erosion CM5 formed during the subsequent rise.

This interpretation improves upon the single incision scheme proposed by Boreen and Walker (1991). It also suggests a correlation of surfaces CM4 and CM5 with the two transgressive surfaces of erosion at Crystal.

ACKNOWLEDGEMENTS

The person I would like to thank the most is Dr.R.Walker. This is due to all of his time he gave to me, his great help every step of the way, his enthusiasm and to all the grammar lessons. I would also like to thank him for finding funding so I could do a thesis. I would like to give many thanks to David James and Wascana Energy for the funding as without them I wouldn't have been able to do this thesis.

I would like to thank James MacEachern for answering all of my continuous questions on trace fossils.

The grad students (and post doc), Jin-Hyung Lee, Alessandro Terzuoli, Johnny Casas and Geoff Orton, need to be thanked for putting up with me all year, as I took up lots of space and tons of time on the computer. Of course, thanks the Geology department and the ladies in the office for tolerating all my questions.

I have to apologize and say thank you to my room-mate, Lara Puttee, for putting up with my absentee as a room-mate. Jason Coates and Katie Hamilton need a big thanks for listening and helping to increase my chocolate intake throughout the entire year.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Scientific Problem and Objectives

There is an ongoing debate concerning the formation of linear sandbodies. The two possibilities are that they formed offshore bars or that they represent lowstand or transgressive incised shorefaces. The arguments are given in detail in Bergman and Walker (1987, 1988) for Cardium linear sandbodies. In the Viking Formation, Joffre field is one of several linear sandbodies, and was interpreted as a transgressive incised shoreface by Downing and Walker (1988), initially the Viking sandbody had been interpreted as offshore bars (Hein et al, 1986; Leckie, 1986). Joffre is part of a linear trend of sandbodies, from Gilby (Raddysh, 1988) through Joffre (Downing and Walker, 1988), Mikwan and Fenn to Chain that stretches from Central Alberta toward Saskatchewan.

The objective of this thesis is to extend southwestward the work of Downing and Walker (1988) on the Joffre field, from central Alberta towards Saskatchewan. The thesis will examine the continuity of the Viking sandbodies, will identify and correlate all the bounding discontinuities present, and will attempt to relate those discontinuities to existing stratigraphic schemes (Boreen and Walker, 1991) in nearby areas, primarily Crystal (Pattison and Walker, 1994).

Also, to correlate between the erosion surfaces interpreted by Downing and Walker (1988), Fig.27 and those suggested by Boreen and Walker (1991) for the Joffre area in correlation to Crystal, Fig.29.

1.2 Study area

The study area is located in south central Alberta, Fig.1. It contains one elongate sandbody that trends northwest-southeast and forms a continuation of the Joffre field (Downing and Walker, 1988). The producing sandbody in the Joffre field is in the Viking Formation. Fig.2 shows the location of the Viking Formation with respect to other Formations. The rocks are essentially flat lying and are not faulted.

1.3 Database and Method

The database for this study consists of 12 cores (Appendix 1) and 185 resistivity logs.

The cores were used to identify facies and the surfaces or contacts separating the facies, physical sedimentary structures, biological structures (trace fossils), grain size, and trends in the lithology.

All cores were photographed in their boxes, and detailed photographs were taken of specific features in the cores.

Resistivity well logs were used to construct the cross sections because they were available in all wells. The well log signatures were matched with features found in the cores in order to interpret facies in uncored wells.

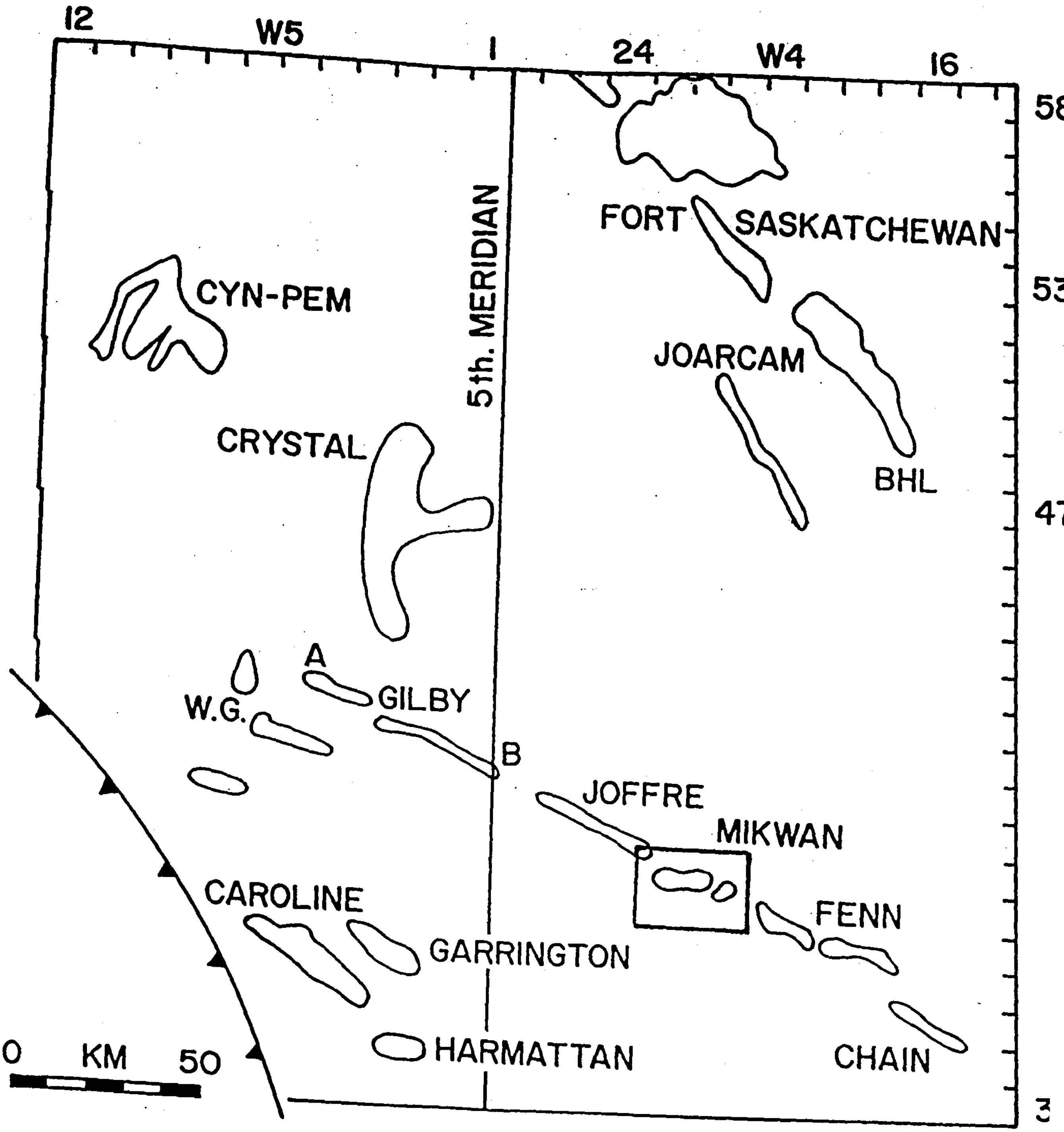


Fig. 1 Location of the study area.

LOWER CRETACEOUS			
UPPER ALBIAN			CEN
H. gigas	?	M. manitobensis	
JOLI FOU FORMATION	VIKING FORMATION	WESTGATE FORMATION	BASE OF FISH SCALES

Fig.2 The location and age of the Viking Formation with respect to surrounding Formation

CHAPTER 2: STRATIGRAPHY

2.1 General Stratigraphy

The internal subdivisions of the Viking Formation are relatively recent and informal. Hein et al. (1986) subdivided the formation into Viking A and Viking B reservoir sand bodies. Older stratigraphic work is cited by Hein et al. (1986) but is not repeated in this thesis.

2.1.1 *Lithostratigraphy*

Bloch et al. (1993) subdivided the Viking and adjacent units into the Joli Fou Formation, Viking Formation, Westgate Formation, and the Fish Scales Formation, Fig.. The Joli Fou contains the shales located below the Viking Formation, and the Westgate Formation contains the shales located above the Viking main sandstones. The Base of Fish Scales is the contact between the Westgate Formation and the Fish Scales Formation, and is commonly used as a datum.

These formations contain several erosion surfaces or bounding discontinuities that can be mapped and used to subdivide the formation allostratigraphically.

2.1.2 *Allostratigraphy*

A detailed local stratigraphy of the Joffre field was established by Downing & Walker (1988). Three erosion surfaces, E1, E2, and E3 and two core markers CM4 and CM5, were defined and considered to be bounding discontinuities. Six facies associations, one through six, were defined between the bounding discontinuities. No formal allostratigraphy was proposed.

Boreen and Walker (1991) mapped the Joffre field northwestward into the Willesden Green area. Three bounding discontinuities were used to define 5 allomembers. Allomember E is equivalent to the Westgate Formation of Bloch et al. (1993) and its uppermost boundary is the Base of Fish Scales log marker. The erosion surfaces were termed VE2, VE3 (which is spilt into 'a' and 'b'), and VE4.

2.1.3 *Redefined Allostratigraphy*

Pattison and Walker (1994) proposed a modified allostratigraphy because of the recognition of two distinct channel incisions at Crystal. At Crystal, Fig.28, both incision 1 and incision 2 have been preserved, but only one transgressive surface of erosion has been preserved. Presumably, the fill of channel one was truncated by a transgressive surface of erosion before the second channel was incised. The transgressive surface of erosion that truncates the second channel fill appears to have also eroded the transgressive surface of erosion that truncated channel fill 1. It will be suggested in this thesis that both transgressive surface of erosions were preserved in the study area.

It will also be suggested that bounding surfaces E1 and E2 formed during pauses or minor regressions in the overall transgression after the occurrence of the first major drop of relative sea level that caused the first channel incision at Crystal. CM4 is now thought to be the transgressive surface of erosion that truncated the fill of that first channel. CM5 is now thought to be correlative with the transgressive surface of erosion that truncated fill of the second channel at Crystal.

2.2 Literature Review

2.2.2 *Development of Ideas*

The linear Viking sandbodies encased in marine mudstone were originally interpreted as "offshore bars" (Hein et al., 1986; Lechie, 1986). Since the increasing recognition of the importance of sea level change, some "offshore bars" in various stratigraphic units have been re-interpreted as transgressive incised shorefaces (e.g., Bergman and Walker, 1987, 1988 for the Cardium Formation in Alberta).

Hein (1986) described the coarsening upward sequences deposited in the Caroline, Garrington and Harmattan East fields, and Leckie (1986) described the coarse sandstones and conglomerates at Caroline. They were interpreted as being deposited as ridges on a tidally affected offshore shelf during the Viking transgression. The sediment was transported to its position on the shelf by "shelf currents", "storm driven currents", or "normal tidal currents" (Hein et al., 1986; Lechie, 1986).

Downing and Walker (1988) re-examined the linear Joffre field with the incised shoreface hypothesis in mind. They discussed the problem of how the sands encased in marine mudstone formed, particularity, 1) how the sands were transported across marine mudstone, 2) how sand was moulded into a long narrow ridge on the shelf, and 3) how coarsening upward sequences formed on the shelf. An erosion surface was identified below the sandstones at Joffre, and an incised shoreface interpretation was proposed, using the Cardium Formation (Bergman and Walker, 1987, 1988) as a close analogy.

Downing and Walker (1988) suggested that surfaces E1 and E2 were created by relative lowerings of sea level followed by transgressive shoreface incision. During lowering of the sea level the gradient of rivers increased and coarser sediment could then be transported seaward, and incorporated into the transgressive shoreface. Association 3 (Downing and Walker, 1988), the facies above the surface E2, was interpreted as middle to lower shoreface deposits. During rise of relative sea level, the shoreline moved rapidly to the southwest and erosion associated with this transgression reworked the formerly exposed relatively flat subaerial surface.

Following Downing and Walker's (1988) work at Joffre, Power (1988) studied another similar Viking sand body at Joarcam. He subdivided the Viking Formation into 4 allomembers, A, B, C and D, which were interpreted as a clastic wedge deposited during a minor regression within a larger scale transgression. The erosion surfaces at Joarcam could not be mapped into the Joffre area.

Reinson (1988) interpreted Crystal as a single incised channel filled with tidal channel and estuarine deposits. It was thought to be a multi stage channel filling event under conditions of rising sea level, with each depositional stage in the channel representing a stillstand during one overall transgressive event.

Boreen and Walker (1991) examined the continuation of the Joffre trend toward Willesden Green. The erosion surface below the shoreface at Joffre could be traced to Willesden Green as well as the shoreface sandstones. Incised valleys were also mapped at Willesden Green.

Davies and Walker (1993) studied the Caroline and Garrington fields. The section of the Viking Formation studied was VE4 to BFS (Base of Fish Scales). They described sandstones and conglomerates interbedded with marine black shales, and interpreted the coarse facies as extensions of the lower shoreface formed during minor regressions interspersed within the main transgression. These forced regressions created a time when coarse sediment was able to be transported seaward and deposited on black mudstones. The black mudstones were deposited as the transgression cut off the source of the sediment to the prograding shoreface and buried the onlapping tongue with transgressive black mudstone.

Pattison and Walker (1994) re-examined Crystal and discovered two channels rather than the single channel described by Reinson (1988). A fall of relative sea level created the first incision, and as relative sea level subsequently rose, the channel was filled and then truncated. As relative sea level continued to rise, the transgressive surface of erosion at Crystal extended southwestward to Joffre, Fig.29, forming the surface named CM4 by Downing and Walker (1988) (Fig.27).

A second incision at Crystal occurred when relative sea level fell again. The subsequent rise created a transgressive surface of erosion, termed transgressive surface of erosion 3 by Pattison and Walker (1994) (Fig.26). This surface has been renamed CM5 in this thesis.

2.2.2 *Relevance to this thesis*

This thesis re-evaluates all of the erosion surfaces of Downing and Walker (1988) and proposes explanations of the CM4 and CM5 surfaces. These explanations were made possible by the recognition of two incisions at Crystal (Pattison and Walker,1994) with the implication of two transgressive surfaces of erosion, only one of which is ever preserved at Crystal. It will be shown that the two transgressive surface of erosions implied at Crystal can probably be correlated with CM4 and CM5 (Downing and Walker, 1988). Fig.3 correlates the terminology used by several authors and the terminology used in this thesis.

POWER	DOWNING	BOREEN	DAVIES	THIS THESIS	PATTISON
BFS (Base of Fish Scale)	BFS	BFS	BFS	BFS	BFS
No Equiv.	LM 6	No Equiv.	E5 E4 E3 E2 E1	VE4-BFS	
above CM1	Asso.6	Facies Asso.E	"	"	No Equiv.
CM1	E3	VE 4	VE 4	VE4	TSE4
No Equiv.	Asso.5	FA D	FA D	CM5-VE4	No Equiv.
"	CM 5	VE 3b	VE 3b	CM5	TSE3
"	Asso.4	FA C	FA C	CM4-CM5	No Equiv.
CM 3	CM 4	No Equiv.	No Equiv.	CM4	"
No Equiv.	Asso.3	FA C	FA C	E2-CM4	"
"	E2	No Equiv.	No Equiv.	E2	"
"	Asso.2	"	"	E1-E2	"
"	E1	VE 3a	VE 3a	E1	"
"	Asso.1	"	"	Regional Succession 6 5 4 3 2 1	Regional Succession
"	LM 1	base of Viking B.V	B.V	B.V	B.V

Fig.3 Comparison of Terminology

CHAPTER 3: FACIES AND SURFACE DESCRIPTIONS

3.1 REGIONAL VIKING SUCCESSIONS

Six coarsening upward mudstone to siltstone successions represents the beginning of the Viking Formation. The first two successions are interpolated from the resistivity logs (no cores penetrate that deep) but they are similar to the four successions above them. Successions three through six are characterized by mudstones grading upwards into bioturbated siltstones and sandstones, and each one is capped with a flooding surface, Fig.4 .

The third succession ranges in thickness from 1.3 m to 2 m. It consists of bioturbated mudstone with an increasing siltstone content upwards. The main traces are *Terebellina, Helminthopsis, Chondrites, Planolites, Paleophycus and Skolithos*, which are mainly found at the top of the succession. The top contact, or flooding surface, is sharp and separates the silty, more bioturbated mudstones below from the dark mudstones of the fourth succession above the contact.

The fourth succession is 1.0-2.75 m thick. It begins abruptly with a dark mudstone and becomes siltier and increasingly bioturbated upwards. Trace fossils include *Terebellina, Helminthopsis, Chondrites, Planolites, Paleophycus and Skolithos* and are mainly found at the top of the succession. The top contact is a sharp, flooding surface marking the end of the silty

Fig.4 Core 10-8-37-23W4, located within the linear sandbody. This core is a good representation of all the erosion surfaces and facies

bioturbated mudstones of the fourth succession and the beginning of the dark mudstones of the fifth succession.

