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SEDIMENTOLOGY AND STRATIGRAPHY OF THE LOWER CRETACEOUS VIKING FORMATION, CHIGWELL FIELD, ALBERTA, CANADA

SEDIMENTOLOGY AND STRATIGRAPHY OF THE LOWER CRETACEOUS VIKING FORMATION, CHIGWELL FIELD, ALBERTA, CANADA

By

Indraneel Raychaudhuri

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ABSTRACT

Ongoing regional studies of the Viking Formation (Upper Albian Stage, Lower Cretaceous) have revealed four regionally extensive erosional bounding surfaces within the interval. Examination of twenty-seven Viking cores from the Chigwell field allowed the nature of the erosional surfaces to be investigated. The examination of cores also permitted the sequences of sediments between the erosional bounding surfaces to be documented. Once documented in a series of well log and core cross sections, an attempt to interpret the nature and morphology of the erosional surfaces and the sediments they envelope was made.

The development of the erosion surfaces is problematic. It is suggested here that relative sea level fluctuations played a major role in the formation of both the erosion surfaces and the sediments found at Chigwell.

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This thesis is dedicated to the memory of Dwayne Pomeroy. May he rest in peace.

Finally, I'd like to thank whoever or whatever is responsible for the equations of chaos, for they allow there to be people who dream of lone hands and, more importantly, people who still don't know how to ride a bicycle.

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CHAPTER 1: INTRODUCTION AND STATEMENT OF THE PROBLEM

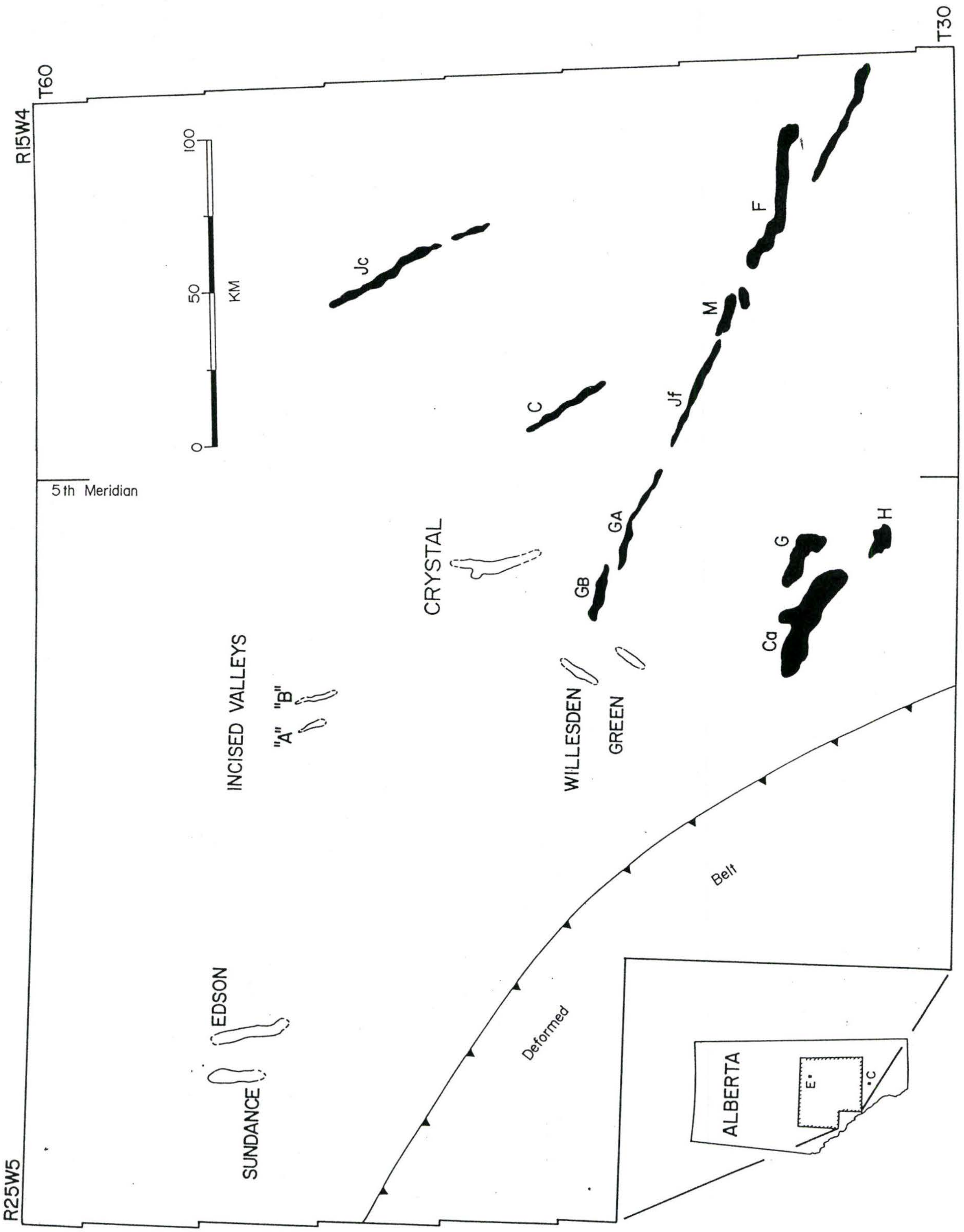
1.1 INTRODUCTION

This study was undertaken in order to contribute to the regional studies of shallow marine Viking sand bodies and their depositional histories ongoing at McMaster University. Many Cretaceous formations, such as the Cardium and the Viking, are oil and gas bearing in Alberta and so the depositional histories of the individual fields may prove to be useful in the exploration for further oil and gas reserves. This thesis will document the facies, stratigraphy, general sand body geometry, and sedimentology of the Viking field at Chigwell.

1.2 STATEMENT OF THE PROBLEM

This study was designed to link the Viking fields at Joarcam and Joffre. Chigwell is the only area with plentiful Viking cores that lies between Joarcam and Joffre (Fig. 1.1). In addition, Chigwell has a long, linear morphology and trend roughly paralleling those of Joarcam and Joffre. The origin of these long, linear shallow marine sand bodies has proven to be problematic and their development as either offshore, or shoreline attached bodies has been thoroughly debated in recent literature (Downing and Walker, 1988; Leckie, 1986;

Figure 1.1 The location of the major Viking oil and gas fields relevant to this study. Note the long, linear nature of Joarcam (Jc), Chigwell (C), Joffre (Jf), Gilby B (GB), Gilby A (GA), Fenn (F) and Mikwan (M). Also note Caroline (Ca), Garrington (G), Harmattan (H) as well as the locations of Edmonton (E) and Calgary (C) on the map of Alberta.


R15W4
T60
T30
R25W5
0
50
100
KM
5th Meridian
Jc
C
Jf
M
F
GA
GB
G
H
Ca
CRYSTAL
INCISED VALLEYS
"A"
"B"
WILLESDEN
GREEN
EDSON
SUNDANCE
Deformed
Belt
ALBERTA
E
C

Beaumont, 1984). Work at Joarcam (Power, 1986) has suggested a progradational shoreface interpretation, whereas Downing and Walker (1988) have interpreted Joffre as an incised shoreface deposit. Chigwell therefore links Joarcam and Joffre in both a stratigraphic and depositional context.

CHAPTER 2: VIKING STRATIGRAPHY AND STUDY METHODS

2.1 STRATIGRAPHY

The Viking Formation was deposited in the late Albian Stage of the Lower Cretaceous. In the Chigwell area (Figs. 1.1 and 2.1), the Viking is a marine sandstone both underlain and overlain by marine shales (Fig. 2.2). The average thickness of the Viking interval at Chigwell is approximately 30 metres. The Viking Formation of the Central Alberta Plains is equivalent to the Bow Island Formation of Southern Alberta, the Paddy and Cadotte Members of the Peace River Group of Northwestern Alberta, the Pelican Formation of Northeastern Alberta as well as various units in the United States of America (Fig. 2.2).

2.1.1 VIKING ALLOSTRATIGRAPHY

At the present time, a Viking allostratigraphy is being developed. Recent regional mapping has revealed four erosional bounding surfaces within the Viking (A.D.Reynolds, pers.comm., 1989). The Viking erosion surfaces are more complicated than those defined for the Cardium Formation (Plint et al., 1986, 1987) because they cut into each other. Six allomembers have been recognized within the Viking (Fig. 2.3).

Figure 2.1 Location map of the Chigwell area log cross sections AA', BB', CC', DD', EE' and FF'. The locations of cores examined in the creation of core cross sections A, B, C, D, E and F are also shown.