The fifth succession is 0.4 to 1.6 m thick, averaging 1.2 m. It is characterized by mudstone, with increasing silt content and bioturbation upwards. Trace fossils are mainly found towards the top of the succession and include *Terebellina, Helminthopsis, Chondrites, Planolites, Paleophycus and Skolithos*. The top contact is a sharp flooding surface. It separates the bioturbated siltstone of the fifth succession from the mudstone in the sixth succession.

The sixth succession, less than 1 m in thickness, is characterized by dark mudstone. It is only present in half of the cores, and in the others, it appears to have been cut out by the erosion surface E1 from above. *Skolithos* can be found in the siltstones at the top of the succession, protruding down from the E1 surface and filled with coarser sands.

3.2 E1 Surface

The E1 surface is a sharp contact, truncating the coarsening-upward regional successions below and separating them from the extensively bioturbated sandstones above, Fig.5. Sand- and silt filled burrows penetrate downward from the contact, but there is no coarse lag concentrated immediately above the contact.

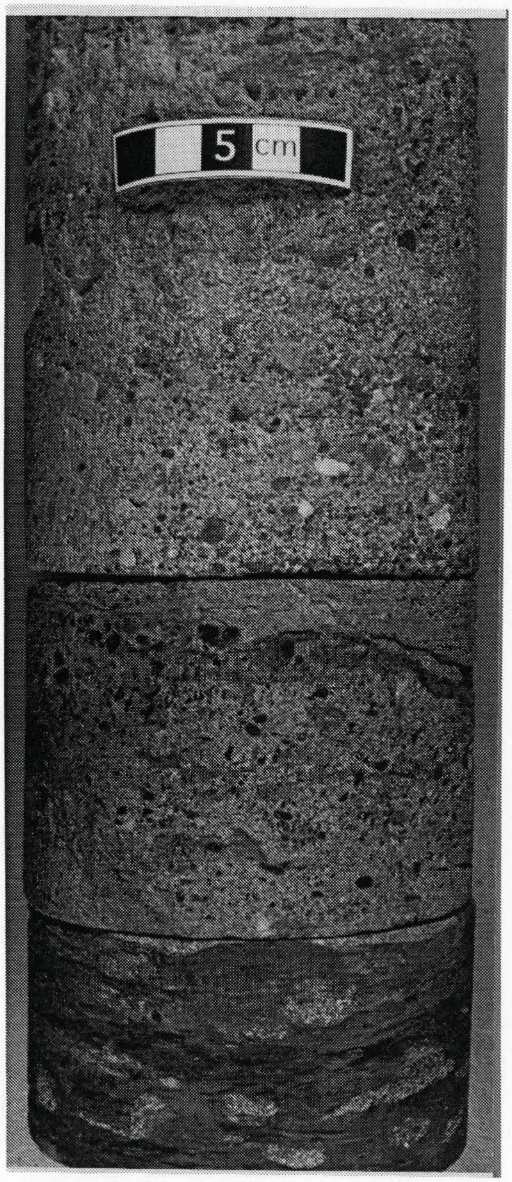


Fig.5 Core 10-2-37-23W4, the E1 surface cutting into the Regional Successions.

3.3 E1-E2, Extensively Bioturbated Sandstones

The average thickness of E1-E2 is just over 3.0 m (range 0.8 m to about 6 m). The facies is characterized by pebbles or granules at the base, grading up into extremely bioturbated sandy mudstone, Fig.6.

In the lower part (up to 70 cm above the base) the facies is characterized by pebbles or granules scattered in sandstone. The pebbles range from 1-2 cm diameter and the granules average 3 mm in diameter, Fig.5.

This portion grades into extensively bioturbated sandstones, Fig.7, with the sand coarsening upward from fL to fU. Most of the beds, up to 5 cm, are structureless but some contain cross-bedding. Chert grains, up to 5 mm in diameter, die out upwards, Fig.6.

The sediment is bioturbated with *Terebellina, Helminthopsis, Asterosoma, Paleophycus, Teichichnus, Siphonichus,* and *Planolites*. *Rosselia, Rhizocorallium, Zoophycos* and *Schaubcylindrichnus* also occur in most of the cores. Glauconite is scattered throughout the sediment. Bentonite layers occur approximately 1.4-2 m from the top of the facies.

Siderite is commonly found at the top of the unit, occurring just below the top contact, and ranging in thickness from a few centimeters to 22 cm, Fig.4. *Skolithos* or *Diplocraterion* burrows are also found protruding up to 39 cm downward from the top contact. They are filled with coarse glauconitic sand characteristic of the E2-E4 sandstones, Fig.8.

Fig.6 Core 7-13-37-24W4, is located within the linear sandbody.

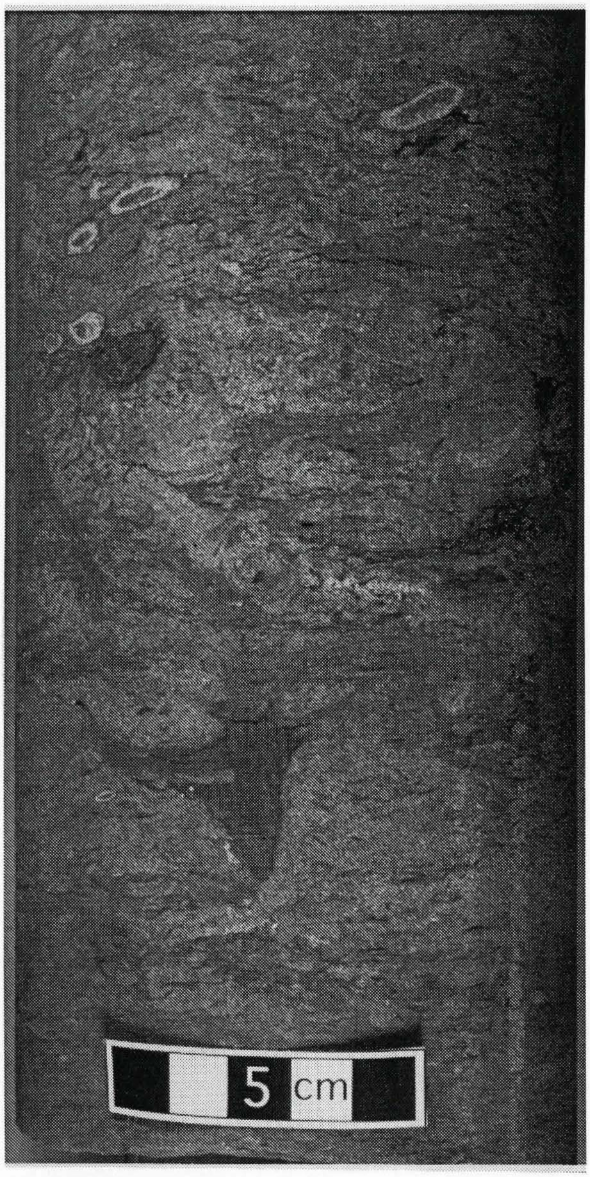
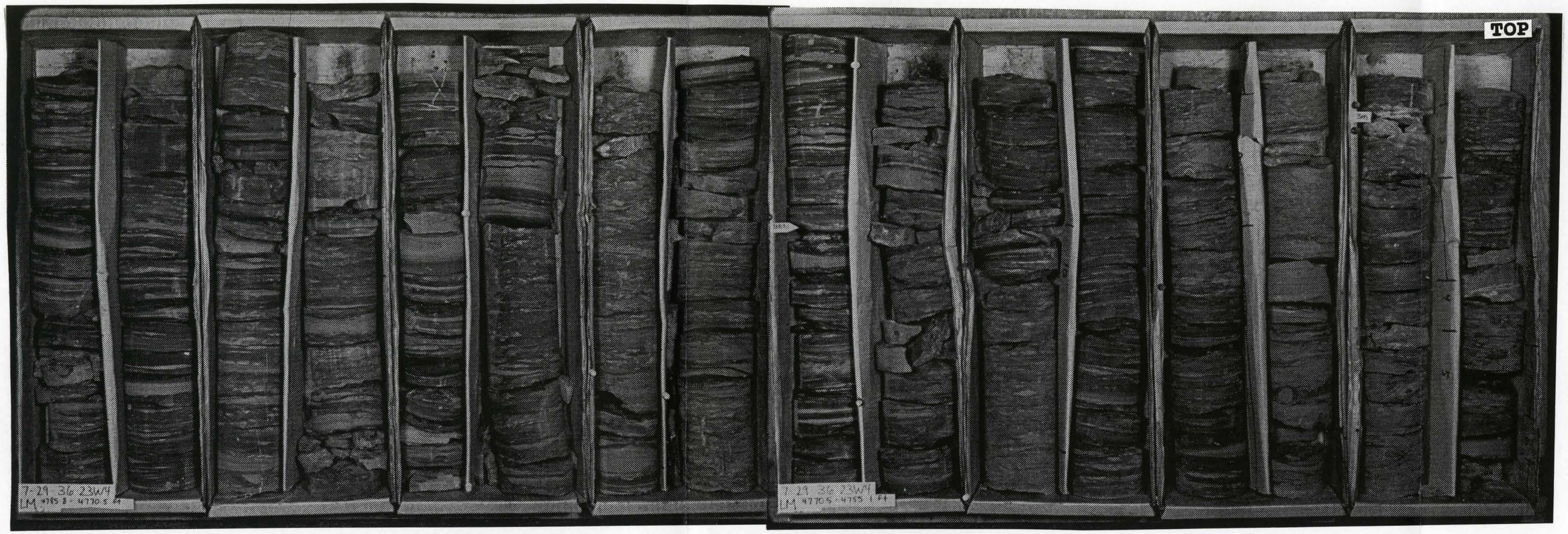
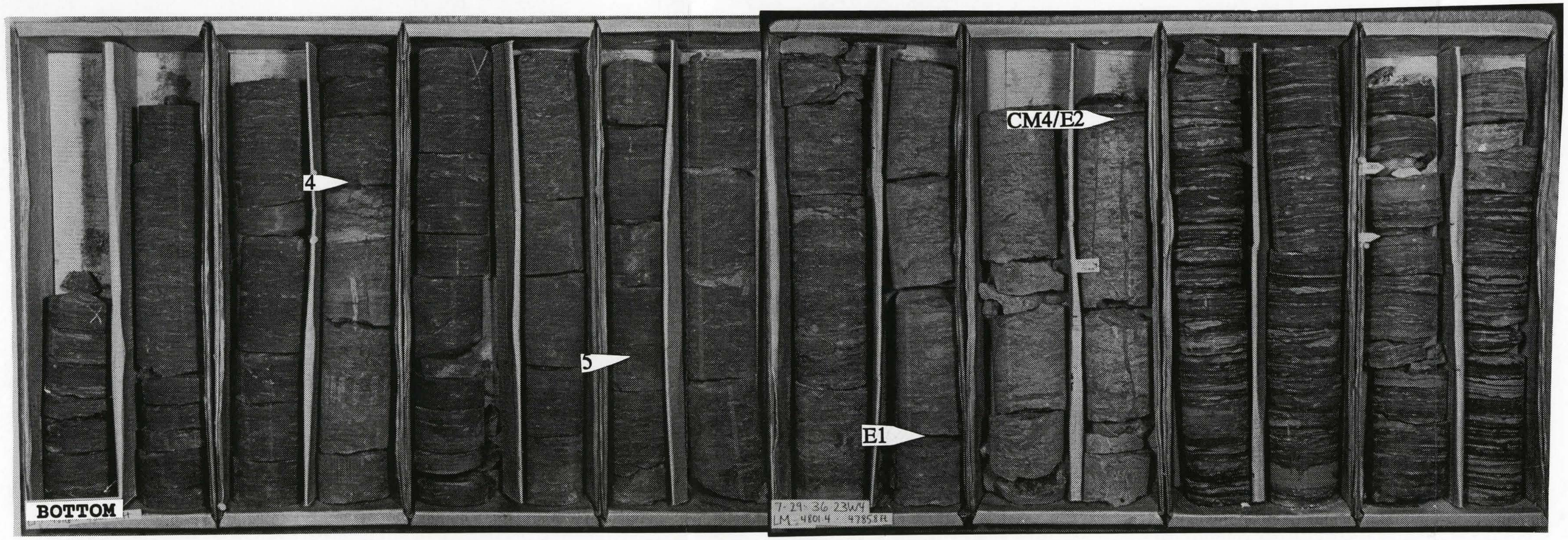


Fig.7 Core 7-20-36-23W4, extensively bioturbated sandstones of the E1-E2 facies.

Fig.8 Core 7-29-36-23W4, located south of the main sandbody. CM5 has cut down onto CM4 and onto E2. The E2-CM4 facies is represented by the fill in the *Skolithos* shaft which is protruding from the CM5 surface and filled with coarse glauconitic sands.


TOP


CM4/E2
4
5
E1
BOTTOM

3.4 E2 Surface

The E2 surface separates the extensively bioturbated sandstones below from the cleaner, coarser sands of the E2-CM4 facies above. Immediately below this contact are sideritized layers from 2-22 cm thick and/or *Diplocraterion or Skolithos* shafts protruding downward up to 39 cm into the E1-E2 bioturbated mudstone. The shafts are infilled with the cleaner, coarse, glauconitic sands of E2-CM4 facies, Fig.9. There is no coarse lag concentrated immediately above the contact.

3.5 E2-CM4, Main Viking Sandstones

The E2-CM4 facies has an average thickness of just over 2 m (range 0.6 m to 4.5 m). The sandstones are characterized by cross-bedding or horizontal laminations. Sandstone beds are commonly interbedded with either bioturbated sandstones, or mudstones containing sandstone and siltstone laminations, Fig.10.

The sandstone beds with sedimentary structures range in thickness from 0.08 m to 0.64 m. Grain size averages between mL and mU but can reach to cU. The sandstones are cross-bedded, horizontally laminated, or they can be structureless, Fig.11. Chert granules in the sandstones average 3 mm diameter (maximum 7 mm). Glauconite is abundant throughout the entire unit in many cores but in some other cores only traces of glauconite occur throughout.

The bioturbated mudstones can range in thickness

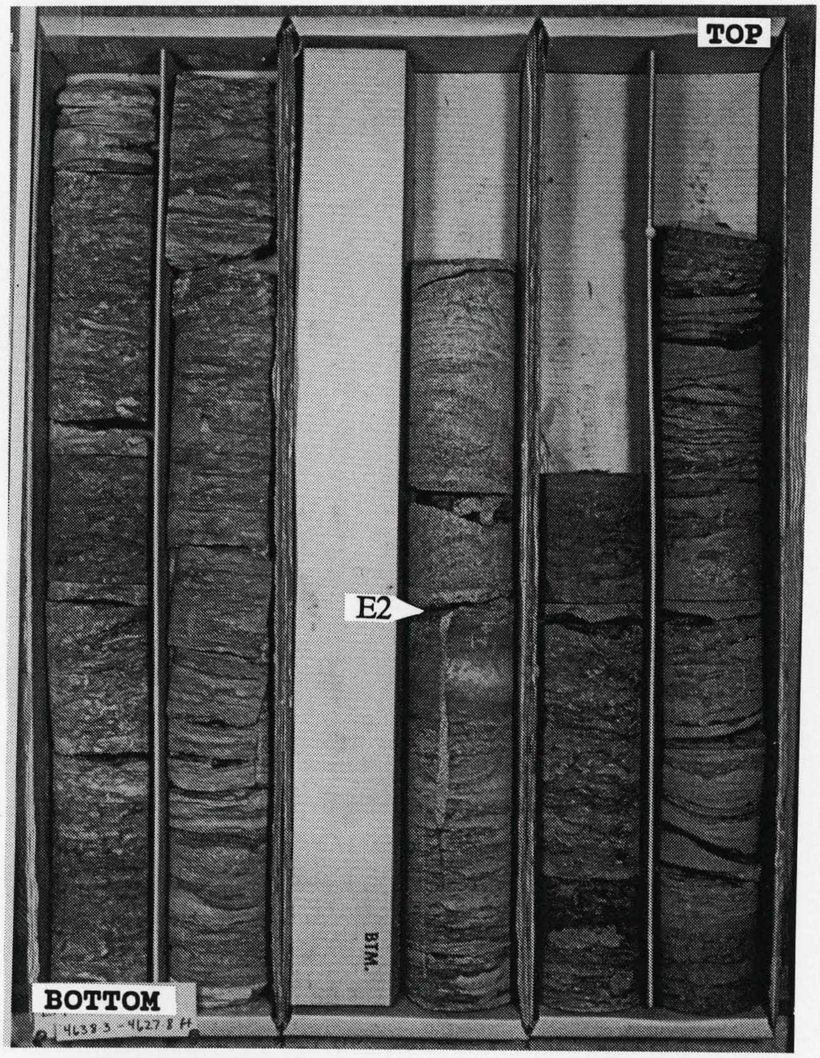


Fig.9 Core 11-33-37-24W4, the E2 surface is overlying a siderite bed and a *Diplociterion* is protruding down into the E1-E2 facies from the E2 surface.

Fig.10 Core 7-1-37-24W4, is a good representation of sharp erosion surfaces and clear facies.


TOP
CM5
CM4
E2
E1
BOTTOM

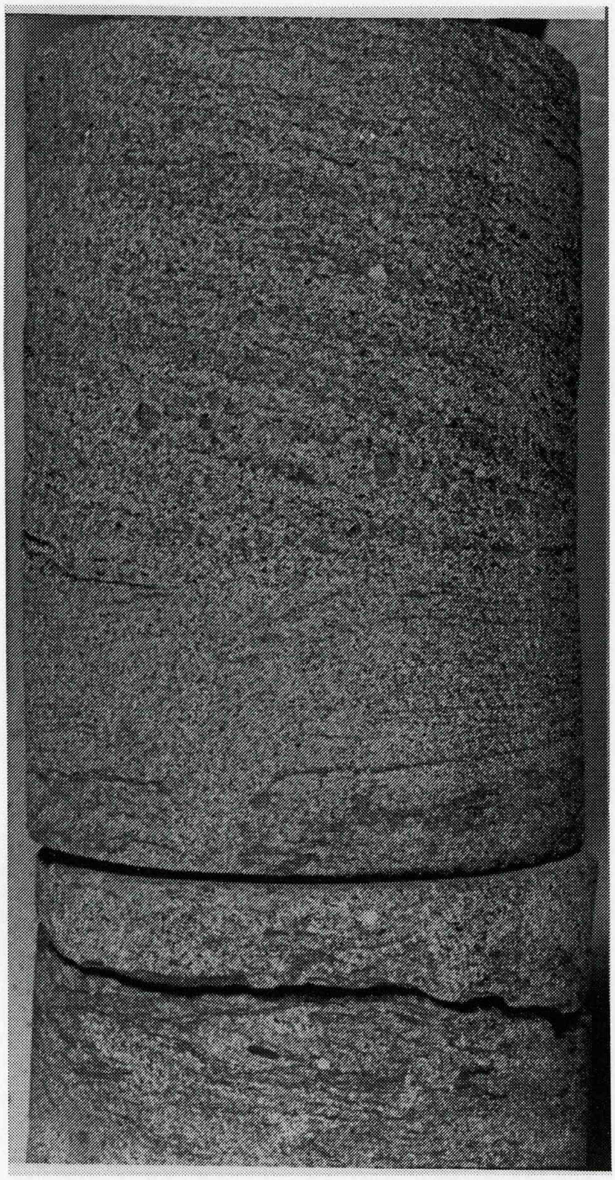


Fig.11 Core 7-1-37-24W4 at 4635 ft. The clean coarse cross-bedded sandstone of E2-CM4, the main Viking sandstone.

from 0.2 m to 1.5 m, Fig.12. The sediment is bioturbated with *Terebellina, Planolites, Skolithos/Diplocraterion*. *Skolithos* shafts are found protruding down from the structured, cleaner sands into the bioturbated units. Mud drapes are abundant throughout the bioturbated sections.

The black mudstones with sandstone and siltstone laminations range in thickness from 0.3 m to 1.3 m. The laminations have an average thickness of just under 1 cm, but are found up to 5 cm. Some of the sandstone and siltstone laminations are rippled, most are bioturbated but are still distinguishable as laminations.

3.6 CM4 Surface

The CM4 surface is a sharp contact that separates the E2-CM4 cross-bedded sandstones below and the CM4-CM5 siltstone and sandstone laminated mudstone above. No chert pebbles occur at this contact, Fig.13. There are no lags concentrated immediately above the contact and burrows penetrating down from the surface occur in only a few cores.

3.7 CM4-CM5, Mudstones

CM4-CM5 has an average thickness of just under 1 m (range 0.5 m to 1.7 m). It is characterized by black mudstone with siltstone and sandstone laminations. The laminations have an average thickness of just under 1 cm (maximum 5 cm). Chert grains in the sand laminations are

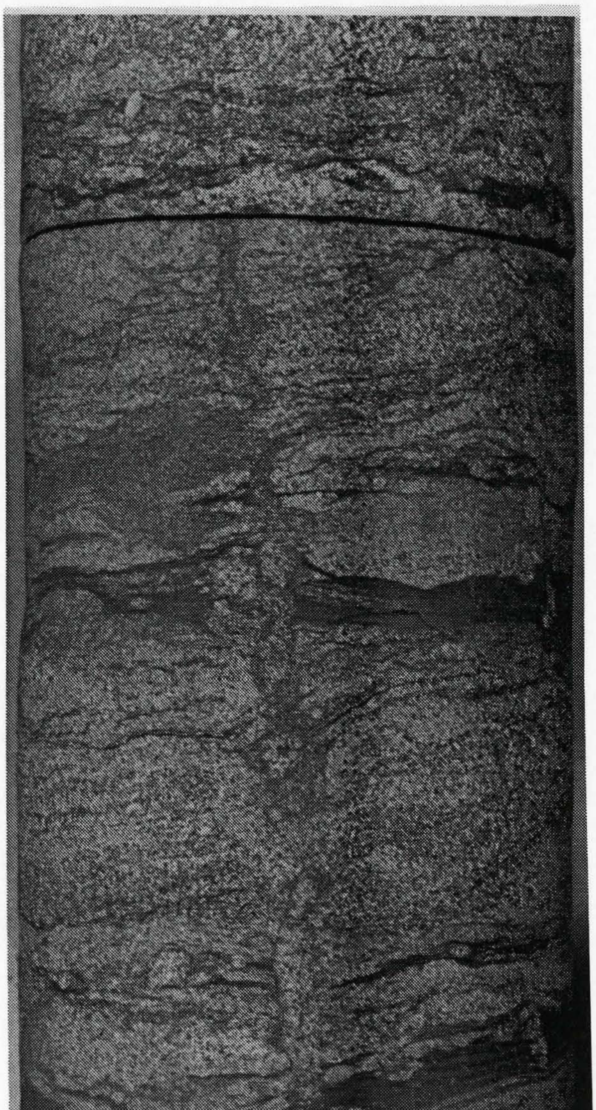


Fig.12 Core 7-1-37-24, bioturbation within the main Viking sandstone. *Skolithos* shaft, protruding down from a cleaner, structured sand.

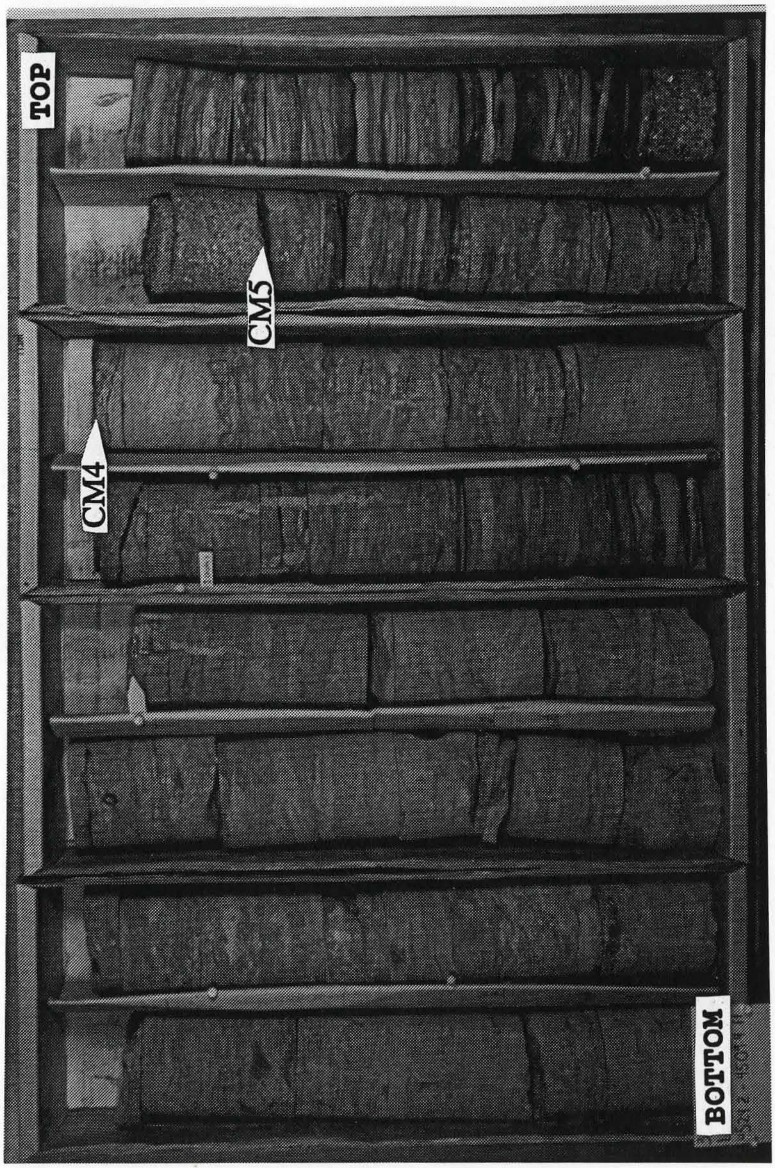


Fig.13 Core 3-18-37-23W4 at 4524 ft. Note the sharp CM4 and CM5 surfaces and the CM4-CM5 facies.

up to 2 mm diameter.

These laminations can be rippled and lenticular in shape, or horizontal. They can be entirely sandy or contain mud drapes. Their contacts with the black mudstone vary from being sharp and planar to sharp and wavy. The sandstone and siltstone laminations can also be found bioturbated and the contacts with the mudstone become fuzzy, Fig.13. The sediment is bioturbated with *Planolites, Terebellina* and small, 1 cm deep *Skolithos*. The *Skolithos* is found both in the bioturbated laminations and protruding from the bioturbated laminations into the black mudstone. In more than half of the cores the CM4-CM5 facies is absent. This absence is interpreted to be due to erosion, with the CM5 surface cutting down onto the CM4 surface, Fig.14 and cross section, Fig. 25b.

3.8 CM5-Surface

The CM5 surface is a sharp contact which overlies the siltstone- and sandstone- laminated mudstones of the CM4-CM5 facies. Above the surface is the CM5-VE4 mudstones, Fig.13. The contact is characterized by either a few pebbles up to 1 cm diameter, or chert granules up to 5 mm diameter; this coarse layer can range in thickness from 0.02 m to 0.55 m. Sideritization can be found just below the CM5 surface. *Skolithos* burrows penetrate down into the CM4-CM5 laminated mudstones and are filled with the coarse sediment from the CM5 surface.

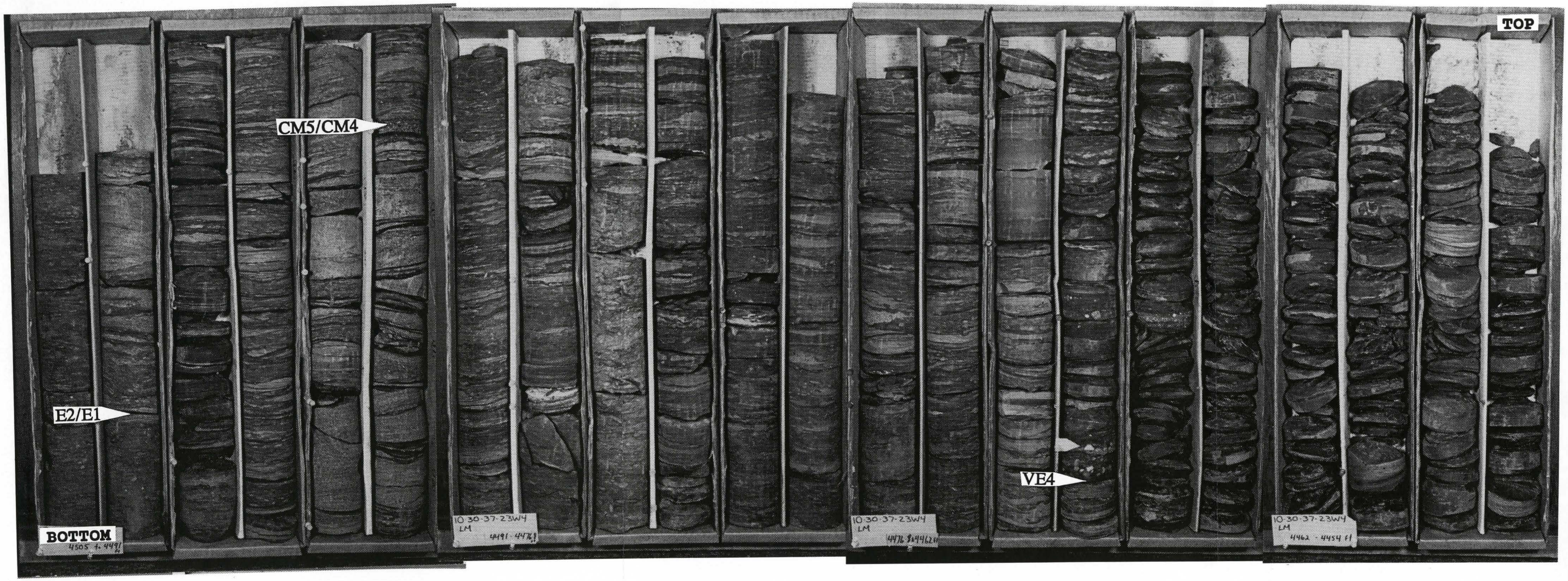


Fig.14 Core 10-30-37-23W4, is located North of the linear sandbody. Note the erosion of the E1-E2 facies, E1 surface, and the erosion of CM5 onto CM4. The main Viking sandstones are muddier because this core is further North than the other cores, therefore further into the basin.

In cores from the northern part of the study area, CM5 cuts down to the CM4 surface, eroding out most or all of the CM4-CM5 laminated mudstones, Fig.14. Southward the south the CM5 surface is less prominent in the cores. The abundance or the coarse lag on CM5 has decreased, and CM5 appears to have eroded down onto, or close to CM4.

In the southern part of the study area, CM5 is more distinguishable. It is overlain by abundant chert granules up to 5 mm diameter and commonly there are also a few large pebbles up to 1 cm diameter, Fig.13.

3.9 CM5-VE4, Laminated Mudstone

The thickness of CM5-VE4 ranges from 5.5 m to 13.75 m (average about 8.5 m). It is characterized by abundant chert granules or solitary pebbles, followed by dark mudstone with siltstone laminations, and dark mudstone bioturbated with siltstone, Fig.18. These two lithologies are interbedded throughout the unit.

The granule layer can be either cross-bedded or structureless. The chert granules are up to 5 mm diameter. A few pebbles up to 1 cm diameter also occur as part of the lag on CM5. The layer ranges from 0.02 m to 0.55 m thick, Fig.13.

The dark mudstone with siltstone laminations ranges in thickness from 0.3 m to 5 m (average 1.8 m). The siltstone laminations in the mudstone average less than 1 cm in thickness (maximum 5 cm). The laminations are lenticular, rippled, horizontal or bioturbated. The bioturbated laminations include the trace fossils *Terebellina,* and *Skolithos* in the form of 2cm deep shafts, protruding into the mud from the bioturbated lamination. The bottom and top contacts of the laminations are sharp and either planar or wavy, Fig.15. These laminations resemble those found above the CM4 contact.

The very bioturbated silty mudstone in which laminations can not be distinguished range in thickness from 0.15 m to about 1.7 m, (average about 0.7 m). The sediment is bioturbated with *Terebellina, Chondrites, Planolites, Zoophycos, Shaubcylindrichnus, Paleophycus,* and *Skolithos,* Fig.16. Mud drapes are characteristic of these units (Reineck and Wunderlich, 1968).

Most of the cores have at least one bentonite layer about 2.5-4.0 m above the CM5 surface. Toward the south, a second bentonite can be found approximately 9.0 m above the CM5 surface. Commonly, there is a thicker sandy sideritized unit toward the top of the CM5-VE4 facies, just below the VE4 contact.