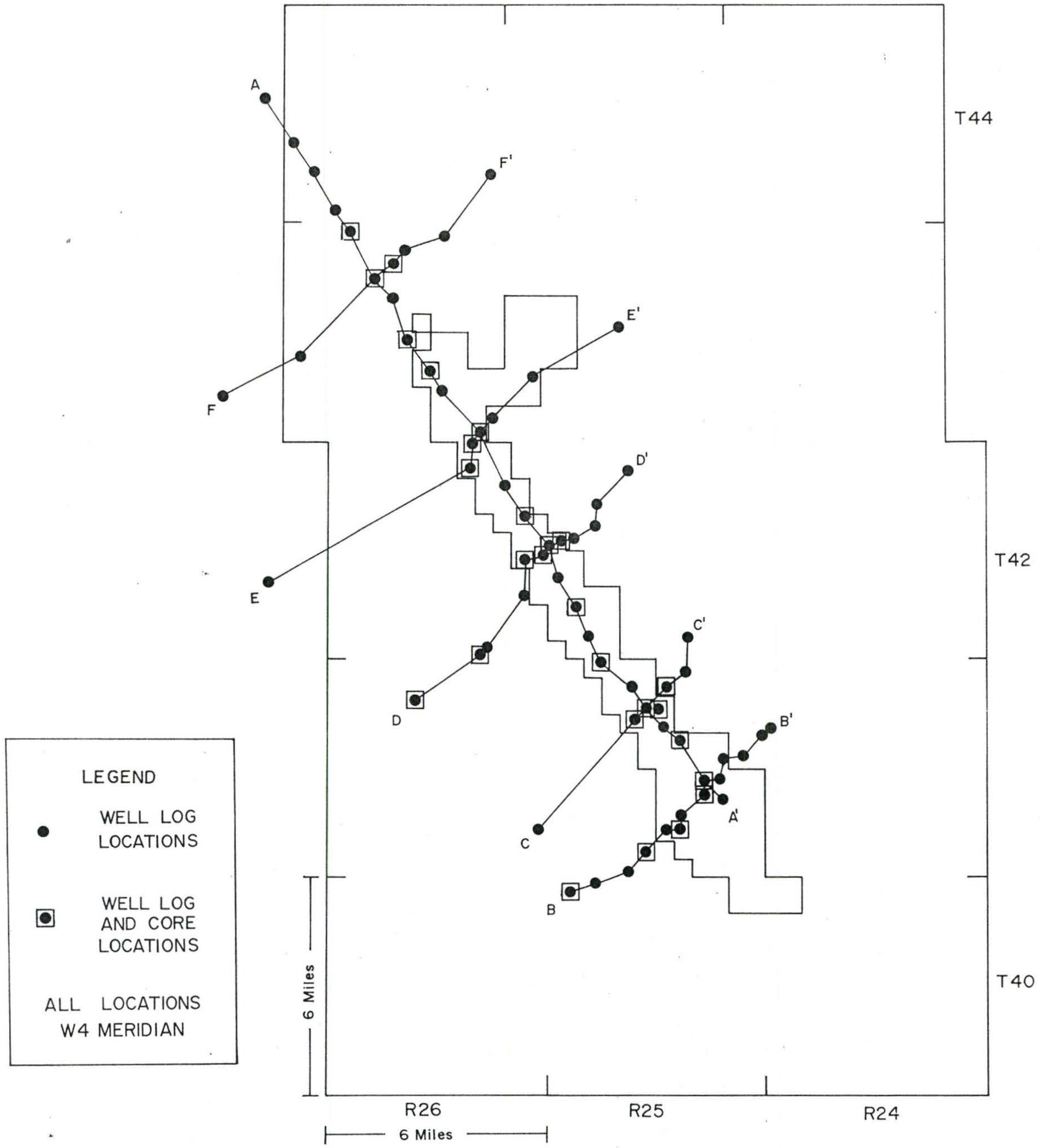
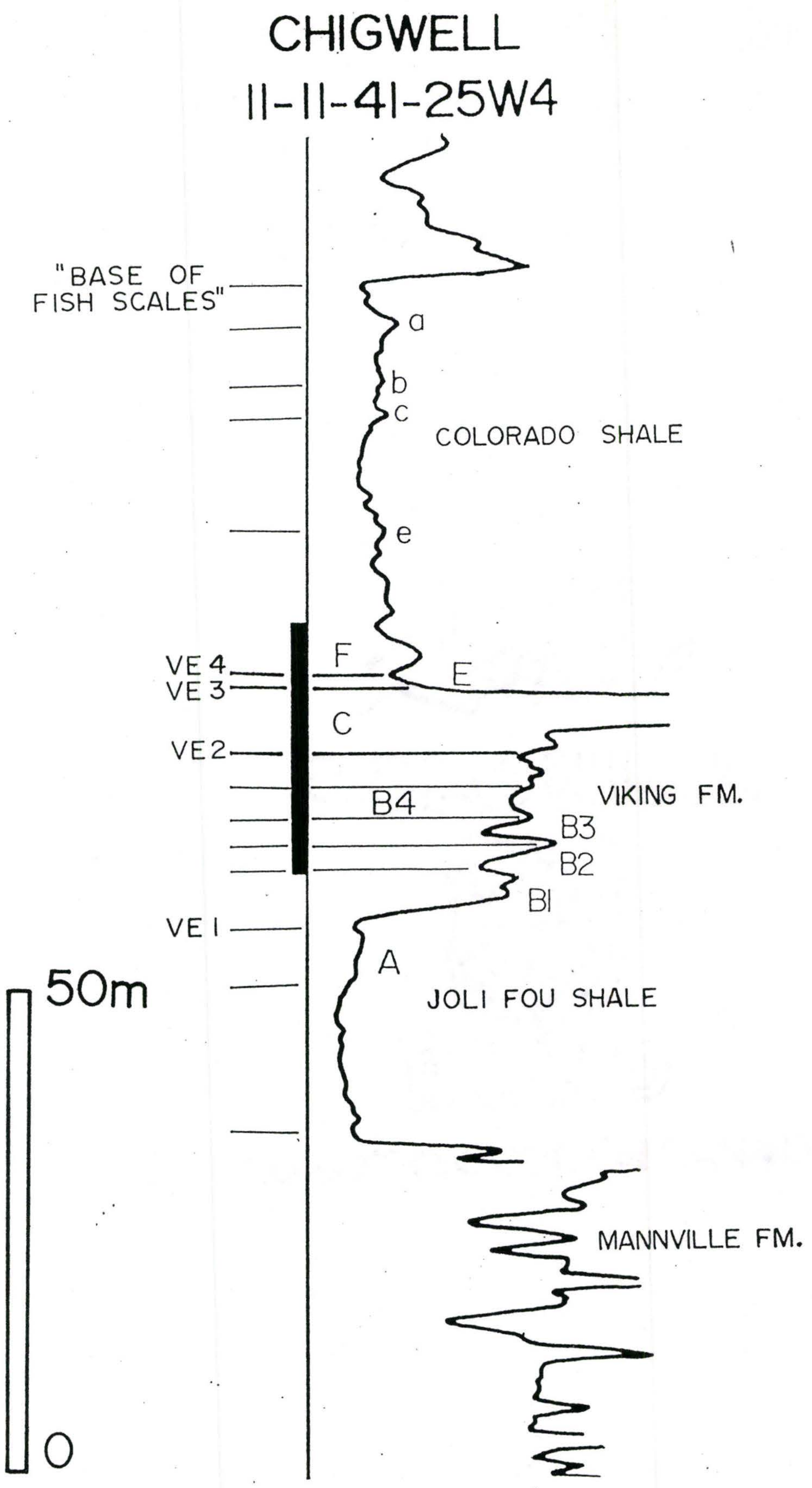

A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
T44
T42
T40
R26
R25
R24
6 Miles
6 Miles
LEGEND
WELL LOG LOCATIONS
WELL LOG AND CORE LOCATIONS
ALL LOCATIONS W4 MERIDIAN

Figure 2.2 Correlation of the lithostratigraphy and biostratigraphy (foraminiferal zones) of the Viking Formation in Central Alberta with Montana and Wyoming.

Absolute Age (MYA)	BIOSTRATIGRAPHY		LITHOSTRATIGRAPHY			
					EQUIVALENTS	
	STAGES	ZONES		CENTRAL ALTA.	MONTANA	WYOMING
	CENOMANIAN	*Textularia alcesensis*	COLORADO GROUP	BASAL FISH SCALES	MOWRY SHALE	MOWRY SHALE
96	ALBIAN	*Miliammina manitobensis*	COLORADO GROUP	COLORADO SHALE		SHELL CREEK FM.
	ALBIAN		COLORADO GROUP	VIKING FM.	NEWCASTLE SANDSTONE	MUDDY SANDSTONE
	ALBIAN	*Haplophragmoides gigas*	COLORADO GROUP	JOLI FOU SHALE	SKULL CREEK SHALE	THERMOPOLIS SHALE
108	ALBIAN	*Guadryina nanushukensis*	BLAIRMORE GROUP	MANNVILLE FM		

Figure 2.3 A typical resistivity well log response in the Chigwell area, showing erosion surfaces VE1, VE2, VE3 and VE4 as well as allomembers A to F, except for allomember D. The thick black line represents the cored interval. Note: The area between B4 and VE2 can be considered a continuation of the B4 cycle at Chigwell.


CHIGWELL
11-11-41-25W4
"BASE OF FISH SCALES"
a
b
c
COLORADO SHALE
e
F
VE 4
VE 3
E
C
VE2
B4
VIKING FM.
B3
B2
B1
VE 1
A
50m
JOLI FOU SHALE
MANNVILLE FM.
0

2.2 STRUCTURAL SETTING

There is a regional Viking dip to the southwest of approximately 0.5 degrees. Chigwell is located in Alberta's Central Plains and lies east of the Cordilleran deformed belt. The cores and well logs examined for this study show no evidence of structural disturbance (e.g. fault repetition of the Viking interval). Jones' (1980) structural cross sections show two main vertical faults at Joffre. They lie on either side of the field and trend parallel to the strike at Joffre. Jones (1980) goes on to suggest that movements on these faults occurred during the early Carboniferous and between the Miocene and the recent; the movements therefore did not directly affect Viking deposition at Joffre. Jones' (1980) study area did not extend as far as Chigwell and so little is known for certain about the structure there.

2.3 PALAEOGEOGRAPHY

During the Cretaceous (late Albian Stage), the dominant features of Western Canada were the growing Western Cordillera and the Western Interior Seaway. The seaway is thought to have filled a shallow foreland basin that was closed at its southern end in the vicinity of northern Colorado. Beaumont's (1984) study, which concentrated on the Joarcam-Joffre area, suggested a minimum distance of two hundred miles (320 kilometres) to the nearest equivalent palaeoshoreline in the west. Hadley (pers.comm., 1989) observed signs of emergence (rooted zones, palaeosols) at Harmattan East; this places the nearest palaeoshoreline to allomember E at Chigwell approximately 150 kilometres southwest of Chigwell. The bentonitic horizons associated with the Viking sediments indicate periodic volcanic activity probably attributable to the tectonically active Western Cordillera.

2.4 STUDY METHODS

In the course of this study, twenty-seven cores were logged and approximately 150 resistivity and gamma ray well logs were examined. The well logs were used to generate six log cross sections and the cores were correlated with their well log responses and used to create six core cross sections (Fig. 2.1). In both cases, the datum used was the statigraphic well log marker "Base of Fish Scales". An isopach map for the "Base of Fish Scales" to VE2 interval was created using data from approximately 150 well logs. All well locations given in this thesis are located west of the fourth meridian unless otherwise noted. Detailed notes were made on sedimentary structures, grain sizes, sand proportion, nature of contacts and biological structures. Grain sizes were measured using a Can-Strat grain size card (e.g. vfL is lower very fine sand and cU is upper coarse sand) and a hand lens. Photographs of individual facies and series of core boxes were taken for several of the examined cores.

CHAPTER 3: FACIES DESCRIPTIONS

3.1 INTRODUCTION

Thirteen facies were recognized while logging core in the Core Research Centre of the Alberta Energy Resources Conservation Board. These facies were then grouped into eight to agree more closely with a regional facies scheme currently being developed at McMaster (A.D.Reynolds and J.J.Bartlett, pers.comm., 1989). The facies are differentiated by their characteristic lithologies, grain sizes, sedimentary structures, and biological (trace fossil) features.

3.2 FACIES 1: DARK MUDSTONE

This facies consists of black mudstone (Fig 3.1) and may contain rare millimetre scale silty streaks that are generally continuous across the width of the core. The only hint of bioturbation was given by the occasional discontinuity of the structureless streaks. No identifiable trace fossils were discernable.

Preliminary Interpretation: This facies was deposited in deep, quiet water in an offshore setting that was well below storm wave base.

3.3 FACIES 2: MUDDY SILTSTONE

The muddy siltstone facies (Fig. 3.2) is a homogeneous mixture of bioturbated silt and mud with 5 to 10% vfL-vfU sand, preserved in rare 1 to 2 cm sand beds that are often discontinuous due to bioturbation. The sand beds are generally sharp based, normally grade upwards and show hints of some undulatory lamination. The sand lenses created gives this facies a horizontally shredded appearance. Recognizable trace fossils include Planolites, Terebellina, and Helminthoida. There are also some sideritized patches up to 10 cm thick.

Preliminary Interpretation: This facies was also deposited in deep, quiet water in an offshore setting well below storm wave base.

3.4 FACIES 3: SANDY SILTSTONE

This facies is a thoroughly bioturbated mixture of silt, sand, and mud (Fig. 3.3). The sand is generally vfL-vfU in grain size and can be found in rare 1 to 3 cm thick preserved sand beds that display wavy/undulatory to parallel laminations. These beds are sharp based and normally grade upwards. The proportion of sand can vary from 10 to 35% which makes this facies paler in colour than facies 2. Facies 3 can also have a horizontally shredded appearance, but is normally a homogeneous dark grey colour. The homogeneity is due to the high intensity of bioturbation. There is a wide variety of trace fossils with the most common being Helminthoida, Terebellina, and Asterosoma. Other less common trace fossils include Planolites, Skolithos, Teichichnus, Zoophycos(?) and Palaeophycos(?). Helminthoida is by far the most plentiful trace fossil in this facies. Facies 3 is also sideritized in patches, from 8 to 20 cm thick (avg. 13 cm thick). Preliminary Interpretation: This facies was deposited in a low energy environment below storm wave base. The trace fossils indicate deposition in an outer shelf type environment.

3.5 FACIES 4: PALE SANDSTONE

The pale sandstone facies (Fig.3.4a, b, c) is a thoroughly bioturbated mixture of sand (vfU-fU), silt and mud. Sand generally makes up 30 to 95% of the facies, making this facies paler than facies 1, 2, or 3. The sand is commonly glauconitic. No bedding or sedimentary structures are preserved, due to the pervasive bioturbation. The muddy and silty streaks appear "wispy" in nature. The trace fossils visible in this facies include Terebellina, Planolites, Skolithos, Asterosoma, Teichichnus, Ophiomorpha, Zoophycos(?), Rosselia(?), Arenicolites(?), and Conichus conicus(?). Small subangular chert grains (1-6 mm with avg.