3.10 VE4 Surface

The VE4 surface truncates the CM5-VE4 laminated and bioturbated mudstones. There is commonly a 0.15 m to 0.5 m thick sideritized unit or there can be smaller portions of siderite from 2-4 cm located just below the VE4 surface. Black fissile mudstones occur above the VE4 surface. The surface is immediately overlain by a pebbly

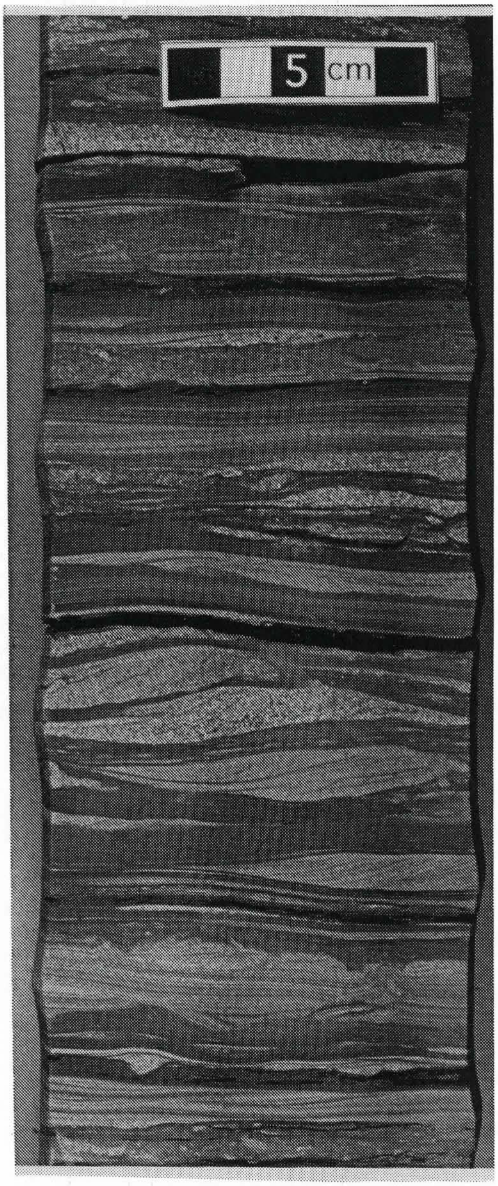


Fig.15 Core 3-31-36-22W4, siltstone laminations interbedded in mudstone, CM5-VE4.

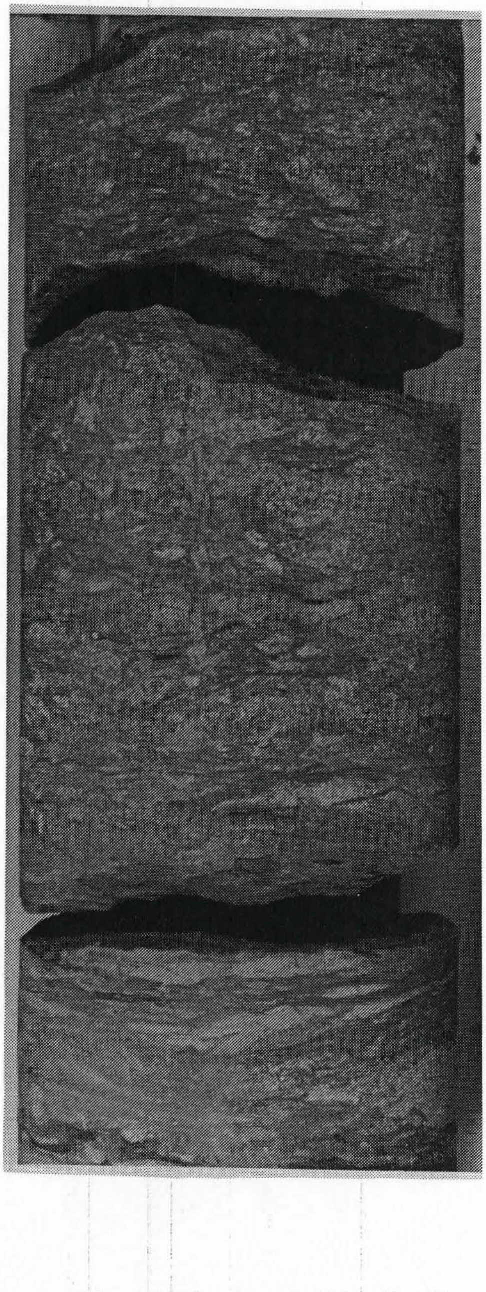


Fig.16 Core 7-1-37-24W4 at 4629.5 ft, bioturbated silty mudstone, laminations are indistinguishable, CM5-VE4.

mudstone, thickness ranging from 0.02 m to 0.4 m, Fig.17. with pebbles up to 3 cm diameter encased in black mudstone, Fig.18.

3.11 VE4- BFS, Black mudstone

VE4-BFS ranges in thickness from 6 m to 15 m. It consists of very fissile black mudstones with minimal amounts of siltstone, Fig.18. Within the black fissile mudstones, some cores have one or two more layers of the pebbly mudstones similar to those found immediately above the VE4 surface. They occur within the first few meters above the VE4 surface. The black fissile mudstones represents the uppermost part of the Viking Alloformation (Davis and Walker, 1993).

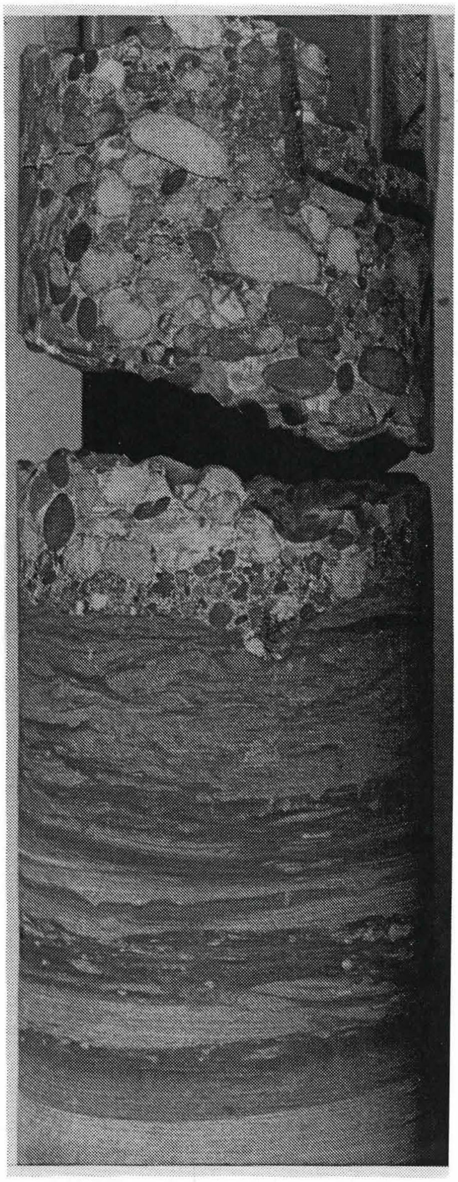
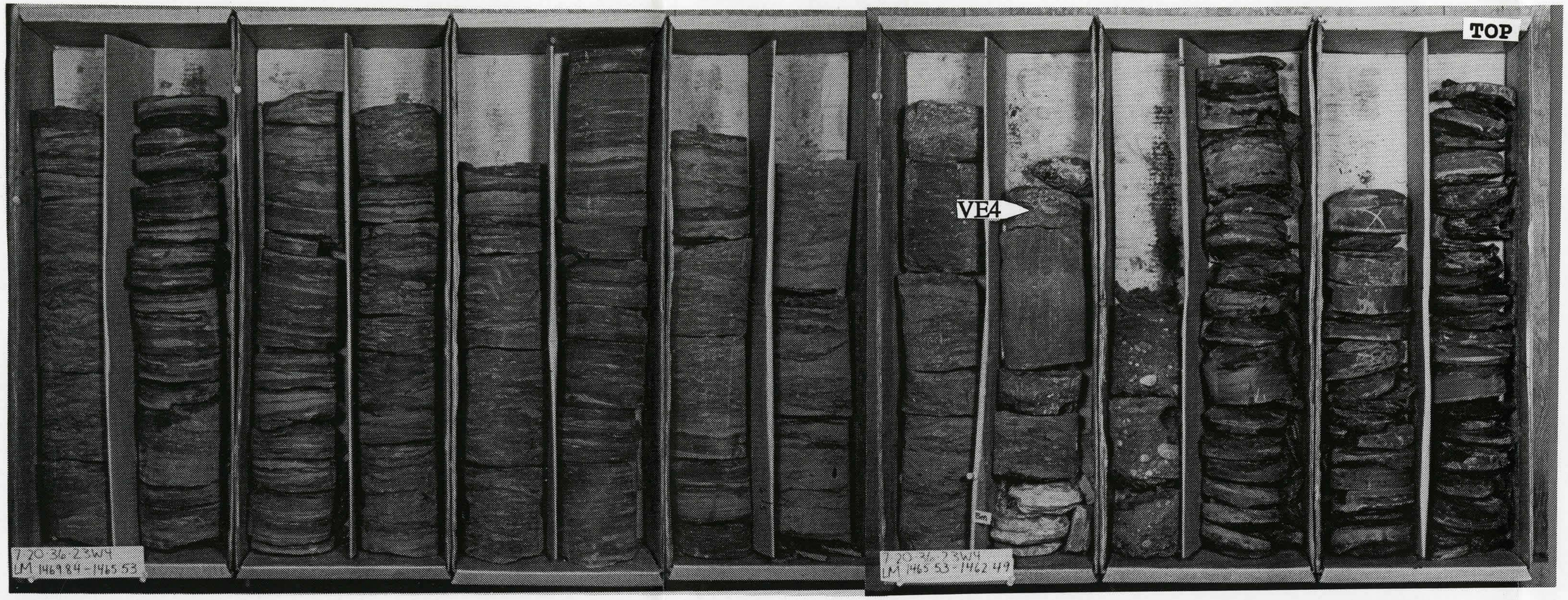
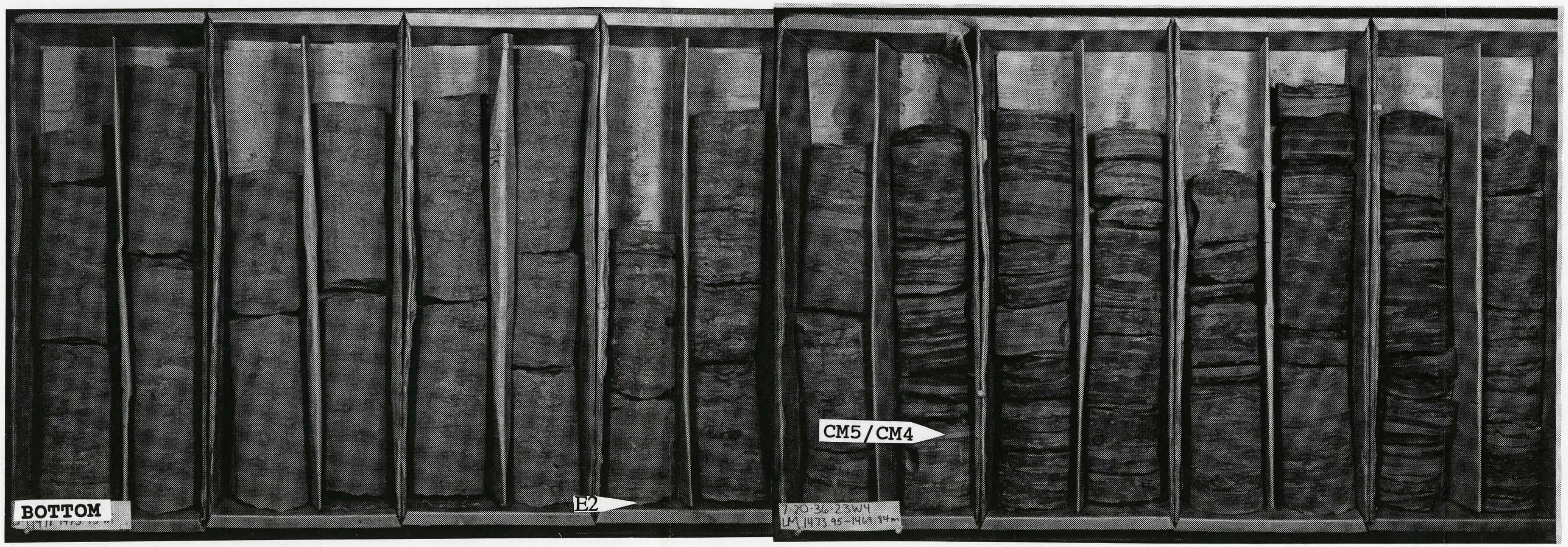


Fig.17 Core 7-1-37-24W4, the VE4 surface, overlain by a pebbly mudstone.

Fig.18   Core 7-20-36-23W4, note the siderite bed below the VE4 surface, and the pebbles encased in mudstone above the VE4 surface. Located south of the linear sandbody.


TOP
VE4
7-20-36-23W4
LM 1469.84-1465.53
7-20-36-23W4
LM 1465.53-1462.49


BOTTOM
E2
CM5/CM4
7-20-36-23W4
LM 1473.95-1469.84m

CHAPTER 4: LOG AND CORE CROSS SECTIONS DESCRIPTIONS

4.1 Introduction

Four cross sections have been constructed, Fig.19. Correlations are based upon signatures in the resistivity logs together with all available core information.

The base of the Viking Formation is taken at the beginning of the Regional Viking Successions and marked by the first deflection in the resistivity log above the Joli Fou shales. The top of the Viking Formation is taken at the inflection point in the resistivity log representing the incoming of mudstones of the Westgate Formation.

In most Viking studies, the Base of Fish Scales is used as the datum. However, in this thesis a datum below the main Viking sandstone body has been the chosen at the base of regional succession 4. This will hopefully show the true nature of the erosion surfaces. It is assumed that the base of Regional succession 4 was a reasonably flat and planar surface at the time of deposition.

4.2 Regional Successions

The base of regional succession 4 was chosen as the datum, and is assumed to represents a flat substrate. The stratigraphic rises or drops of erosion surfaces are relative to this datum. Regional successions 1, 2 and 3 are fine grained and probably coarsen slightly upward. They are situated below the datum and are log picks as

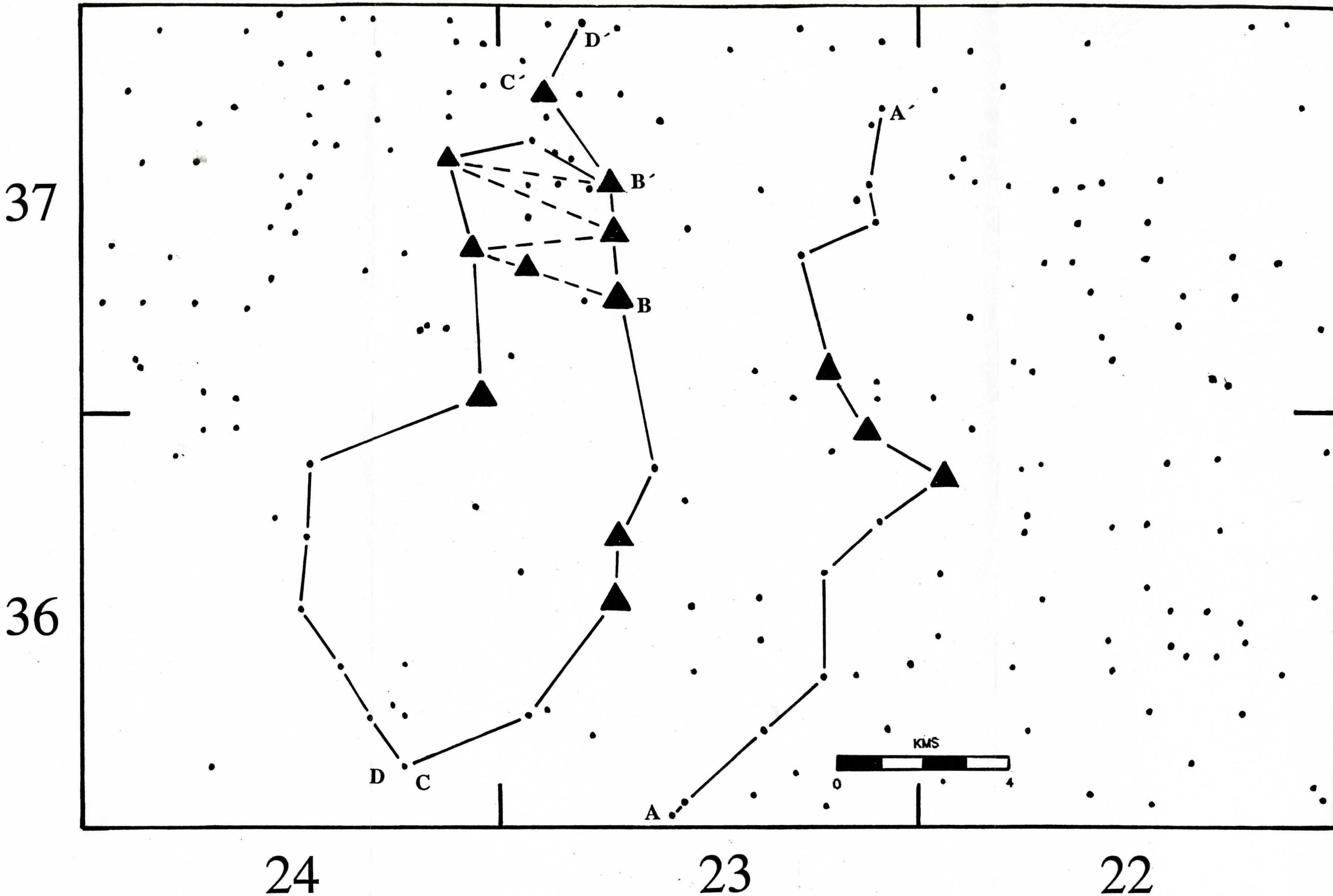


Fig.19 The study area. The circles represent resistivity logs and the triangles represent cores. The four cross sections illustrated were used for this thesis. AA', CC' and DD': perpendicular to the main sandbody.
BB', the segmented line, is parallel to the sandbody.

most welled cores do not penetrate deep enough to contain them. Regional successions 5 and 6 are situated above the datum and occur in most cores, Fig.24b. The regional successions are parallel to the datum.

Regional successions 5 and particularly 6 are cut out by E1 northward or basinward. The erosion of succession 6 can be identified where E1 overlies regional succession 5. Erosion of regional succession 5 can be recognized where E1 rests directly on the Regional succession 4 (Fig.20).

4.3 E1 Surface

In the south E1 is 2.7 m above the datum. In the north E1 is 1.3 m above the datum. The maximum erosional relief is 1.4 m.

E1 is represented by the first major spike in the resistivity log representing an increase in sandstone, Fig.24a. In the south of the study area E1 drops northwestward (Fig.25b). In well 3-31-36-22 E1 is 4 m above the datum and in well 14-36-36-23 E1 is 0.5 m above the datum resulting with a relief of 3.5 m over 2 km (Fig.20). E1 also drops stratigraphically along strike of the main sandstone body from the westnorthwest towards the eastsoutheast (Fig.24a). This drop of E1 is represented in well 10-8-37-23 where E1 is 4 m above the datum to well 7-13-37-24 where E1 is 6 m above the datum representing a relief of 2 m in 3.5 km, Fig.21. E1 drops stratigraphically northward but not as abruptly, with 2.5

Fig.20 Core cross section AA′, taken from within the log correlation of Fig.25b.

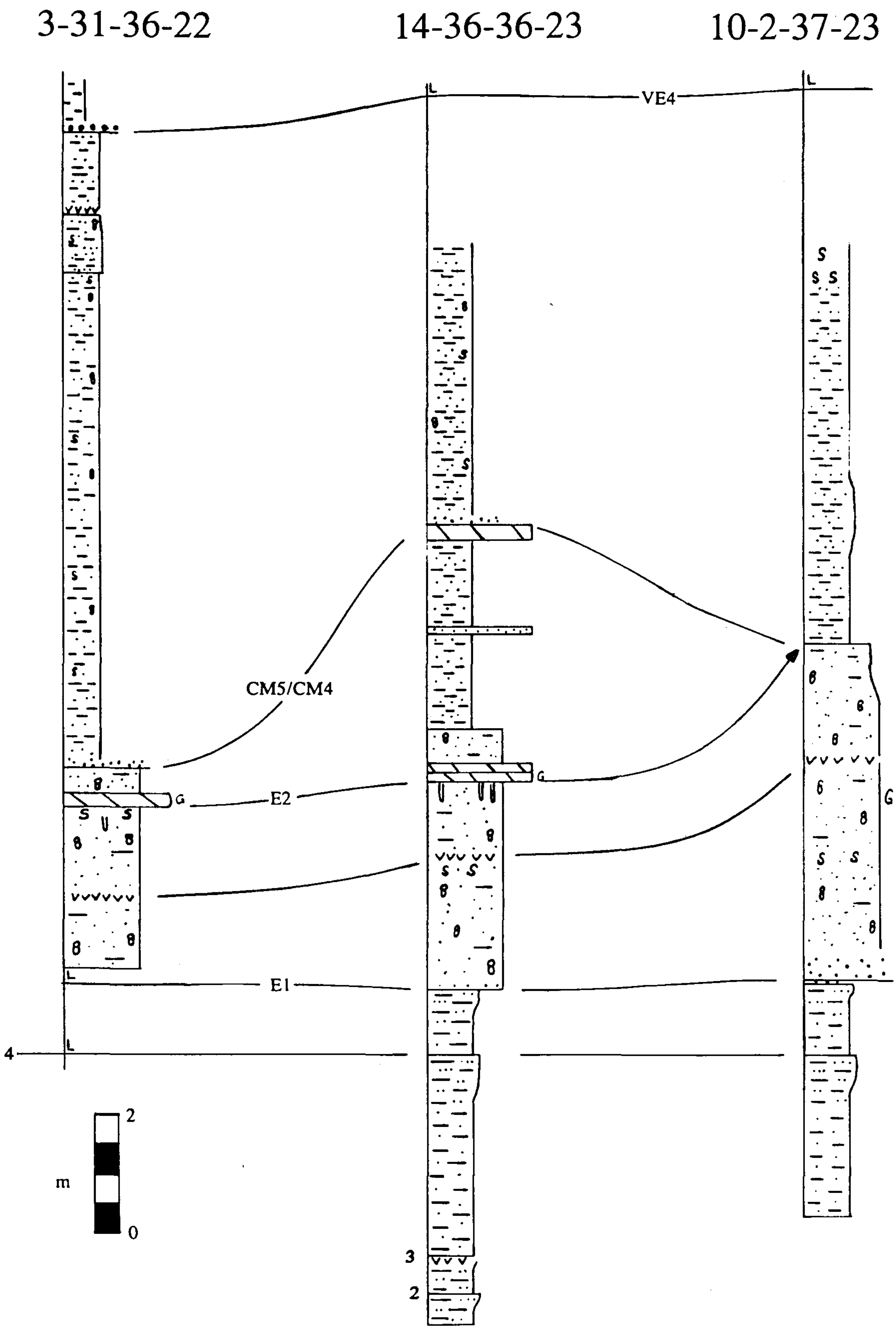
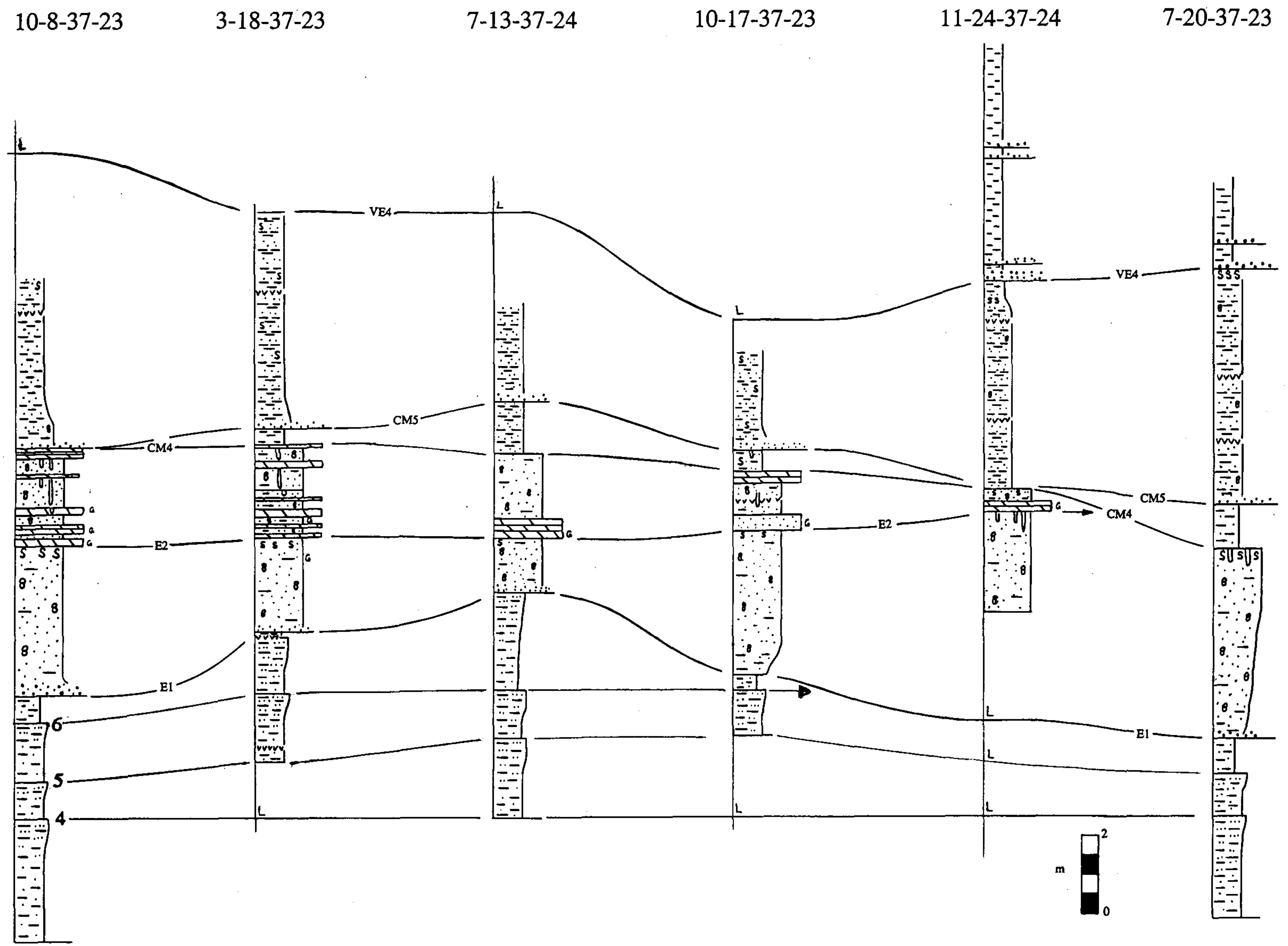

3-31-36-22
14-36-36-23
10-2-37-23
VE4
CM5/CM4
E2
E1
4
3
2
G
m
2
0

Fig.21 Core cross section BB′, taken from within the log correlation of Fig.24a.


10-8-37-23
3-18-37-23
7-13-37-24
10-17-37-23
11-24-37-24
7-20-37-23
VE4
CM5
CM4
E2
E1
6
5
4
m
2
0

m relief over 2.3 km (Fig.22). This drop is shown in well 7-20-37-23W4 where E1 is 5 m above the datum and in well 7-1-37-24W4 where E1 is 2.5 m above the datum. Farther northward, E1 becomes parallel to the datum with no significant change in relief.

Because E1 is drops towards the north, it progressively cuts out regional successions 5 and 6. This is shown by E1 overlying regional successions 4 and 5 (Fig.22), in wells 11-24-37-24 to 7-20-37-23, respectively.

E1 is cut out by E2 north of the main sand body (Fig.22, well 10-30-37-23) where E2 overlies the regional successions with no E1-E2 facies preserved.

4.4 E2 Surface

In the south E2 is 12 m above the datum. In the north E2 is 4.5 m above the datum. The maximum erosional relief is 7.5 m. E2 drops stratigraphically northward toward the main sandstone body (Fig.24a). From core 7-20-36-23W4 where E2 is 11.5 m above the datum to well 10-8-37-23W4 where E2 is 6.5 m above the datum, Fig.23. This represents a drop of 5 m. E2 begins to rise immediately south of the main sandstone body and flattens with respect to the datum immediately north of the sandstone body (Fig.22). This is represented from well 7-1-37-24W4 where E2 is 6.5 m above the datum to well 11-24-37-24W4 where E2 is 8.5 m above the datum therefore E2 rises 2.0 m over a distance of 5.5 km. E2 drops at

Fig.22 Core cross section DD′, taken from within the log correlation of Fig.25a.

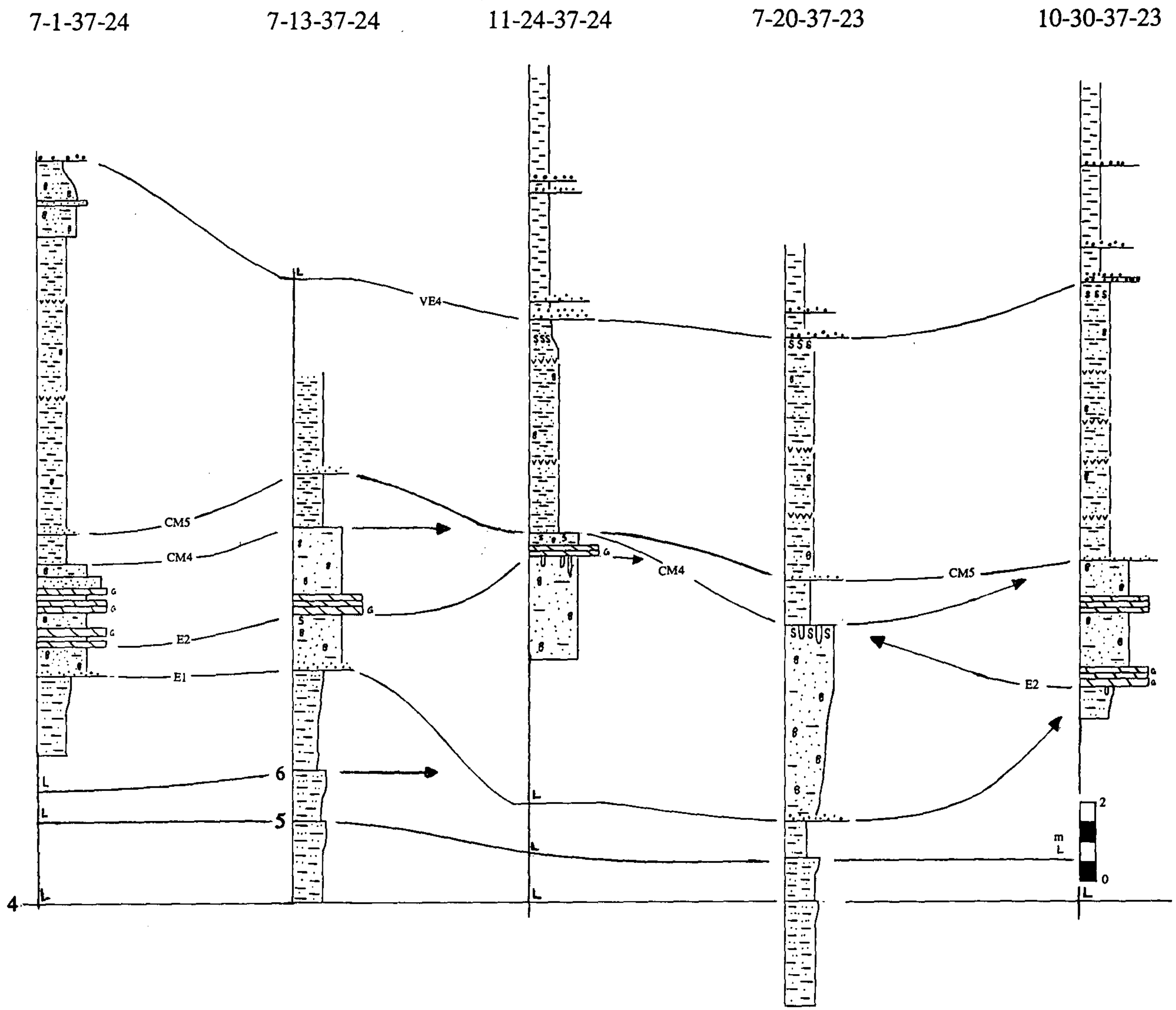
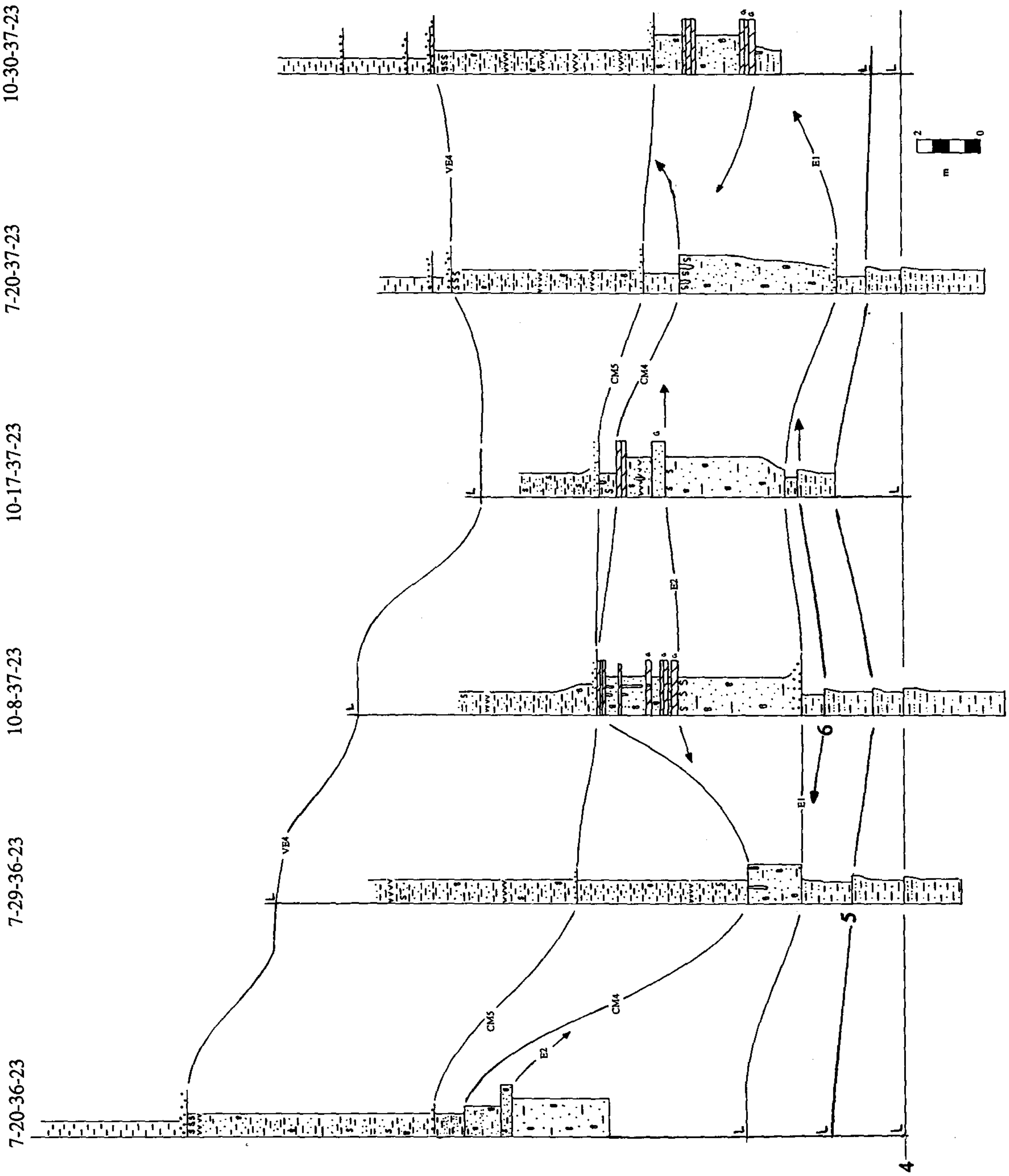