3.5mm), mud rip-ups (3mm), small fragments of organic material, sideritized rip-up clasts and some mU-cU grained sand are commonly scattered throughout this facies. The ripped-up material is generally found near the base of the facies.

Preliminary Interpretation: This facies was probably deposited in a shallow water, moderate energy to deep water, low energy environment. The abundant trace fauna (*Cruziana* ichnofacies) and high sand percentage probably favour a shallow water, moderate energy environment.

3.6 FACIES 5a: TANGENTIALLY CROSS BEDDED AND STRUCTURELESS SANDSTONES

This facies is essentially 100% sand and has a wide variety of grain sizes from mL-vcU/pebbly. The facies is predominantly cross bedded at angles close to or at the angle of repose. The toesets of the cross beds appear to fade out tangentially, and within any given cross bed set, the angle of cross bedding appears to increase upwards very slightly (Figs. 3.5a, b). The sand is commonly highly glauconitic, and the glauconite together with "coffee grounds" often lie on and accentuate the cross laminae in a cross bed set. The cross bed sets range in size from 3 to 20 cm with most being in the 7 to 12 cm range. The above range is of minimum set sizes because the tops and bottoms of the sets are usually

Figure 3.1 Facies 1 from 4-19-42-25 at 1362.5 m.

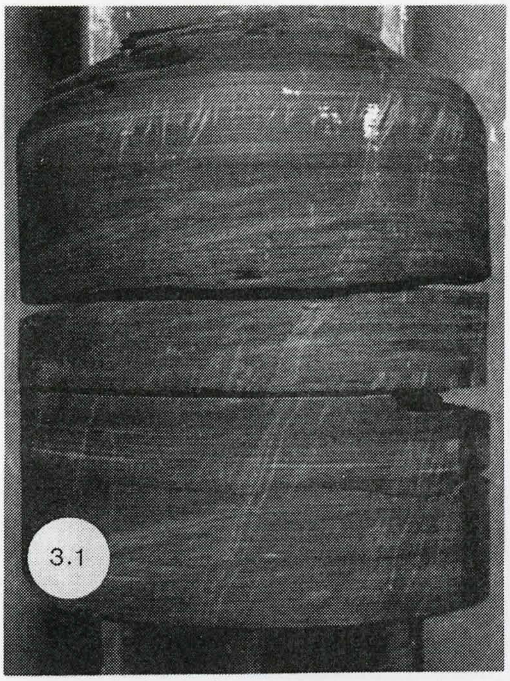
Figure 3.2 Facies 2 from 7-6-42-7W5 (Willesden Green) at 2286 m.

Figure 3.3 Facies 3 from 4-19-42-25 at 1380 m. Note *Helminthoida* (H).

Figure 3.4a Facies 4 from 10-28-41-25 at 1460 m. Note *Asterosoma* (A).

The scale bars are 3 cm in length.

The cores are approximately 3.5 inches wide.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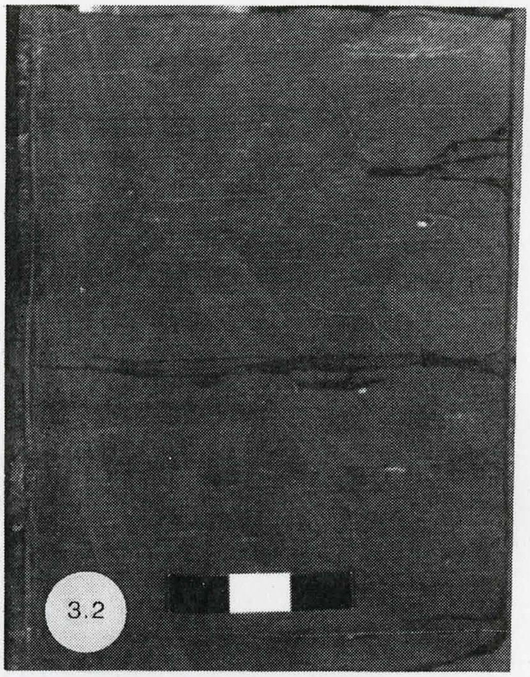
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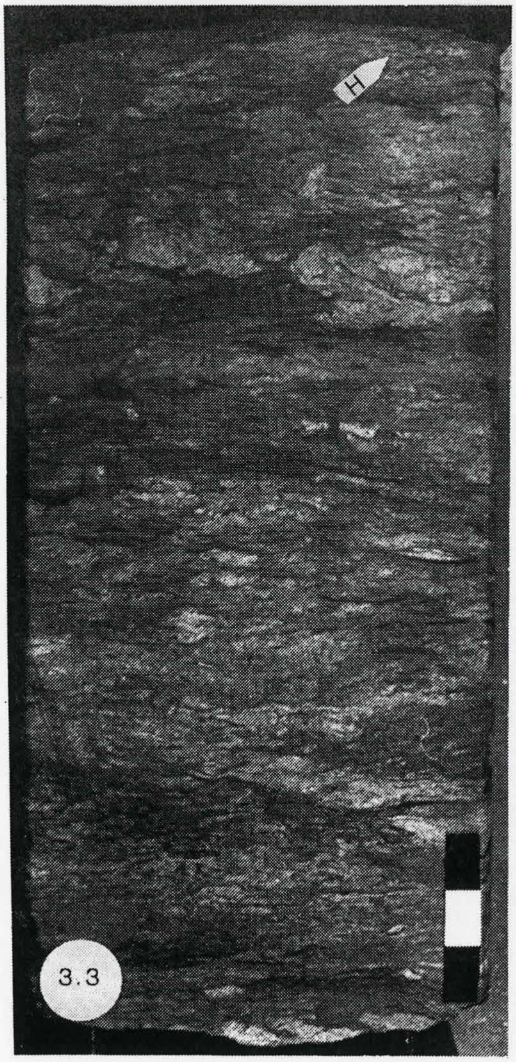
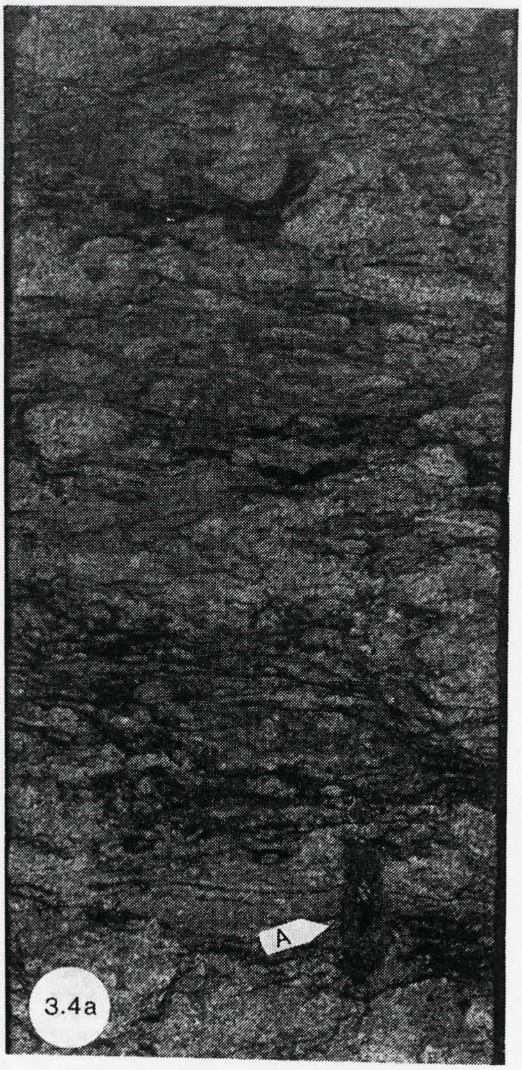

H
3.3


A
3.4a

unclear. The cross bed sets are draped rarely by 0.5 to 1.0 cm jet black mud beds that may or may not contain Planolites. These black mud beds can be discontinuous on the scale of the core. Throughout this facies, occasional black organic material and sideritized rip-ups are found. In addition, 1 to 7 mm chert grains were observed randomly scattered throughout the facies.

Towards the coarser end of this facies (cU-vcU), the rock consists of either massive coarse grained sandstone (Fig. 3.5c) or cross bedded coarse grained sandstone (Fig. 3.5d). When apparently structureless, this variation of facies 5a very often has 2.5 to 7.0 mm pebbles and 3.0 to 6.5 cm siderite clasts scattered throughout it. The massive, structureless coarse grained sandstone can also be streakily sideritized. Rare Ophiomorpha traces that are observable in this facies were generally associated with the coarser grained sediment.

The cross bedded coarse grained sandstone is similar to most of facies 5a except that the cross beds are pebbly and mixed with vC sand and subangular chert grains (1-6 mm in diameter). The pebbles average 0.8-1.0 cm in diameter and are mostly well rounded chert pebbles. Cross bed set sizes average 5.0 to 7.0 cm (maximum 15 cm). Once again, the cross bed set sizes are minimum values. The nature and occurrence of siderite and black mud drapes are the same for this part of facies 5a as for the finer grained end of the facies. The

Figure 3.4b Facies 4 from 6-28-43-26 at 1412.5 m. Note *Terebellina* (T).

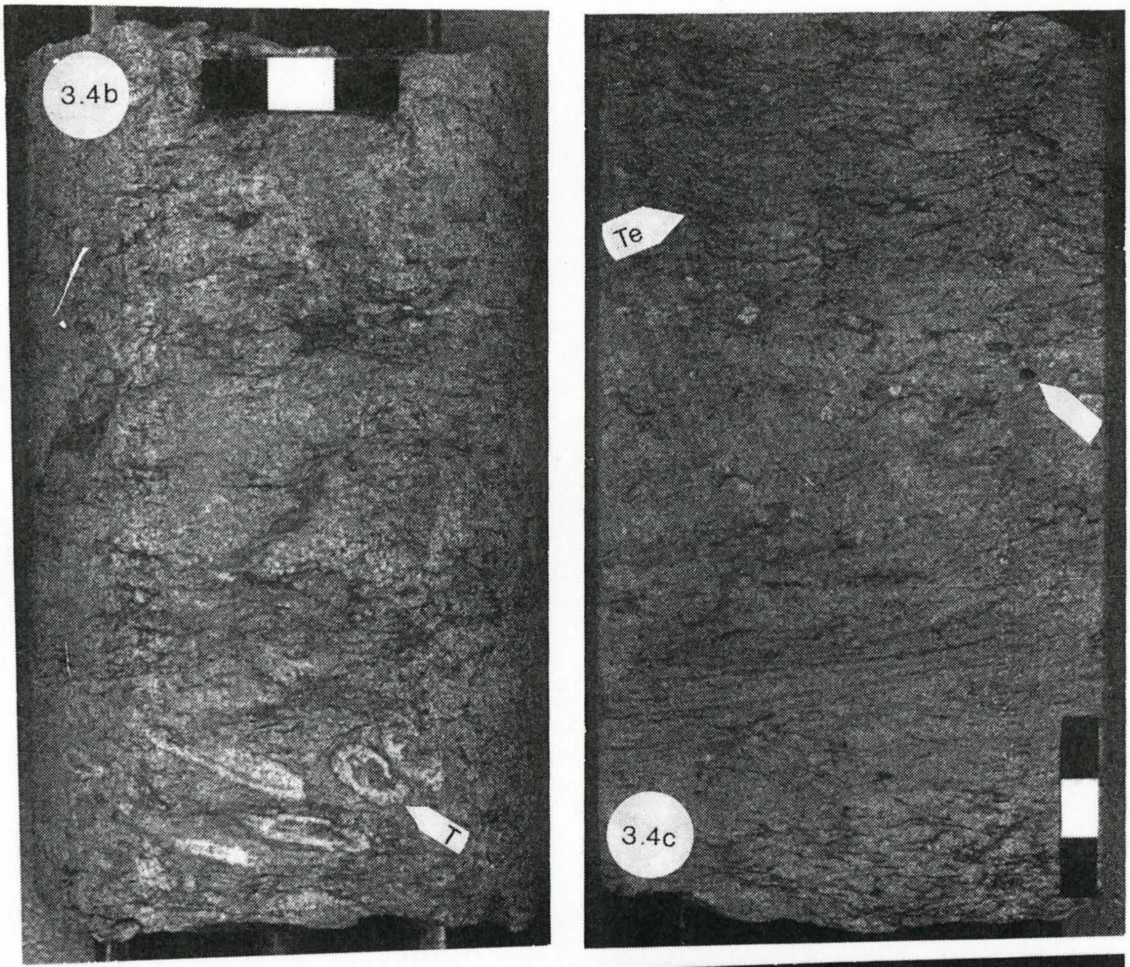
Figure 3.4c Facies 4 from 4-19-42-25 at 1374.5 m. Note *Teichichnus* (Te) and rounded black chert granule (arrow).