7-1-37-24
7-13-37-24
11-24-37-24
7-20-37-23
10-30-37-23
VE4
CM5
CM4
E2
E1
CM4
CM5
E2
6
5
4
m
2
0

Fig.23 Core cross section CC′, taken from within the log correlation of Fig.24b.


7-20-36-23
7-29-36-23
10-8-37-23
10-17-37-23
7-20-37-23
10-30-37-23
VE4
CM5
CM4
E2
E1
m
2
0
4
5
6

the same rate as found south of the main sandstone body. E2 trending westnorthwest to eastsoutheast is parallel to the datum.

E2 and E1 are parallel to each other in the southern part of the study area. This continues northward until the point where E1 drops stratigraphically and E2 rises (Fig.22, well 7-13-37-24). This is represented by a thicker E1-E2 facies and occurs in the main sandstone area. E2 then drops and cuts into E1. This drop is represented by E2 overlying the regional successions.

4.5 CM4 surface

In the south CM4 is 12.7 m above the datum. In the north CM4 is 6 m above the datum. The maximum erosional relief is 6.7 m. In the south of the study area CM4 drops stratigraphically northward (Fig.23). This drop is represented in well 7-20-36-23 to 7-29-36-23 where CM4 is 12.7 m and 4.4 m above the datum, respectively, resulting in a relief of 8.3 m over 1.7 km. CM4 then rises northward (Fig.23). This is shown by well 7-29-36-23 where CM4 is 4.4 m above the datum, and well 10-8-37-23 where CM4 is 8.2 m above the datum, resulting in a 3.8 m rises over 5.7 km. This occurs up to the south edge of the main sandstone body. Immediately south of the main sandstone body CM4 drops stratigraphically northward (Fig.23). This is shown in cores 10-8-37-23 to 7-20-37-23 where CM4 is 9.5 m and 8 m above the datum, respectively. This results in a drop of 1.5 m over 2.2

km. In the north section of the study area CM4 begins to rise again. Westnorthwest to eastsoutheast or along strike of the main sandstone body CM4 is parallel to the datum. CM4 cuts out E2 in the southern part of the study area. CM4 also cuts out the E2 surface and some of or all of the E1-E2 facies north of the main sandstone body. There is a consistent thickness of the sandstone body, E2-CM4, in the westnorthwest-eastsoutheast direction because E2 and CM4 are parallel to each other. Immediately north and immediately south of the main sandstone body, E2 is cut out or most of the E2-CM4 facies is cut out. This is represented by CM4 overlying E1-E2 facies (Fig.23).

4.6 CM5 Surface

In the south CM5 is 12.8 m above the datum. In the north CM5 is 7 m above the datum. The maximum erosional relief is 5.8 m. CM5 drops stratigraphically towards the north (Fig.23). This occurs as far as about 3.5 km south of the main sandstone body, where CM5 rises stratigraphically toward the main sandstone body (Fig.22, from well 7-1-37-24 to 7-13-37-24). In these wells CM5 is 10.5 m and 12 m above the datum, respectively and resulting in a rise of 1.5 m over 3.5 km. Immediately south of the main sandstone body CM5 drops stratigraphically northward (Fig.23). This is shown in wells 7-20-36-23 to 10-30-37-23 where CM5 drops 3.5 m over 12 km (Fig.23). CM5 rises in the westnorthwest -

eastsoutheast direction (Fig.21). Between 10-8-37-23 and 7-13-37-24 CM5 rises 1.5 m in 3.5 km. Because CM4 is parallel to the datum along this trend, evidence of CM5 rising is represented by thicker preservation of the CM4-CM5 facies.

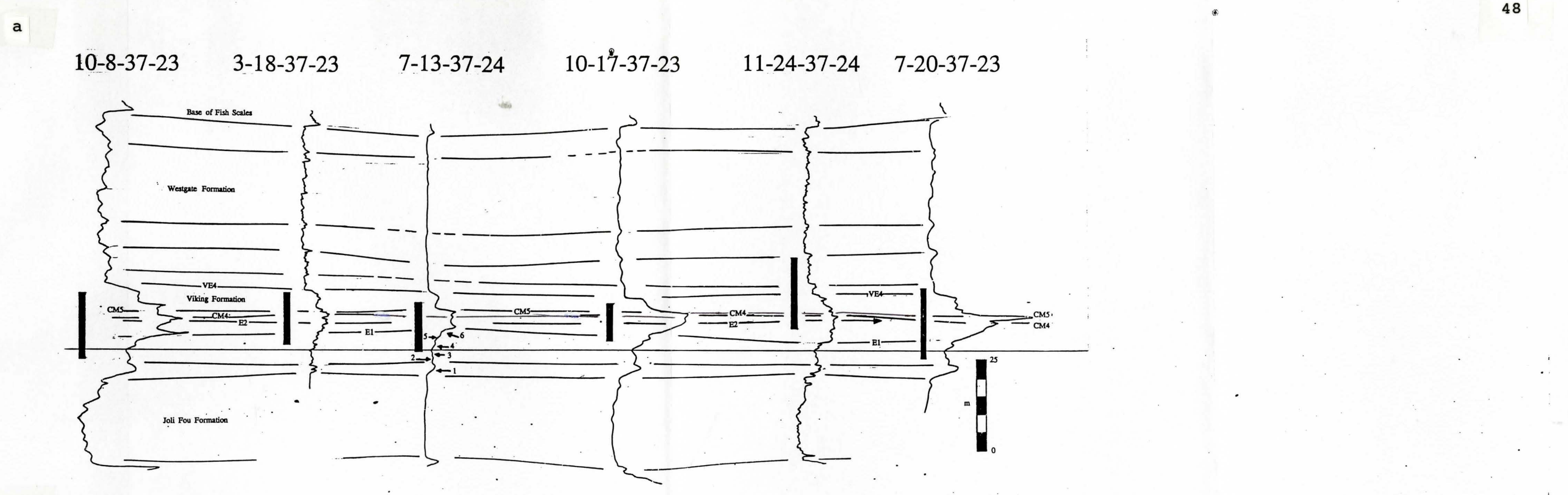
CM5 cuts into CM4 as CM5 drops stratigraphically northward, immediately north of the main sandstone. This is represented by a decrease in thickness of the CM4-CM5 facies or by CM5 overlying the E2-CM4 facies.

4.7 VE4 SURFACE

Erosion surface VE4 drops stratigraphically northward. The relief of the drop is up to 15 m.

Fig.24a Resistivity log correlation BB′

Fig.24b Resistivity log correlation CC′


a
10-8-37-23
3-18-37-23
7-13-37-24
10-17-37-23
11-24-37-24
7-20-37-23
Base of Fish Scales
Westgate Formation
VE4
Viking Formation
CM5
CM4
E2
E1
Joli Fou Formation
25
m
0

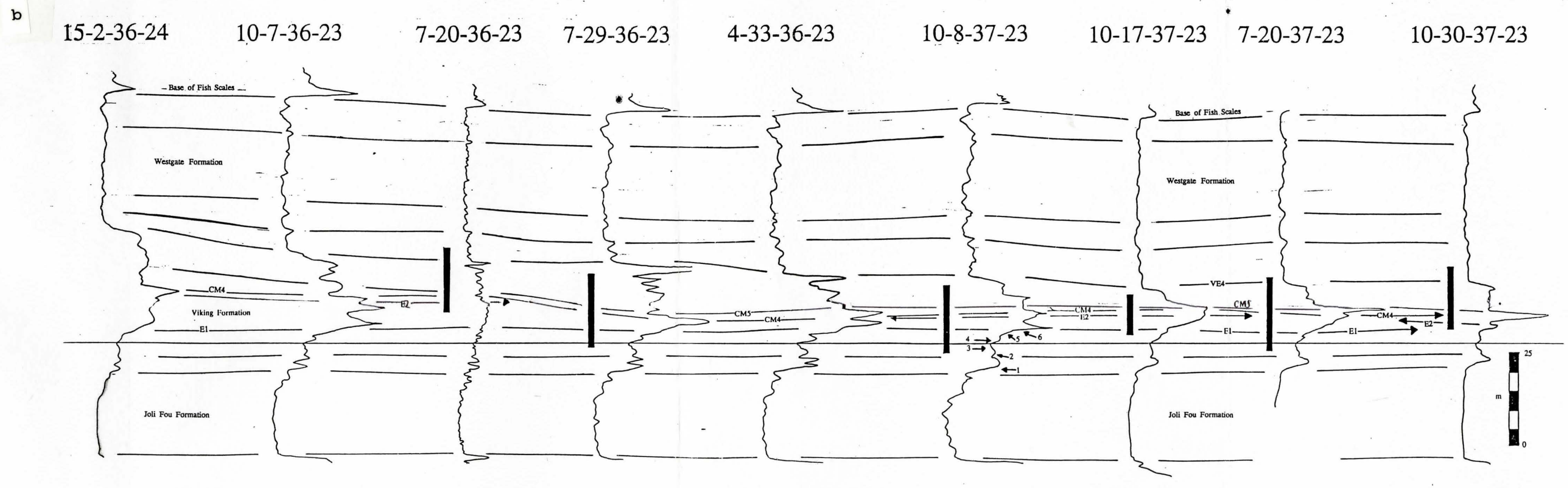
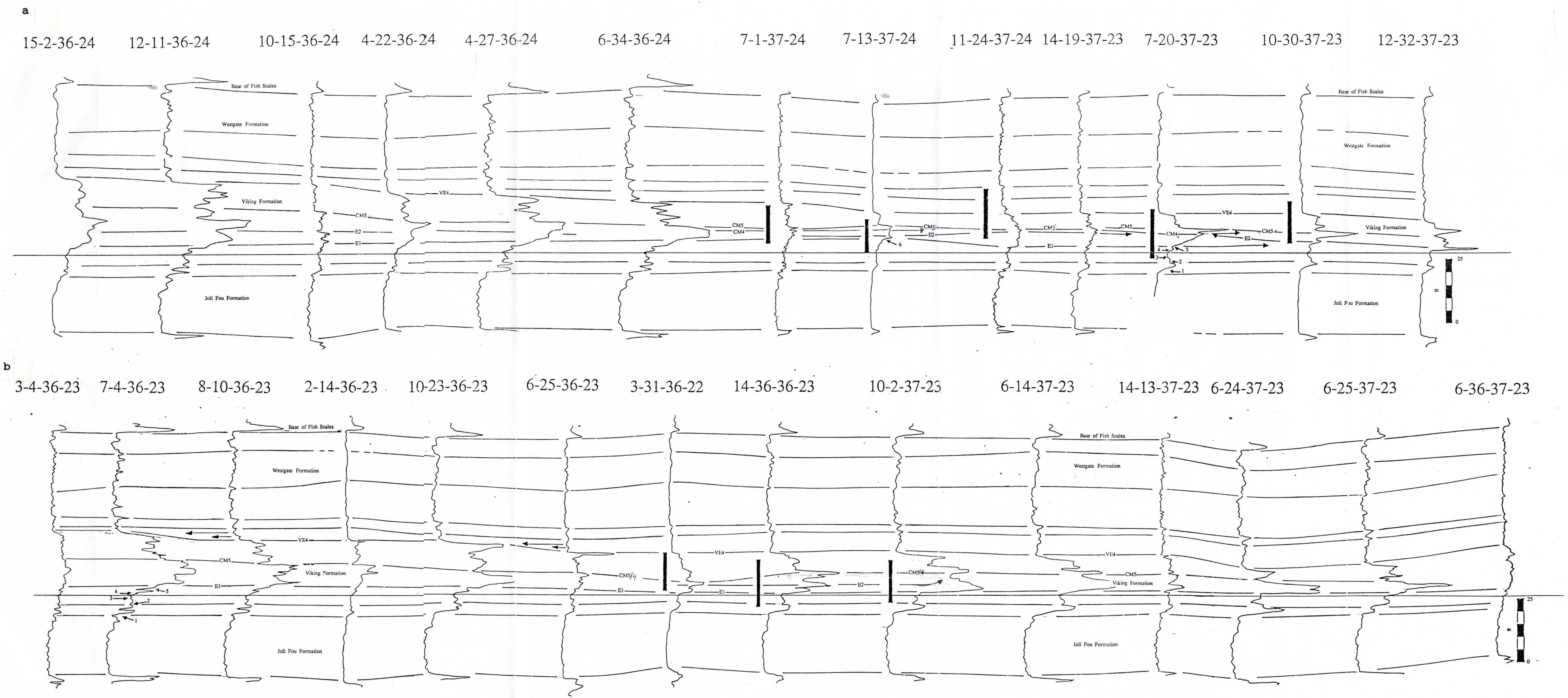

b
15-2-36-24
10-7-36-23
7-20-36-23
7-29-36-23
4-33-36-23
10-8-37-23
10-17-37-23
7-20-37-23
10-30-37-23
Base of Fish Scales
Westgate Formation
CM4
Viking Formation
E1
E2
CM5
VE4
Joli Fou Formation
25
m
0

Fig.25a Resistivity log correlation DD'

Fig 25b Resistivity log correlation AA'


a
15-2-36-24
12-11-36-24
10-15-36-24
4-22-36-24
4-27-36-24
6-34-36-24
7-1-37-24
7-13-37-24
11-24-37-24
14-19-37-23
7-20-37-23
10-30-37-23
12-32-37-23
Base of Fish Scales
Westgate Formation
Viking Formation
Joli Fou Formation
VE4
CM5
CM4
E2
E1
m
25
0
b
3-4-36-23
7-4-36-23
8-10-36-23
2-14-36-23
10-23-36-23
6-25-36-23
3-31-36-22
14-36-36-23
10-2-37-23
6-14-37-23
14-13-37-23
6-24-37-23
6-25-37-23
6-36-37-23
Base of Fish Scales
Westgate Formation
Viking Formation
Joli Fou Formation
VE4
CM5
CM5/4
E2
E1
25
0

CHAPTER 5: INTERPRETATIONS

5.1 Introduction

This chapter focuses on the interpretation of the facies and bounding discontinuities, their distribution in the study area and their environment of formation. It will also relate the positions of the discontinuities to existing stratigraphic schemes (Boreen and Walker, 1991; Pattison and Walker, 1994).