Figure 3.5a Facies 5a from 4-19-42-25 at 1370.5 m.

Figure 3.5b Facies 5a from 10-28-41-25 at 1458 m. Note the increasing angle upwards below the siderite rip-up (Sd) and the glauconite (G).

The scale bars are 3 cm in length.

The cores are approximately 3.5 inches wide.


3.4b
T
Te
3.4c

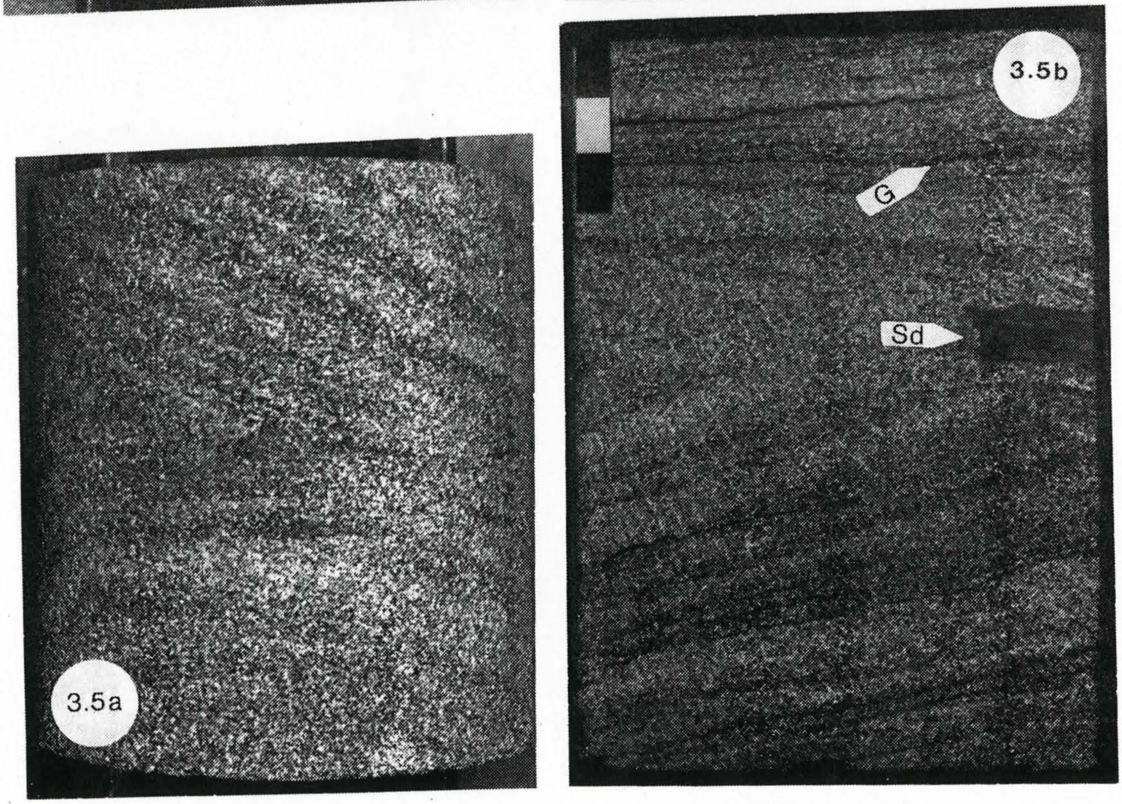

3.5b
G
Sd
3.5a

Figure 3.5c Facies 5a from 16-13-42-26 at 1374 m. Note the massive granular nature with pebbles and sideritized clasts (Sd).

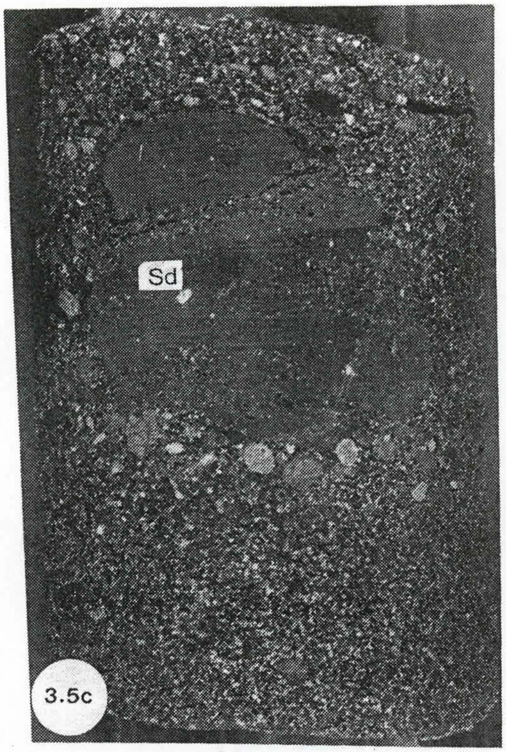
Figure 3.5d Facies 5a from 10-28-41-25 at 1456 m.

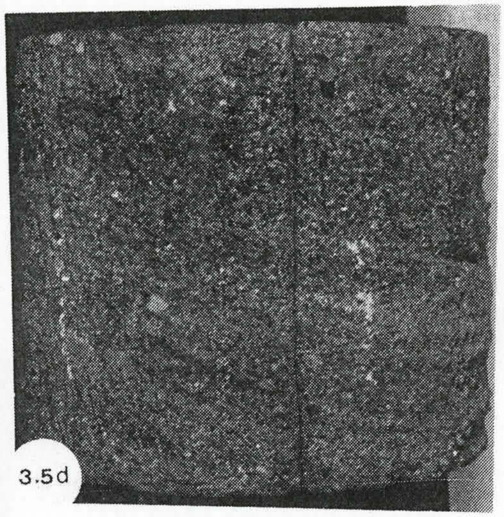
Figure 3.6 Facies 6c from 4-19-42-25 at 1368.9 m. Note sideritized clast (Sd) and sharp upper contact into Facies 7a.

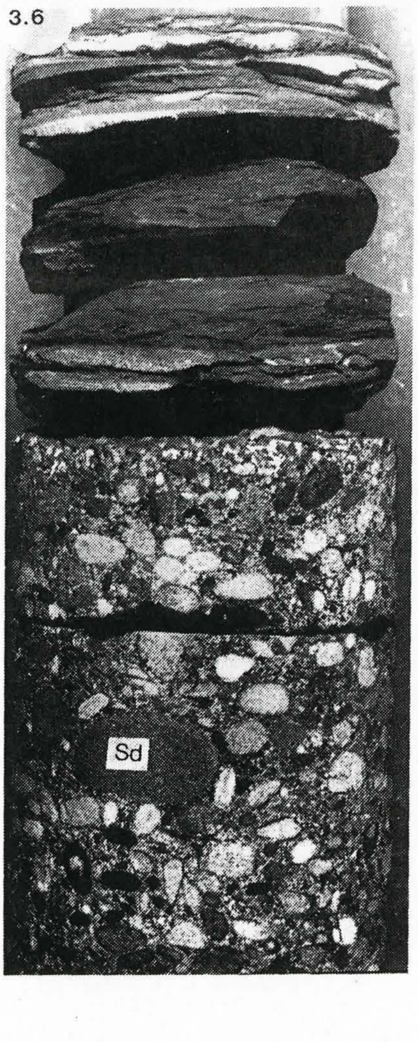
Figure 3.7a Facies 7a from 6-28-43-26 at 1409.2 m. Note the moderate bioturbation.

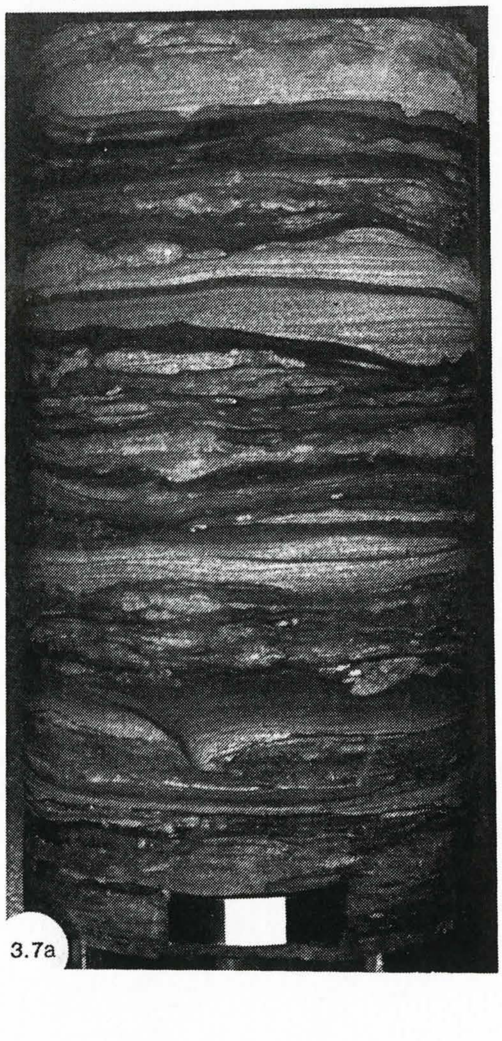
The scale bars are 3 cm in length.

The cores are approximately 3.5 inches wide.


Sd
3.5c


3.5d


3.6
Sd


3.7a

black mud drapes are rare. Note: Facies 5b and 5c are not found at Chigwell.

Preliminary Interpretation: This facies was deposited in an environment where unidirectional currents were strong enough to allow the creation of trough cross bed sets (moderate to high energy, constant water activity). The depositional environment is one in which no mud is being deposited and the sand is being cleaned up.

3.7 FACIES 6c: MASSIVE PEBBLY CONGLOMERATE

This facies (Fig. 3.6) is made dominantly of well rounded chert pebbles that range in size from 0.8 mm to 35 mm (average 12 mm) in diameter. Some of the conglomerate is clast supported but most of this facies is matrix supported. The matrix is usually cL-cU, gritty, subangular sand (range mL-vC). The conglomerate is poorly sorted and occurs in thicknesses from 1 to 30 cm (avg. is 10-12 cm). Rare sand rip-ups and siderite rip-up clasts are found in this facies. The siderite rip-ups are generally well rounded and range in size from 2.4 to 7.3 cm in diameter. Note: Facies 6a and 6b are not present at Chigwell.

Preliminary Interpretation: Based solely on the facies itself, one could not give an interpretation of this facies since it has no visible features characteristic of a certain depositional environment. Facies 6c must be dealt with in the context of its surrounding facies and bounding surfaces.