5.2 Regional Successions

Successions of slightly bioturbated mudstone with increasing siltstone upwards are found below the main sandstone body. The features found in the regional successions suggest a marine environment with quiet deposition, below fair weather wave base. The traces found are part of the *Cruziana* Ichnofacies (Pemberton et al., 1992). The silt bioturbated into the mudstone was probably transported offshore by storms, but possible storm-formed sedimentary structures have been destroyed by bioturbation.

5.3 E1 Surface

A drop in sea level is recognized at Crystal by a valley incision; this incision surface was termed SB1 + TSE1 by Pattison and Walker (1994). The valley filled as an estuary (Pattison and Walker, 1994) and it is assumed that the valley fill must have been truncated and subsequently eroded, Fig.26. This truncation due to relative sea level rise is interpreted to have occurred also in the Joffre and Mikwan area. The truncation of the first Crystal valley fill is seen at Joffre/Mikwan as a transgressive surface of erosion, E1. E1 erodes the regional successions below. As E1 rises stratigraphically southward more of the regional successions are preserved. In the north, the E1 surface erodes further down into the regional successions.

5.4 E1-E2, Extensively Bioturbated Sandstone

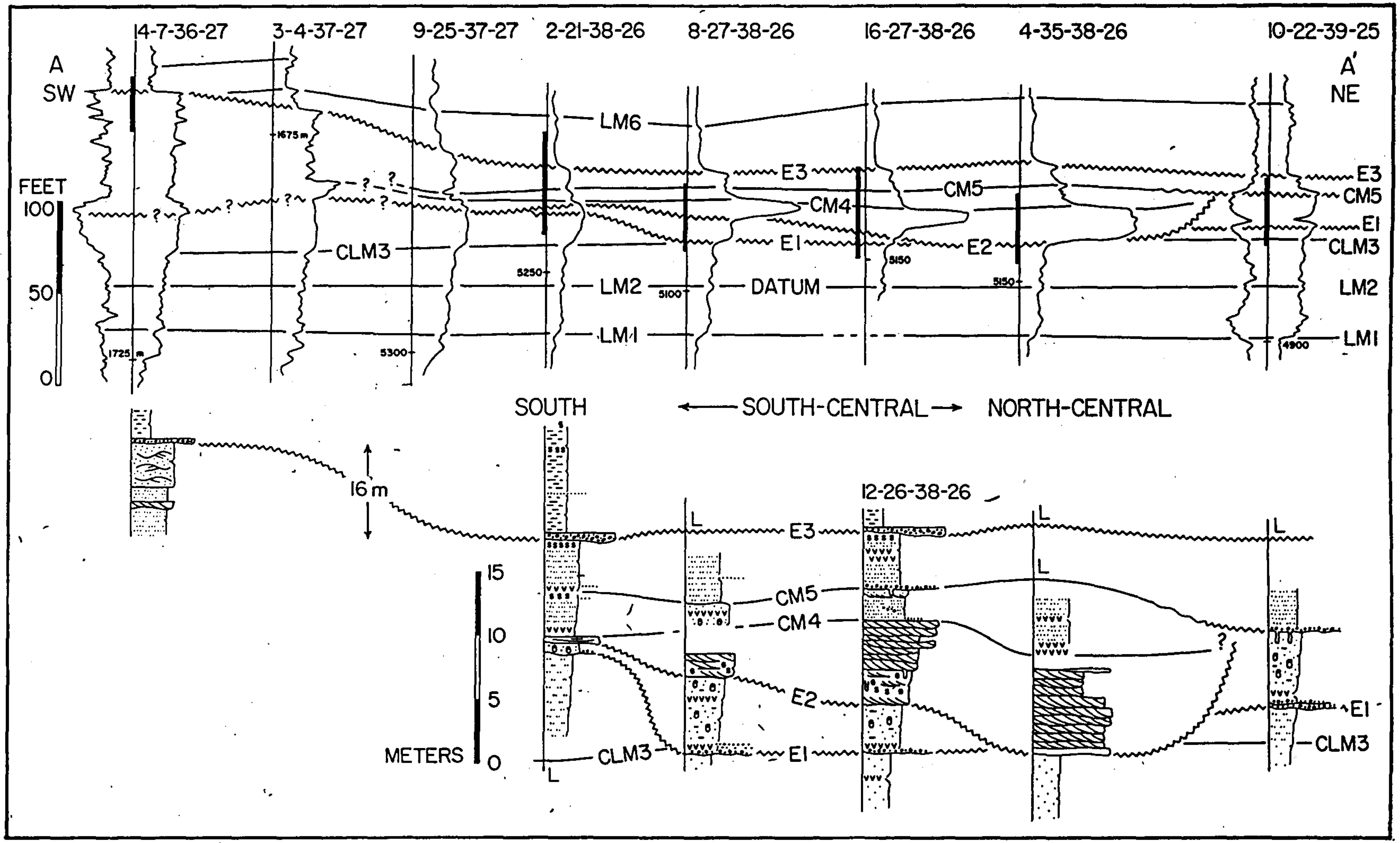
The E1-E2 facies is characterized by pebbles at the base, but generally coarsens upward into extensively bioturbated muddy sandstones with some cross-bedded sandstones. This suggests deposition in a high energy environment, possibly in the lower shoreface. Any structures created by wave action, such as cross-bedding, were mostly destroyed by the high rate of sediment mixing by organisms.

Progradation of the shoreface may have been encouraged by a pause of relative sea level during the overall transgression.

5.5 E2 Surface

The E2 surface underlies the main Viking sandbody in the Joffre area, where the sandbody was interpreted as a shoreface deposit by Downing and Walker (1988), Fig.27. In order for this second shoreface to prograde onto the

Fig.27 Cross section from southwest to northeast by Downing and Walker (1988). Illustrates the erosion surfaces correlated by cores and resistivity logs.


14-7-36-27
3-4-37-27
9-25-37-27
2-21-38-26
8-27-38-26
16-27-38-26
4-35-38-26
10-22-39-25
A
SW
A'
NE
FEET
100
50
0
1675 m
1725 m
5300
5250
5100
5150
5150
4900
LM6
E3
CM5
CM4
E1
E2
CLM3
LM2
DATUM
LM1
SOUTH
SOUTH-CENTRAL
NORTH-CENTRAL
16 m
12-26-38-26
L
METERS
15
10
5
0

E2 surface, a minor sea level drop, followed by a rise and stillstand is required. It has been shown that the E2 surface erodes out some of the E1-E2 facies and/or the E1 surface in the north and in the south of the study area.

The E2 surface represents a firm ground and a period of non deposition. Evidence for this would include the presence of siderite and/or *Skolithos or Diplocraterion* located immediately beneath the E2 surface. This represents the *Glossifungites* ichnofacies (Pemberton et al., 1992). The E2 surface is in places cut out by the CM4 surface which cuts down onto the E1-E2 facies.

5.6 E2-CM4, Main Viking Sandstone

The E2-CM4 facies is characterized by cross-bedded, horizontally laminated or structureless sandstones. These structures suggest an environment of high energy, above fair weather wave base. The bioturbated sections represent a *Skolithos* ichnofacies, with deposition probably in the middle shoreface. There is no facies suggesting the upper shoreface or beach. The energy or sedimentation rate was higher than in the lower shoreface where sedimentary structures were destroyed by bioturbation, as in facies E1-E2.

The E2-CM4 facies was deposited after the incision of E2, and represents progradation during a stillstand of relative sea level within the overall transgression.

5.7 CM4 Surface

The CM4 surface is interpreted to be a surface of erosion produced by the resumed transgression after the stillstand that allowed progradation of the main Viking sandbody (E2-CM4 facies). The CM4 surface cuts out part of the E2-CM4 facies and/or the E2 surface. This occurs mostly in the north. Southward, more of the E2-CM4 facies is preserved because the CM4 transgressive surface of erosion rises stratigraphically. There is no lag on this surface. In only a few cores are there burrows penetrating down into the E2-CM4 facies, suggesting local development of a firm ground.

Southward, CM4 drops immediately south of the main sandbody, but rises again near the southern edge of the study area (Fig.23).

This transgressive surface of erosion can be mapped extensively in the Viking basin, and truncates the main sandstone body. It is correlated with the main transgressive surface of erosion that truncates the first valley fill at Crystal (Pattison and Walker, 1994). It is important to emphasize that although this surface must once have been formed at Crystal, it appears to have been subsequently eroded by the transgressive surface of erosion that truncated the second valley fill at Crystal, Fig.28.

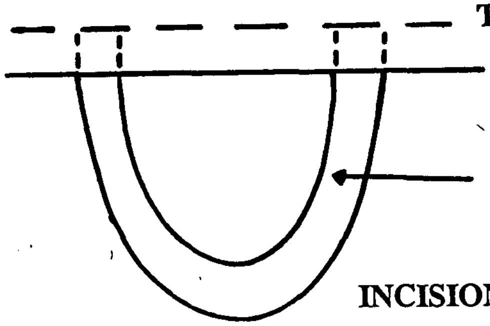


Fig.28 The two valley incisions at Crystal and truncation of their fill by the two transgressive surfaces of erosion, after Pattison and Walker (1994)

5.8 CM4-CM5, Mudstones

The facies CM4-CM5 is characterized by siltstone and sandstone laminations within mudstone. The laminations are rippled, lenticular or horizontal and are separated by mud drapes. This is indicative of a depositional environment of both sand and mud with alternating higher and lower energy conditions (Reineck and Wunderlich, 1968). The laminae fine upward and the bases are sharp. The rippled laminations are interpreted to represent both current and wave action.

This facies occurs above the transgressive surface of erosion, CM4. It is unknown whether this facies formed during the transgression or the subsequent highstand. In either case the depositional environment was one of offshore sand/mud deposition.

5.9 Second Crystal Incision

After the transgression that formed transgressive surface of erosion CM4 and its correlative surface that truncated the first valley fill at Crystal (this surface is not present), another relative sea level drop has been proposed (Pattison and Walker, 1994). Evidence for this sea level drop is the second incision at Crystal (SB2 of Pattison and Walker, 1994). This incision is not seen at Joffre. After incision, subsequent relative sea level rise caused valley two to fill with fluvial and estuarine deposits. These were truncated as the relative sea level rise continued by TSE3 (Pattison and Walker, 1994). In this thesis, the second truncation surface at Crystal is referred to as TSE2 (Fig.26); it is equivalent to TSE3 of Pattison and Walker (1994). The second surface at Crystal (TSE2, Fig.28) is correlated with CM5 at Joffre.

5.10 CM5 Surface

This surface has a sharp base, overlain by scattered pebbles or chert granules, or by a coarse layer up to 0.55 m thick of pebbles and/or chert granules. This coarse material is interpreted as a lag produced by reworking during rise of relative sea level. By comparison with many other pebble-draped surfaces (eg. Bergman and Walker, 1987, 1988), CM5 is interpreted as a transgressive surface of erosion. Evidence for the erosion is that CM5 cuts down onto the CM4 surface or rests on the E2-CM4 facies. Toward the south, CM5 generally rises stratigraphically and more of the CM4-CM5 facies has been preserved.

The CM5 surface is found throughout the area. It is correlated with the second transgressive surface of erosion at Crystal TSE2 (Fig.28), TSE 3 of Pattison and Walker (1994). At Crystal, the surface that truncates the second valley fill (TSE2, Fig.26) is interpreted to have cut out the surface that truncated the first valley fill (TSE1, Fig.28).

Siderite is found just below CM5, along with *Skolithos* burrows that penetrate into the CM4-CM5 facies. This implies the development of a firm ground before the next facies was deposited.

5.11 CM5-VE4, Laminated Mudstones

The CM5-VE4 facies is characterized by burrowed and laminated sandstone and mudstone. The laminations are rippled, lenticular or horizontal, separated by mud drapes. This facies is muddier, better laminated and less bioturbated than the CM4-CM5 facies. This is indicative of a depositional environment of both sand and mud with alternating higher and lower energy conditions (Reineck and Wunderlich, 1968). The laminae fine upward and the bases are sharp. The rippled laminations are interpreted to represent both current and wave action. The environment appears to have been very similar to that of the CM4-CM5 facies.

The laminations are also found to be bioturbated. The same environmental conditions are still implied but no sedimentary structures were preserved because of the intensity of bioturbation.

It is unknown whether this facies is formed during the transgression or the subsequent highstand. In either case they represent offshore sand/mud deposition.

5.12 VE4 Surface

The VE4 surface is characterized by pebbles encased in black mud. It can be traced across the entire Viking basin, and is interpreted as a transgressive lag (Davies and Walker, 1993). This lag was produced by the reworking of sediment during a relative rise in sea level. There is commonly a siderizied unit located just below the VE4 surface.

5.13 VE4-BFS, Black Mudstone

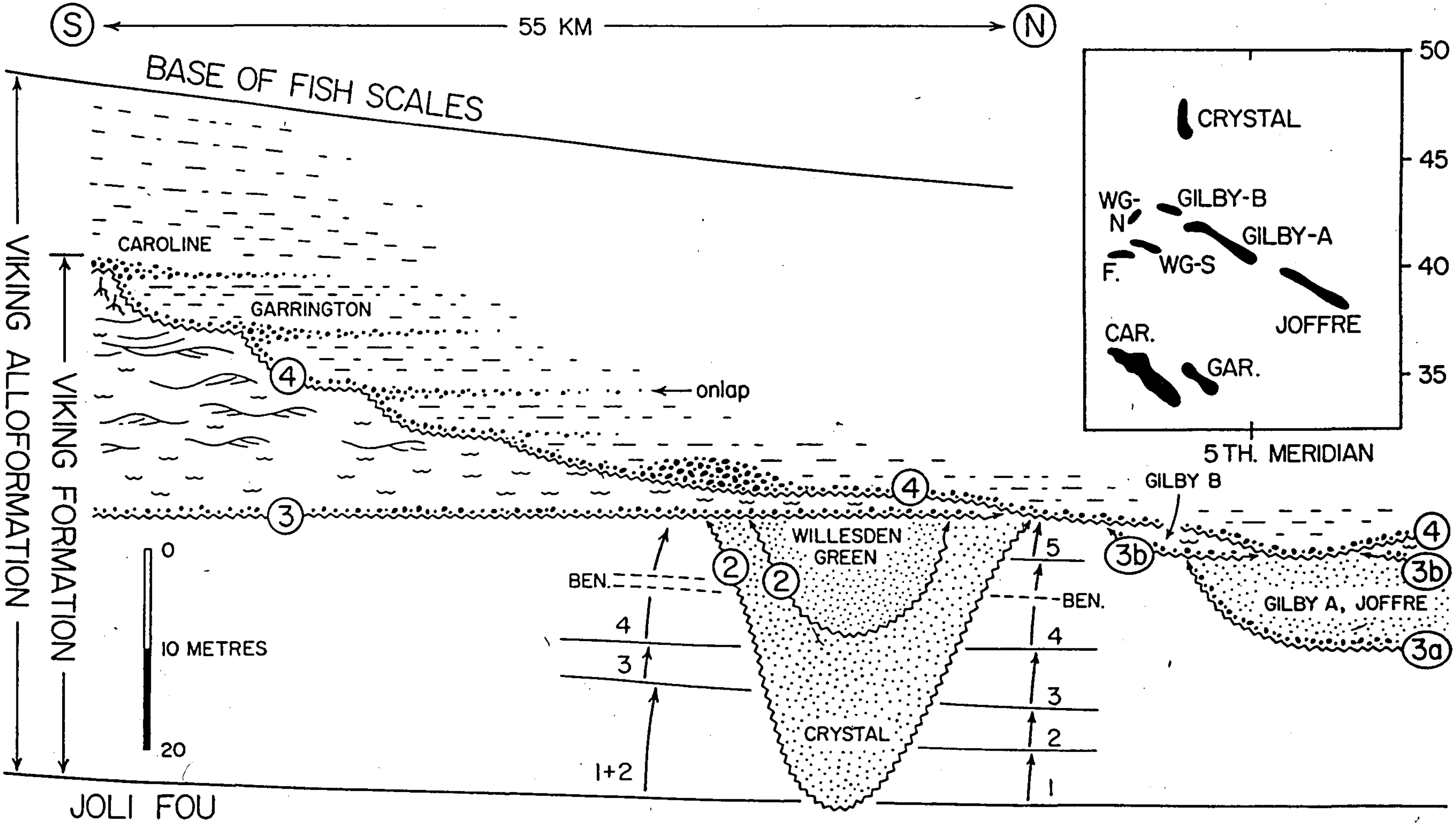
The VE4-BFS facies is characterized by very fissile black mudstone which is indicative of a very low energy environment. This implies the area was then located offshore and well below storm weather wave base, in a setting where mud could settle out.

5.14 INTERPRETATION: Correlation of the Joffre/Mikwan area with Crystal

The correlation between Joffre and Crystal is shown in Fig.29, in the version published by Boreen and Walker (1991). Figure 29 shows one Crystal valley incision and one transgressive surface of erosion underlying the Viking sandstones at Joffre. The sandstones at Crystal and Joffre are then truncated by a single transgressive surface of erosion, 3 (at Crystal) and 3b (at Joffre) (Fig.29).