3.8 FACIES 7a: FINE GRAINED BURROWED LAMINATED MUDSTONE AND SILTSTONE

The fine grained burrowed laminated facies (Figs. 3.7a, b) is composed of mudstone, siltstone and sandstone (vfL-vfU) interbedded on a centimetre scale. The beds range in thickness from 0.5 to 6.0 cm. The interbedding is almost always discernable with the sand beds being quasi-continuous on the scale of the core. The sand beds are sharp based and normally grade up into darker mudstone. The sand beds show undulatory to parallel laminations. This facies is normally moderately bioturbated although in some of the examined cores, facies 7a appears only slightly bioturbated. The recognizable trace fossils include Skolithos, Teichichnus, Planolites, Arenicolites, Terebellina, and Zoophycos. The top and basal 10 cm of the facies commonly contain vC-pebbly sandstone "stringers" (avg. 0.8-1.0 cm thick) and are marked by Skolithos and/or Arenicolites. Some 6 to 10 cm thick sideritized patches are commonly found near the upper contact of the facies. In addition, 1 to 5 cm thick bentonite beds are commonly associated with this facies.

Preliminary Interpretation: This facies was probably deposited episodically from a series of waning storm flows. There is a background deposition of deep, quiet water

Figure 3.7b Facies 7a from 16-32-43-26 at 1413 m. Note the minimal bioturbation, sharp based beds and normal colour grading.

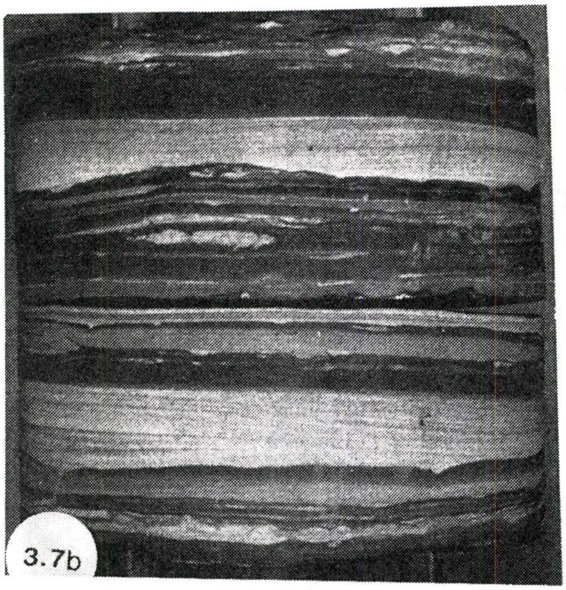
Figure 3.8a Facies 7b from 12-27-41-25 at 1441.8 m. Note the "salt and pepper" appearance of the sand.

Figure 3.8b Facies 7b from 4-19-42-25 at 1365.8 m. Note chert pebble (arrow), Skolithos (Sk), Terebellina (T), and lense of black organic material (OM).

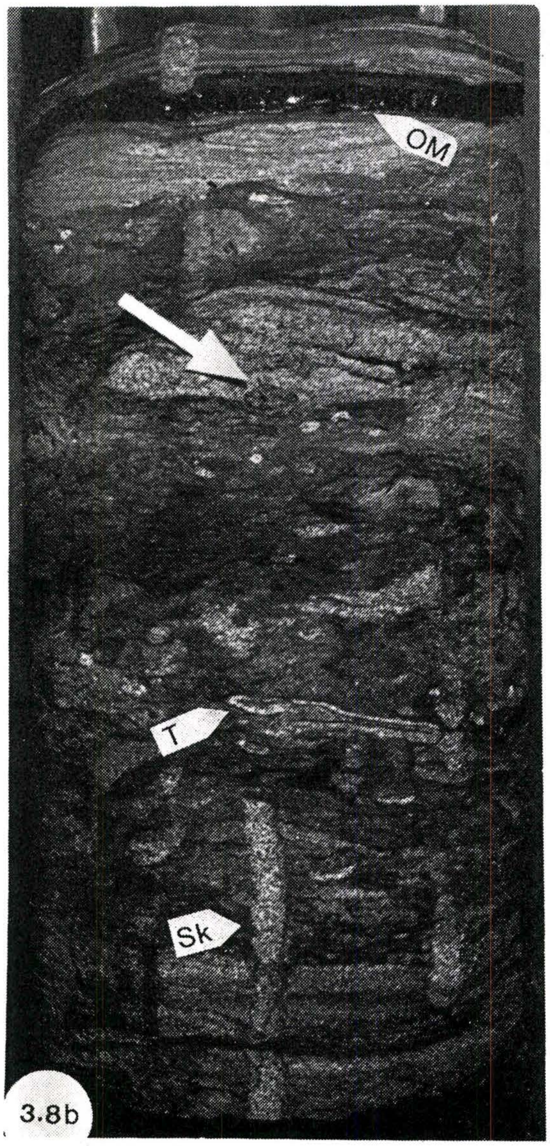
Figure 3.8c Facies 7b from 14-15-43-26 at 1422.5 m. Note the characteristic "dumbell" shaped cross section of Arenicolites.

The scale bars are 3 cm in length.

The cores are approximately 3.5 inches wide.


3.7b


3.8a


OM
T
Sk
3.8b


3.8c

offshore muds into which the waning storm beds intruded.

3.9 FACIES 7b: COARSE GRAINED BURROWED LAMINATED MUDSTONE AND SILTSTONE

This facies is composed of mudstone, siltstone, and sandstone. It is similar in character to facies 7a but is much more variable. The basal portions of this facies are generally mL-cU, gritty, colour graded sand and mud with Arenicolites, Terebellina, and Skolithos (Figs. 3.8a, b, c). This portion is generally found in the basal 75 cm and is often overlain by 20 to 70 cm (average 30 cm) of homogeneous black siltstone. This black siltstone may directly overlie granules/pebbles (0.3- 1.4 cm with avg. 0.6 cm) that are often found at the base of this facies. The gritty, colour graded portion is thoroughly bioturbated, and 1 to 2 cm sand lenses can be associated with shiny black organic material, shale rip-ups (average 0.5 cm) and 0.5 to 0.9 cm chert grains and rock fragments. Throughout facies 7b, much of the sand has a characteristic black and white, "salt and pepper" appearance (Fig. 3.8a, d). Stratigraphically above this portion, the remainder of the facies fines upwards with the exception of four major features.

Rare 10 to 16 cm thick, mL-mU "salt and pepper" sand beds are observable (Fig. 3.8d). These sand beds can be cross bedded or appear structureless. Secondly, cross bedded to massive pebbly (0.7-1.0 cm) mU-cL sand beds can be seen. These beds average 8.0 to 10.0 cm in thickness and can contain 1.0 to 3.0 cm rock fragments, sideritized clasts (maximum 2.8 cm in diameter), and shale and black organic material rip-ups (Fig. 3.8e). The pebbles in these beds were mostly well rounded chert pebbles. Another feature of this facies is the occurence of rare 4.0 to 8.0 cm thick normally graded pebbly beds (Fig. 3.8f). These beds are generally 0.7 to 0.9 cm well rounded chert pebbles at their base, and they grade up all the way into mud. Finally, there are sharp based, vfL-fU silt/sand beds that range in thickness from 2.0 to 6.0 cm. The structures in these beds include parallel laminations, undulatory laminations (Fig. 3.8g), and current to combined flow laminations (Fig. 3.8h). In addition, rare <u>Planolites</u> traces are discernable. Facies 7b also occasionally contains 1.0 to 3.0 cm bentonite beds and 3.0 to 8.0 cm thick sideritized patches. <u>Note:</u> Facies 7c and 7d are not seen at Chigwell.

<u>Preliminary Interpretation:</u> This facies was deposited in a number of ways. The muds were probably deposited offshore in deep, quiet water. The presence of cross bedded sand beds indicates that offshore unidirectional current processes were active. The current/combined flow and graded bed features indicate that offshore deposition was taking place via waning storm flows.

Figure 3.8d Facies 7b from 12-27-41-25 at 1442.15 m. Note "salt and pepper" sand and faint cross bedding.

Figure 3.8e Facies 7b from 12-27-41-25 at 1441.5 m. Note pebbly cross beds.

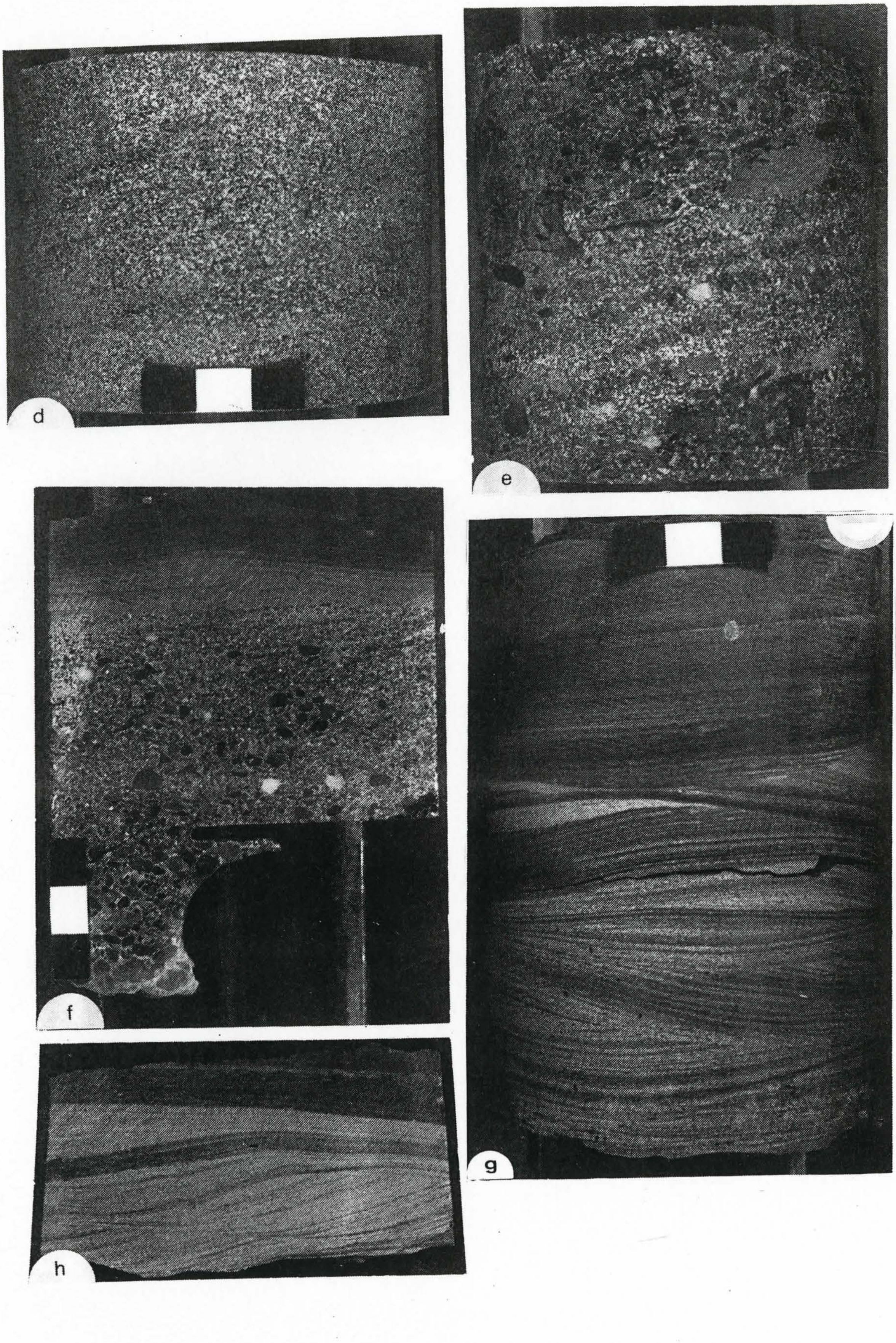
Figure 3.8f Facies 7b from 6-28-43-26 at 1406.5 m. Graded pebble bed.