In their interpretation (Boreen and Walker, 1991), there was an initial lowering of relative sea level to create the valley (surface 2 in Fig.29) at Crystal. The subsequent transgression created a transgressive surface of erosion at Joffre, 3a in Fig.29. A stillstand within the main transgression allowed the progradation of the Joffre shoreface onto the erosion surface, forming the

Fig.29 Interpretation of the bounding discontinuities from Crystal to Joffre by Boreen and Walker (1991).


S
55 KM
N
BASE OF FISH SCALES
CAROLINE
GARRINGTON
onlap
VIKING ALLOFORMATION
VIKING FORMATION
0
10 METRES
20
WILLESDEN GREEN
CRYSTAL
BEN.
4
3
1+2
5
BEN.
4
3
2
1
GILBY B
3b
GILBY A, JOFFRE
4
3b
3a
2
2
3
4
4
JOLI FOU
CRYSTAL
WG-N
GILBY-B
GILBY-A
F.
WG-S
JOFFRE
CAR.
GAR.
50
45
40
35
5 TH. MERIDIAN

main Viking sandbody (Downing and Walker, 1988). Boreen and Walker (1991) and Downing and Walker(1988) then interpreted a resumed transgression which truncates both the sandstones at Joffre (3b) and the estuarine fill at Crystal (3) (Fig.29).

However, at Joffre Downing and Walker (1988) defined two erosion surfaces below the sandbody, E1 and E2 (Fig.27). If 3a correlates with E2, there is no logical explanation of E1 in the Boreen and Walker (1991) scheme.

A similar problem exists above the main sandbody at Joffre, where Boreen and Walker (1991) describe one TSE (3b, Fig.29). However, Downing and Walker (1988) described two erosion surfaces, Fig.27. If the transgressive surface of erosion 3b (Boreen and Walker, 1991) represents the erosion surface CM4 (Downing and Walker, 1988), there is no logical explanation of erosion surface CM5 (Downing and Walker, 1988) in the Boreen and Walker (1991) scheme.

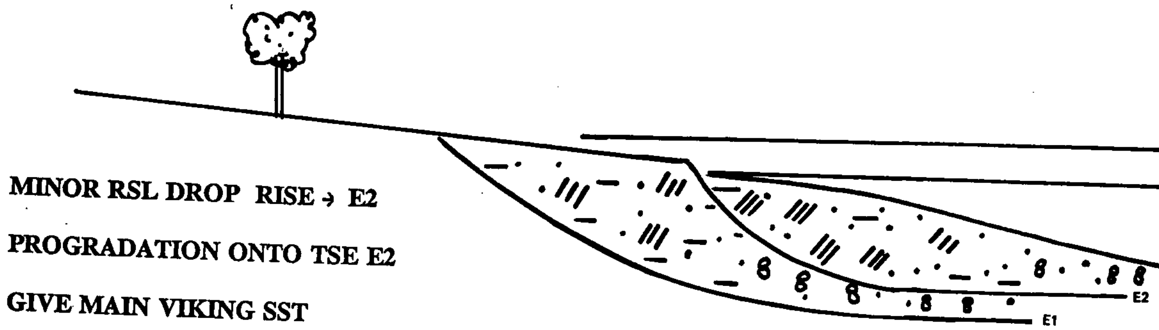
Since the work of Boreen and Walker (1991), it has been shown that Crystal contains two valley incisions instead of just one (Pattison and Walker, 1994). The first incision was created by a drop of relative sea level. With subsequent transgression the first valley filled with estuarine deposits which were truncated by a transgressive surface of erosion, TSE1 of Fig.28. This surface was not recognized or labelled by Pattison and Walker (1994) because, in the interpretation of this thesis, it has been completely cut out by the transgressive surface of erosion that truncated valley fill two. The second valley was created by a drop of relative sea level (Pattison and Walker, 1994). With a subsequent sea level rise, this second incision was filled with fluvial and estuarine deposits which where truncated due to continued rise of relative sea level (TSE2 of Fig.28; TSE3, Fig.26, of Pattison and Walker (1991)). Though TSE1 can not be seen at Crystal, it is assumed that it must have existed and/or might be seen in other areas. It is interpreted that TSE2 truncated not only the second valley fill but also TSE1 (Fig.28). The possibility of two transgressive surfaces of erosion at Crystal suggests a correlation with surfaces CM4 and CM5 at Joffre and Mikwan.

5.15 Interpretation of sequence of events

The relative sea level drop that cut valley one at Crystal was followed by a transgression that created the transgressive surface of erosion E1. E1 cut out some of the marine mudstones beneath. It is interpreted that there was then a stillstand, allowing the shoreface to prograde onto the E1 surface, Fig.30.

For the creation of the transgressive surface of erosion E2, it is suggested that there was a minor sea level drop followed by another rise. It was during this rise that the E2 surface was formed and cut into the former prograded shoreface deposits of E1-E2. Another minor stillstand would have allowed the progradation and

Fig.31 Illustration of E2 cutting into the E1-E2 facies and the progradation of the main Viking sandstones.



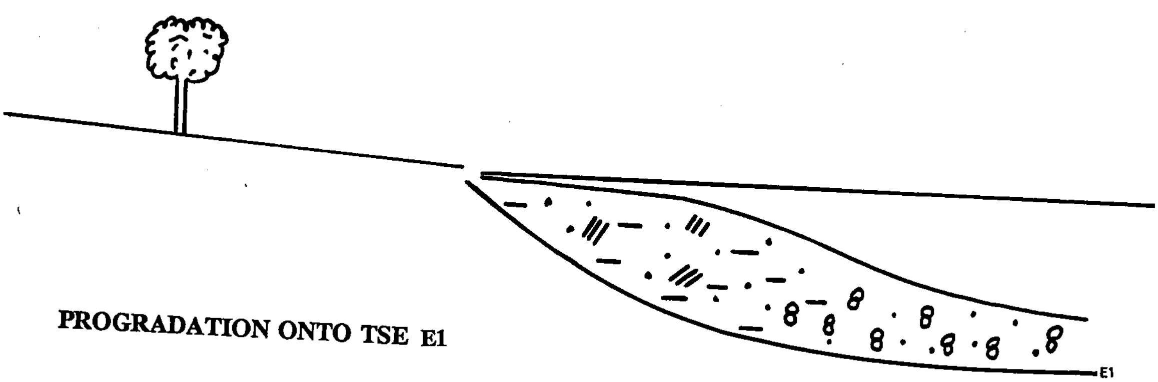


Fig.30 Illustration of E1 and the E1-E2 facies.

deposition of the main Viking sandstones, E2-CM4, Fig.31. These minor fluctuations of sea level gave rise to two erosion surfaces (E1 and E2), and two stacked shoreface deposits where Boreen and Walker (1991) described only one of each.

After deposition of the main Viking sandstones, the transgression resumed and the transgressive surface of erosion CM4 was formed. CM4 truncated the main Viking sandstones, Fig.32. This CM4 erosion surface is correlated with the erosion surface that is assumed to have truncated the first valley incision and fill at Crystal (TSE1, Fig.28). Though this surface is not seen at Crystal, it is inferred to correlate into the Joffre/Mikwan area.

Another relative sea level drop created the second incision at Crystal, SB2 (Pattison and Walker, 1994), or incision 2. With the subsequent sea level rise, the valley filled and was subsequently truncated by transgressive surface of erosion TSE2 (Fig.28). This is correlated with the surface CM5 in the Joffre/Mikwan area, Fig.33. CM5 did not truncate all of CM4 in the Joffre/ Mikwan area, but their correlative surfaces TSE2 and TSE1 (Fig.28) show total erosion of TSE1 by TSE2.

With another sea level drop and subsequent rise, erosion surface VE4 was created. At Crystal, VE4 truncates most of TSE2 (Fig.26) but lies about 6.8 m above the CM5 erosion surface in the Joffre/Mikwan area.

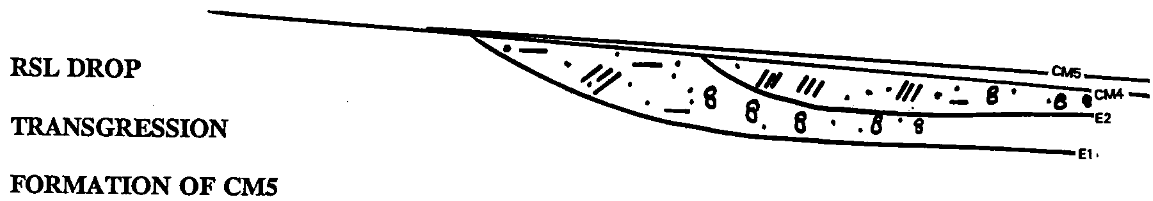


Fig.33 Illustration of the truncation by CM5

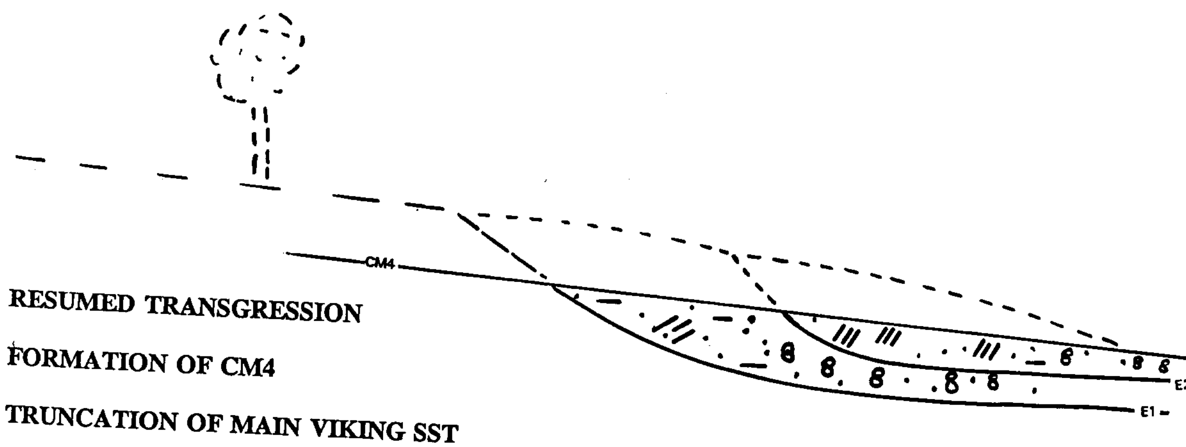


Fig.32 Illustration of the truncation of the main Viking sandstones by CM4.

CHAPTER 6: CONCLUSIONS

1) The 5 erosion surfaces E1, E2, CM4, CM5 and VE4 can be traced along strike from Joffre towards Mikwan southward. They are all transgressive surfaces of erosion.

2) There are two erosion surfaces, E1 and E2, below the main Viking sandstones, rather than the one described by Boreen and Walker (1991).

3) E1 and E2 result from minor sea level fluctuations within an overall transgression. The facies E1-E2 and E2-CM4 represent the lower and middle shoreface, respectively. E2-CM4 is the main producing sandstones in the Viking. These facies were produced by stillstands within the overall transgression.

4) There are two erosion surfaces, CM4 and CM5, above the main Viking sandstones, rather than the one described by Boreen and Walker (1991).

5) CM4 and CM5 are equivalent to the proposed TSE1 and TSE2 at Crystal. CM4 truncates the main Viking sandbody at Joffre and is proposed to have truncated the first valley fill at Crystal. CM5 truncates the second valley fill and cuts out the proposed TSE1(CM4) at Crystal. CM5 is found at Joffre/Mikwan overlying CM4 or the CM4-CM5 facies.

REFERENCES

BERGMAN, K.M. AND WALKER, R.G., 1987, The importance of sea level fluctuations in the formation of linear conglomerate bodies: carrot creek member, Cretaceous Western Interior Seaway, Alberta, Canada: Journal of Sedimentary Petrology, v. 57, p. 651-665.

BERGMAN, K.M. AND WALKER R.G., 1988, Formation of Cardium erosion surface E5, and associated deposition of conglomerate; Carrot Creek field, Cretaceous Western Interior Seaway, Alberta, *in* James, D.P. and Leckie, D.A., Eds., Sequences, stratigraphy, sedimentology: surface and subsurface: Canadian Society of Petroleum Geologists, Memoir 15, p. 15-24.

BLOCH, J., SCHRODER-ADAMS, C., LECKIE, D.A., McINTYRE, D.J., CRAIG., J., AND STANILAND, M., 1993, Revised stratigraphy of the lower Colorado Group (Albian to Turonian), western Canada; Bulletin of Canadian Petroleum Geology, v. 41, p. 325-348.

BOREEN, T. AND WALKER, R.G., 1991, Definition of allomembers and their facies assemblages in the Viking Formation, Willesden Green area, Alberta: Bulletin of Canadian Petroleum Geology, v. 39, p. 123-144.

DAVIES, S.D. AND WALKER, R.G., 1993, Reservoir geometry influenced by high-frequency forced regressions within an overall transgression; Caroline and Garrington fields, Viking Formation (Lower Cretaceous), Alberta: Bulletin of Canadian Petroleum Geology, v. 41, p. 407-421.

DOWNING, K.P. AND WALKER, R.G., 1988, Viking Formation, Joffre field, Alberta: shoreface origin of long, narrow sand body encased in marine mudstones: American Association of Petroleum Geologists, Bulletin, v. 72, p. 1212-1228.

HEIN, F.J., DEAN, M.E., DEIURE, A.M., GRANT, S.K., ROBB, G.A. AND LONGSTAFFE, F.J., 1986, The Viking Formation in the Caroline, Garrington and Harmattan East fields, western south-central Alberta: sedimentology and paleogeography. Bulletin of Canadian Petroleum Geology, v. 34, p. 91-110.

LECKIE, D.A., 1986, Tidally influenced, transgressive shelf sediments in the Viking Formation, Caroline, Alberta. Bulletin of Canadian Petroleum Geology, v. 34, p. 111-125.

PATTISON, S.A.J., WALKER, R.G., 1994, Incision and Filling of a Lowstand Valley: Late Albian Viking Formation at Crystal, Alberta, Canada. Journal of Sedimentary Research, v. B64, n. 3, p. 365-379.

PEMBERTON, S.G., MACEACHERN, J.A., FREY, R.W., 1992, Trace Fossil Facies Models: Environmental and Allostratigraphic Significance, *in* Walker, R.D., and James, N.P., Facies Models: Response to Sea Level Change, p.47-72.

POWER, B.A., 1988, Coarsening-upwards shoreface and shelf sequences: examples from the Lower Cretaceous Viking Formation at Joarcam, Alberta, Canada, *in* James, D.P. and Leckie, D.A., eds., Sequences, stratigraphy, sedimentology: surface and subsurface: Canadian Society of Petroleum Geologists, Memoir 15, p. 185-194.

RADDYSH, H.K., 1988, Sedimentology and "geometry" of the Lower Cretaceous Viking Formation, Gilby A and B fields, Alberta, *in* James, D.P. and Leckie, D.A., eds., Sequences, stratigraphy, sedimentology: surface and subsurface: Canadian Society of Petroleum Geologists, Memoir 15, p. 417-429.

REINECK, H.E., WUNDERLICH, F., 1968, Classification and origin of flaser and lenticular bedding: Sedimentology , v. 11, p. 99-104.

REINSON, G.E., CLARK, J.E. AND FOSCOLOS, A.E., 1988, Reservoir geology of Crystal Viking field, Lower Cretaceous estuarine tidal channel - bay complex, south-central Alberta: American Association of Petroleum Geologists, Bulletin, v. 72, p. 1270-1294.

APPENDIX 1

Core Location	Core Interval	Recovery (meters)	Core Size (inches)
3-31-36-22W4	4563-4613 ft	14.5	3
7-20-36-23W4	1458-1478 m	18	4
7-29-36-23W4	4756-4816 ft	18.7	4
14-36-36-23W4	1402-1420 m	18.1	4
10-2-37-23W4	4537-4597 ft	16.4	4
10-8-37-23W4	4520-4580 ft	17.3	3
10-17-37-23W4	4560-4593 ft	9.93	3
7-20-37-23W4	4485-4589 ft	18.7	4
10-30-37-23W4	4455-4505 ft	15.7	3
7-1-37-24W4	4599-4649 ft	15.3	3
7-13-37-24W4	4498-4543 ft	13.9	3
11-24-37-24W4	4519-4499 ft	18.6	3
16-33-37-24W4	4552-4579 ft	7.5	3
11-33-37-24W4	4614-4664 ft	15.5	3
10-16-37-24W4	4715-4758 ft	11.8	3
4-14-37-24W4	4625-4671 ft	14.1	4