Figure 3.8g Facies 7b from 6-28-43-26 at 1405 m. Undulatory laminations.

Figure 3.8h Facies 7b from 10-28-41-25 at 1445 m. Note the current lamination.

The scale bars are 3 cm in length.

The cores are approximately 3.5 inches wide.


d
e
f
g
h

CHAPTER 4: BOUNDING SURFACES, ALLOMEMBERS AND FACIES ASSOCIATIONS

4.1 INTRODUCTION

The Viking allomembers are bounded by four regionally extensive erosion surfaces: VE1, VE2, VE3 and VE4 (Fig. 2.3). The nature of the erosional contacts and the facies associations within the allomembers are discussed below.

4.2 VE1 BOUNDING SURFACE

VE1 was only observable in a few cores. When visible, VE1 is a sharp boundary that separates allomember A (below) from allomember B (above). Typically, VE1 is underlain by facies 2 and overlain sharply by facies 3. The base of allomember A is undefined at Chigwell but regional correlations show it to commonly be the base of the Viking Formation. The base of allomember A is considered to be VE1 in other Viking fields such as Willesden Green (T.Boreen, pers.comm., 1989). At Chigwell, however, the abrupt change considered to represent VE1 is at the top of allomember A (A.D.Reynolds, pers.comm., 1989).

4.3 ALLOMEMBER B

Allomember B is found directly overlying VE1. It is made up of four smaller cycles: B1, B2, B3 and B4 (Fig. 2.3). The smaller cycles represent four minor sanding upward cycles. These four cycles comprise what are commonly called the underlying "regional" Viking sequences. Between the B4 well log marker and VE2 (Fig. 2.3), there is a region that can be considered to be the upward continuation of cycle B4. Even where cored extensively, allomember B shows tenuous evidence of four discernable sanding upward cycles (Figs. 4.2, 4.3, 4.4). If the cycles are there, they are usually difficult to pick out with good consistency. The facies associated with this allomember are facies 3 and 4 (Figs. 3.3, 3.4a, b, c). Facies 3 is by far the more abundant of the two facies. Where facies 4 is encountered in the B cycles, it is usually either the muddier end member of the facies, or well homogenized, commonly with long (5-15 cm) *Skolithos* burrows. Allomember B is sharply truncated by VE2 (Figs. 2.3, 4.1a, b, 4.4).

4.4 VE2 BOUNDING SURFACE

The VE2 contact is usually characterized in core by a sharp colour and facies change (Figs. 4.1a, b, 4.4). VE2 is underlain by facies 3 and is directly overlain by facies 4 in all examined cores except one: 6-28-43-26 where VE2 is

Figure 4.1a VE2 contact from 6-28-43-26 at 1413.5m. Note the two chert pebbles (arrows).

Figure 4.1b VE2 contact from 12-27-41-25 at 1451m. Note the pebble (arrow) and the sharp change from facies 3 below the pebble to facies 4 above.

Figure 4.1c VE3 contact from 4-19-42-25 at 1369m. Note the sharp facies change, as well as the patchy sideritization just below the contact.

Figure 4.1d VE4 contact from 4-2-42-26 at 4722 feet. Note the sharp facies change and long <u>Skolithos</u> burrow at the contact.

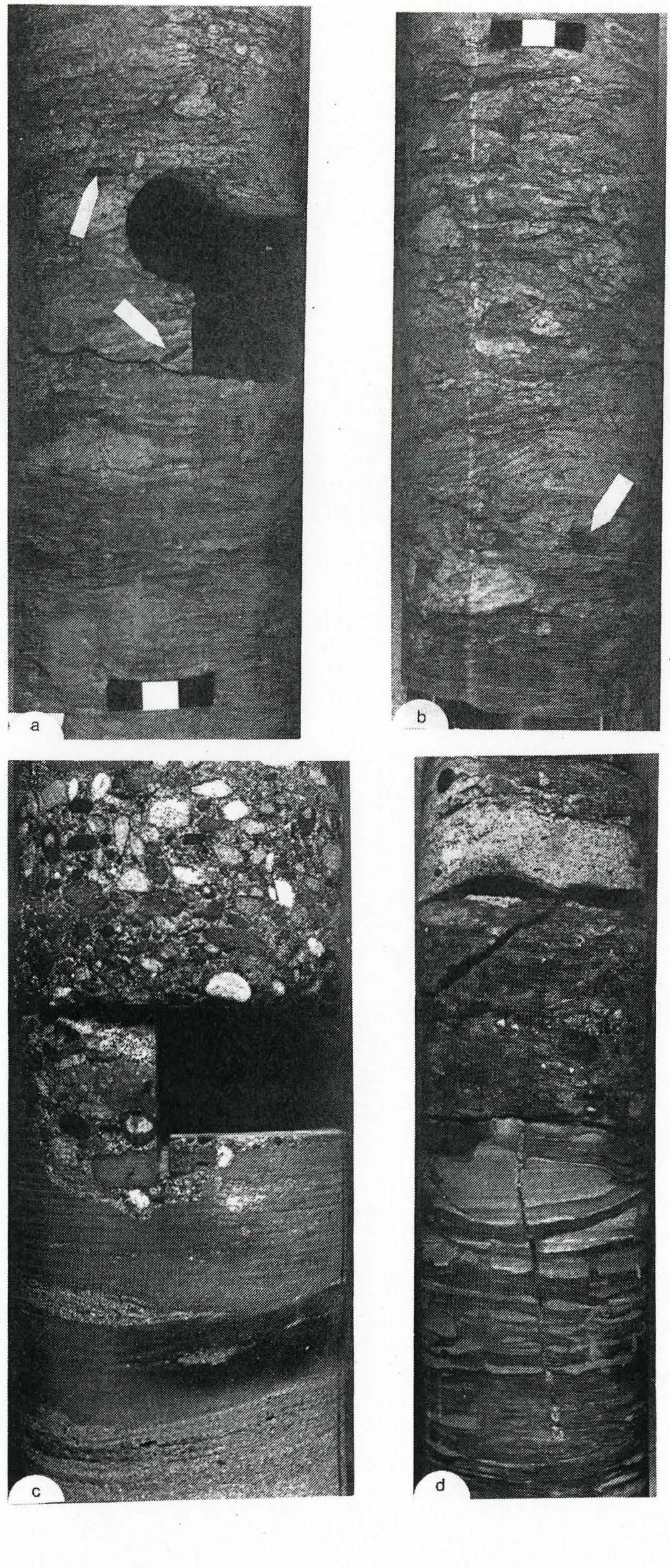

a
b
c
d

Figure 4.2 Core boxes from 6-34-41-25 (1461.89-1466.2m). The base of the core is in an allomember B sub-cycle. All core box photographs read stratigraphically upwards from bottom left to top right.

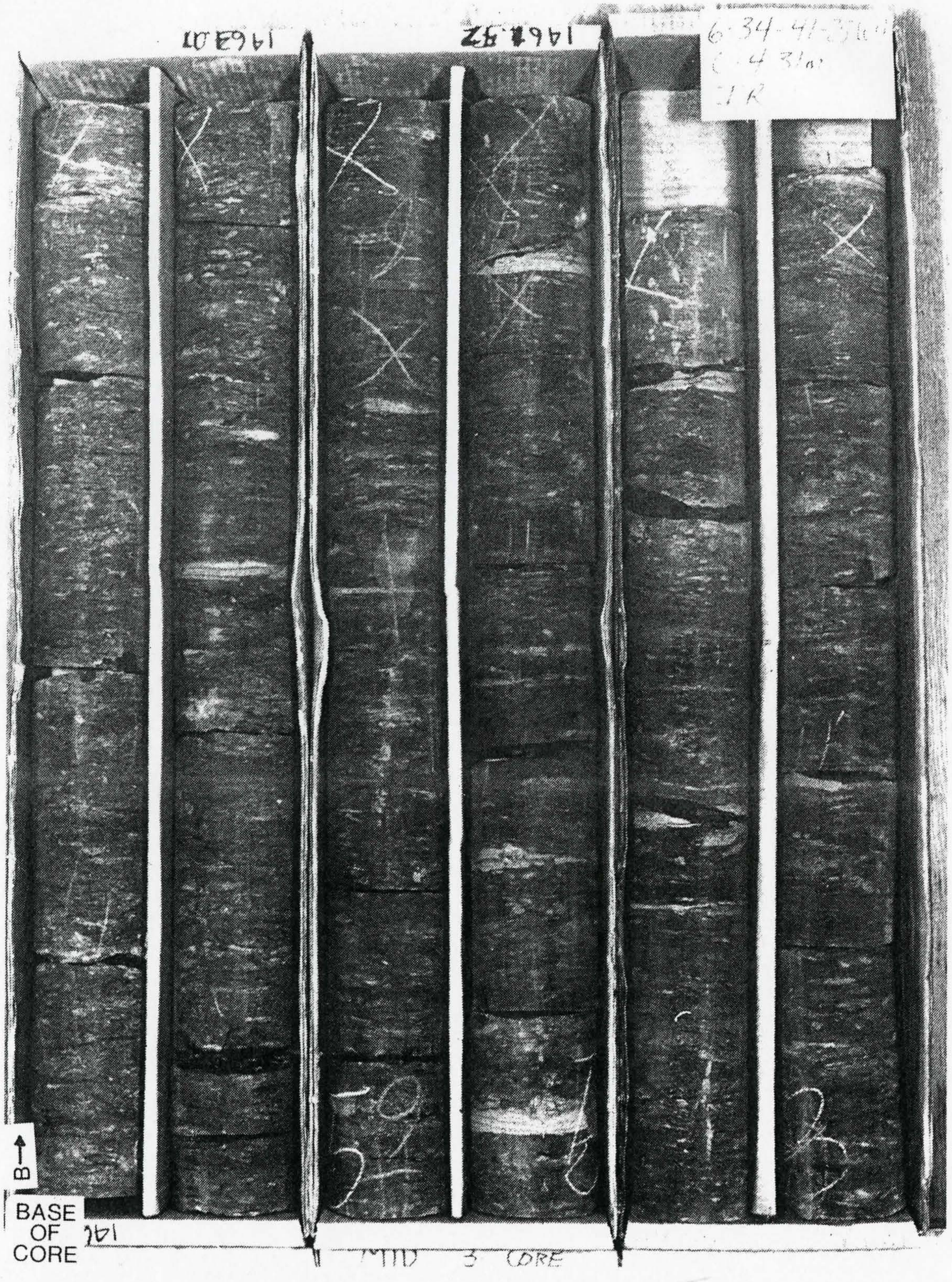
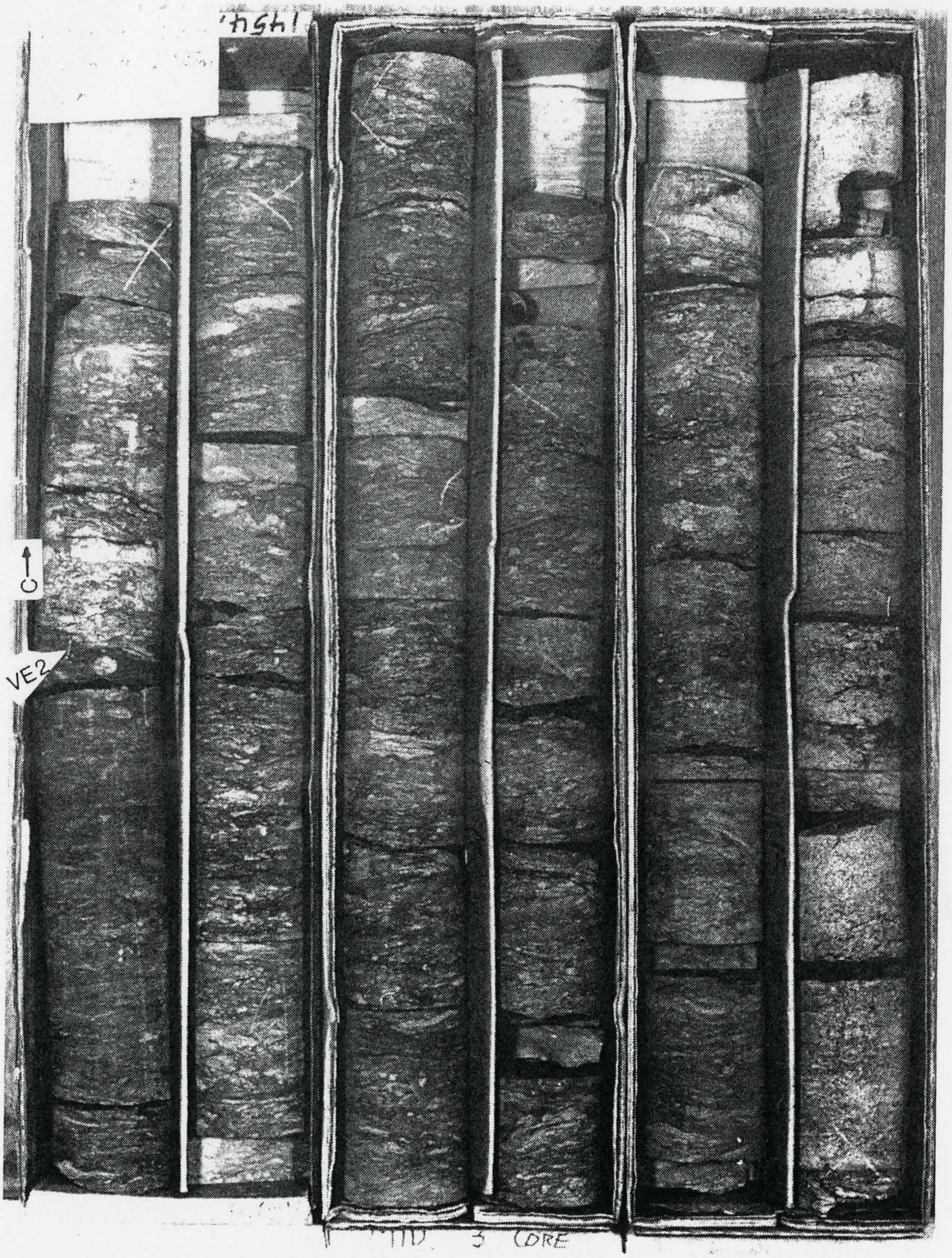

B
BASE
OF
CORE

Figure 4.3 Core boxes from 6-34-41-25 (1457.95-1461.89m). Continuation of underlying "regional" Viking sequences (allomember B).


1457.76
1456.33

Figure 4.4 Core boxes from 6-34-41-25 (1453.65-1457.95m). Note the razor sharp VE2 contact and the onset of allomember C.


C
VE2

directly overlain by facies 5a (10 cm cross bed set). The facies 4 rocks that overlie VE2 are somewhat different than those associated with allomember B in that they are mostly less homogeneous, sandier, and have a wider variety of trace fossils than those in allomember B (Fig. 3.4b, c). VE2 can have ripped up shale or organic material associated with it that can both be up to 6 cm long by 2 mm thick. VE2 can also have a few chert pebbles (1.0-2.2 cm) and/or angular to subangular chert grains (mL-vcL) on or near it (Figs. 4.1a, b). The VE2 contact can be burrowed by Arenicolites(?) (in 16-28-43-26), Rosselia (in 6-28-43-26), Skolithos (in 16-10-43-26, 16-32-43-26) or Planolites (in 6-34-41-25) (Fig. 4.4).

4.5 ALLOMEMBER C

Allomember C lies directly on VE2 (Figs. 2.3, 4.4) and this is where the main oil reservoir sands are stratigraphically situated. The facies association within allomember C consists of interbeds of facies 4 and facies 5a. There is a general trend of increasing grain size, percentage of sand and amounts of facies 5a upwards. That is, in a general sense, allomember C sands and/or coarsens and becomes more cross bedded upwards (Figs. 4.4, 4.5). Allomember C is approximately 4.0 to 5.0 metres thick and is truncated sharply at its top by VE3 (Fig. 4.5).

Figure 4.5 Core boxes from 6-34-41-25 (1449.72-1453.65m). Note the VE3 contact, allomember E, VE4 and the beginning of allomember F. Also note that "b" stands for bentonite and "s" represents siderite.

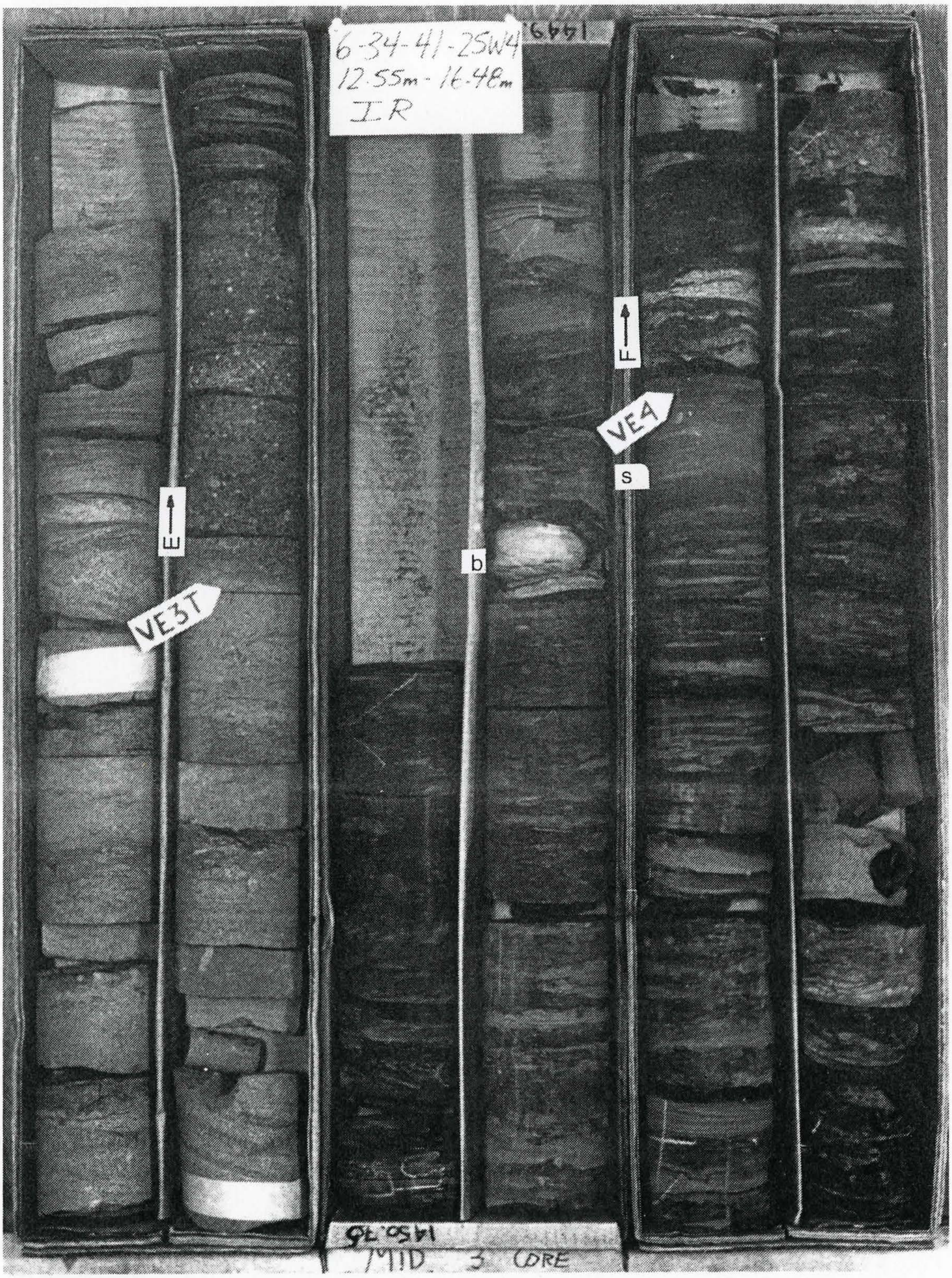
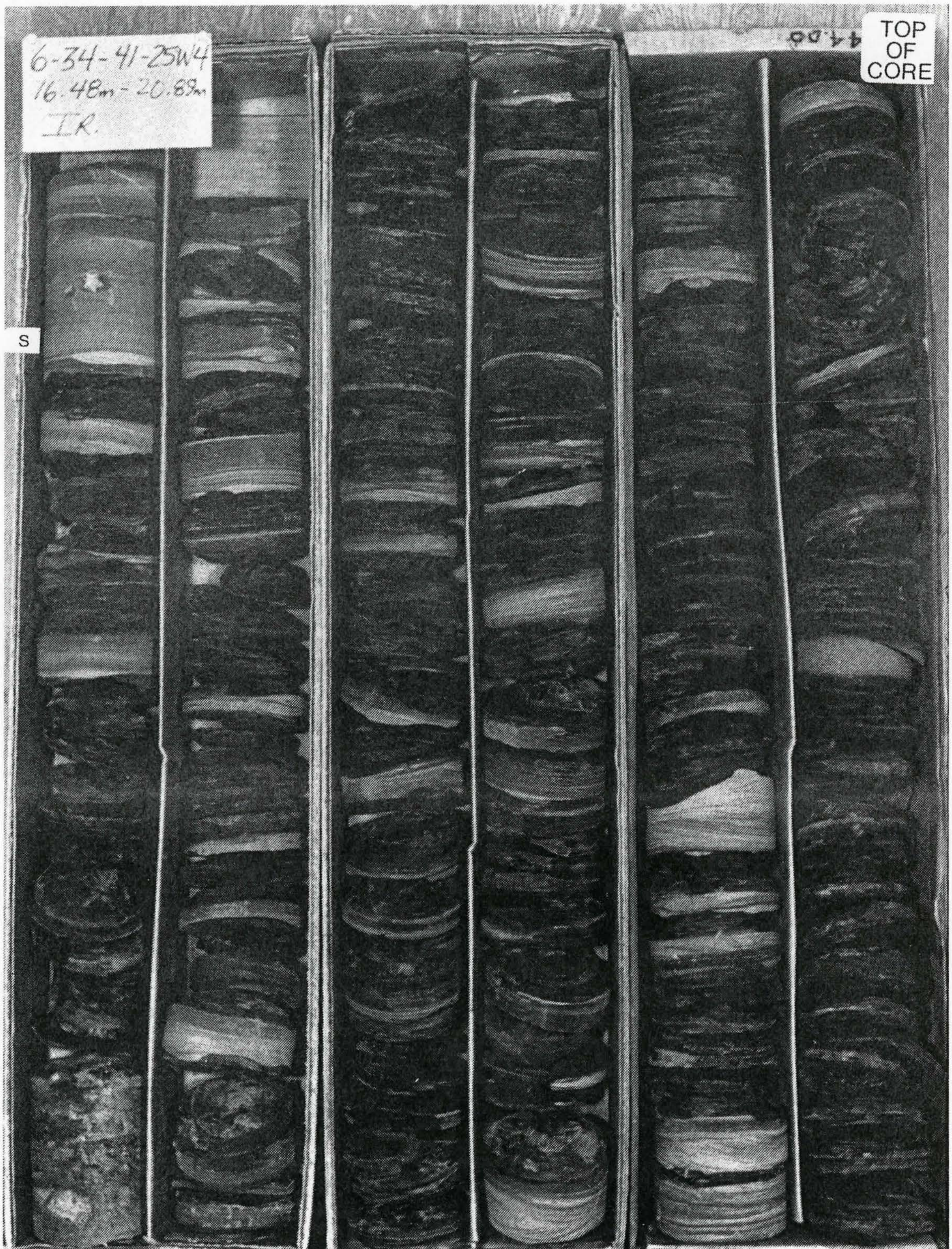

6-34-41-25W4
12.55m - 16.48m
IR
VE3T
VE4
b
s
E
F
MID 3 CORE

Figure 4.6 Core boxes from 6-34-41-25 (1445.31-1449.72m). Continuation of allomember F. Note that there are fewer and finer sand beds upwards.


6-34-41-25W4
16.48m-20.89m
I.R.
TOP
OF
CORE
S
MID 5 CORE

4.6 VE3 BOUNDING SURFACE

The VE3 contact is characterized in core by a sharp facies change from facies 4 or 5 below, to facies 6c above (Fig. 4.1c, 4.5). Sideritized patches commonly occur just below VE3 (Figs. 4.1c, 4.7) and there are rare VE3 contacts burrowed with Skolithos burrows. There is a possible escape burrow at the VE3 contact in 6-19-42-25. The bioturbation at VE3 commonly results in pebbles and coarse material being found up to 10 cm below the actual VE3 contact.

4.7 ALLOMEMBER E

Allomember E overlies VE3 (Fig. 2.3) and has two facies associated with it: facies 6c and facies 7a (Fig. 4.5). Facies 6c always directly overlies VE3 although in a few rare cases, there is only a thin veneer of facies 6c. Usually there is between 10 and 30 cm of facies 6c that lie directly on VE3. Facies 7a makes up the bulk of allomember E; the allomember can range in thickness from approximately 15 centimetres to 2 metres. Allomember E is sharply truncated by the VE4 surface (Figs. 4.5, 4.7, 4.8). NOTE: Allomember D (channelized) is not present at Chigwell.

Figure 4.7 Core boxes from 4-19-42-25 (1366.1-1370.5m). Note the VE3 and VE4 surfaces.


4-19-42-25W4
11.43m to 15.82m
IR
VE3T
VE4

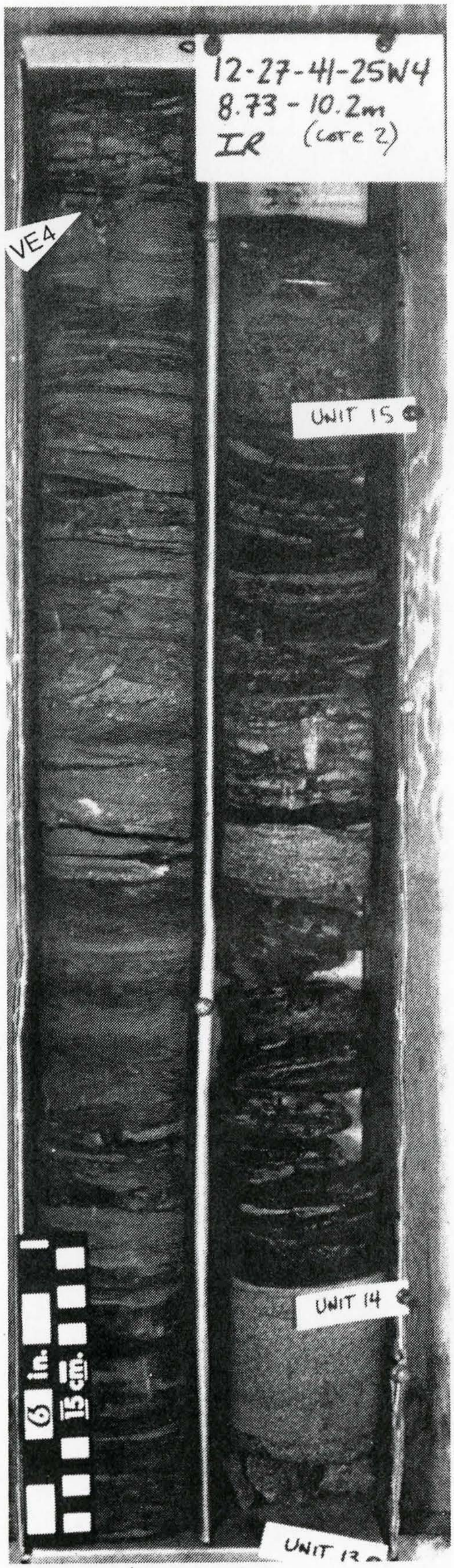
4.8 VE4 BOUNDING SURFACE

The VE4 bounding surface can be recognized in core by the sharp facies change that accompanies it. Facies 7a is found below VE4 and facies 7b occurs above VE4 (Figs. 4.1d, 4.5, 4.7, 4.8). Patches of sideritization are usually observable up to 10 cm below VE4. Most VE4 contacts display spectacular *Skolithos* and/or *Arenicolites* burrows (Figs. 4.1d, 4.8). In addition, VE4 contacts are frequently overlain by a thoroughly churned mixture of subangular to angular mL-cU sand, 3-10 mm diameter rock fragments and/or well rounded, 0.5-1.0 cm chert pebbles (Fig. 4.1d).

4.9 ALLOMEMBER F

Allomember F lies above VE4 (Fig. 2.3) and is associated with facies 7b, 2 and 1 (Fig. 2.3). This allomember tends to have fewer, thinner sand beds upwards (i.e. fining up) and normally grades up into facies 2 and more rarely into facies 1 (Figs. 4.5, 4.6, 4.8). The top of allomember F is undefined.

Figure 4.8 Core box from 12-27-41-25 (1441.5-1443m). Note the _Skolithos_ burrow at the VE4 contact and the gritty, "salt and pepper" nature of the sand in the basal 75cm of allomember F above it.

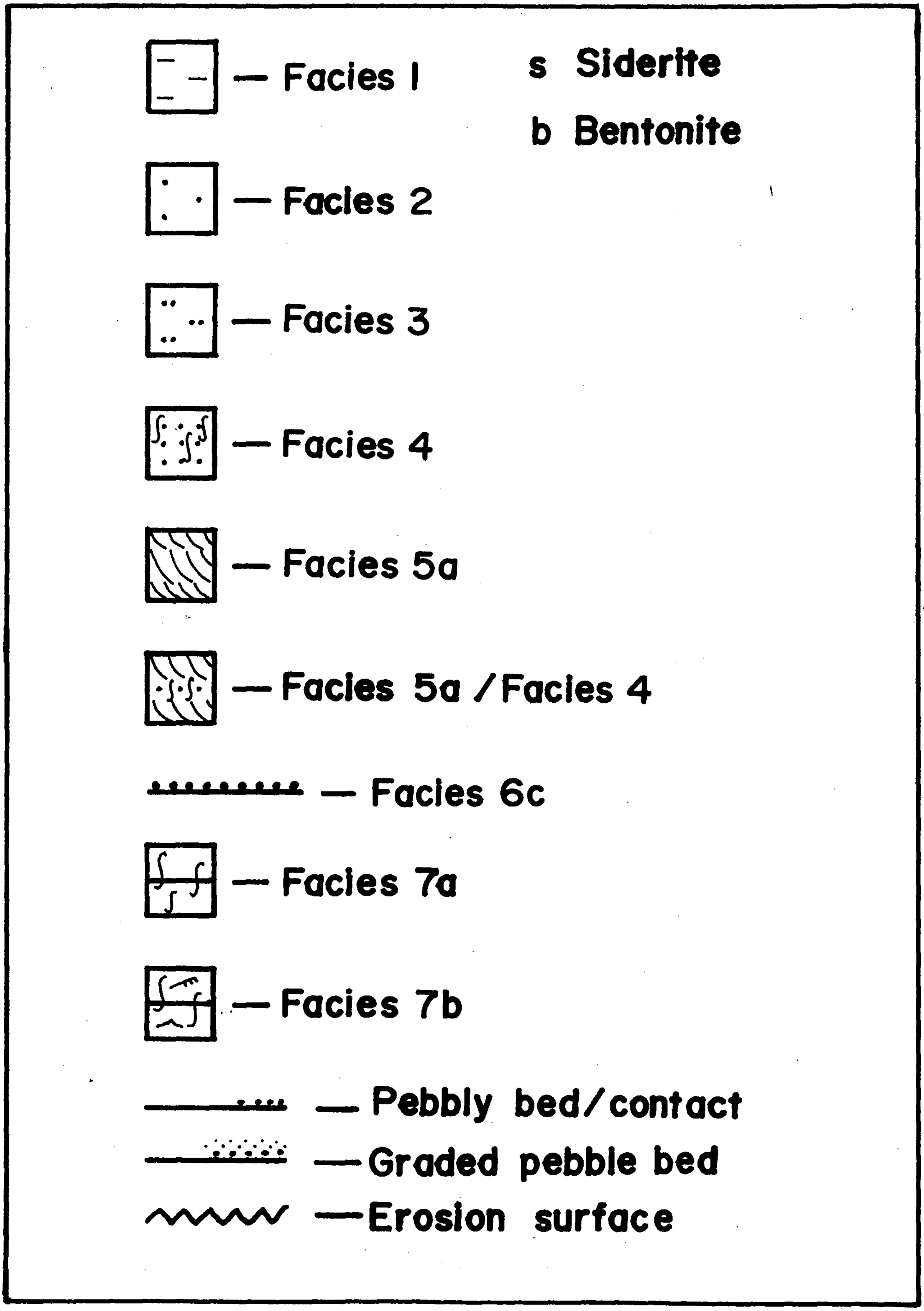

12-27-41-25W4
8.73 - 10.2m
IR (core 2)
VE4
UNIT 15
UNIT 14
UNIT 13
6 in.
15 cm.

CHAPTER 5: LOG AND CORE CROSS SECTIONS

5.1 INTRODUCTION

The log and core cross sections are located in figure 2.1 and presented below. The solid black bars on the log cross sections represent the cored intervals used in the creation of the core cross sections. If the scales are closely compared, the amounts of relief on the VE (Viking erosion) surfaces on the log cross sections are not exactly the same as those observable on the core cross sections. This is because of errors inherent in the well logs, which were printed from a number of different machines. This resulted in scale differences of plus or minus 6%. Therefore, the discrepancy in absolute amounts of relief between log and core cross sections is attributable to this uncorrected scaling error. The general legend (Fig. 5.1) applies to both log and core cross sections. Where erosion surfaces are correlated on the core cross sections in the absence of core control, the position of the erosion surfaces have been interpreted from the corresponding well logs. In addition, BFS stands for "Base of Fish Scales" on the log cross sections. The "Base of Fish Scales" well log marker is considered to be relatively flat. Other well log markers that lie between BFS and the Viking interval (Fig. 2.3) seem to follow the BFS correlation trend much more closely than

Figure 5.1 Legend for all the following log and core cross sections.


— Facies 1
s Siderite
b Bentonite
— Facies 2
— Facies 3
— Facies 4
— Facies 5a
— Facies 5a / Facies 4
— Facies 6c
— Facies 7a
— Facies 7b
— Pebbly bed/contact
— Graded pebble bed
— Erosion surface

the correlation trend of the VE surfaces. The important implication is that the VE surfaces are erosive and actually cut down into lower strata.

5.2 LOG CROSS SECTION AA' AND CORE CROSS SECTION A

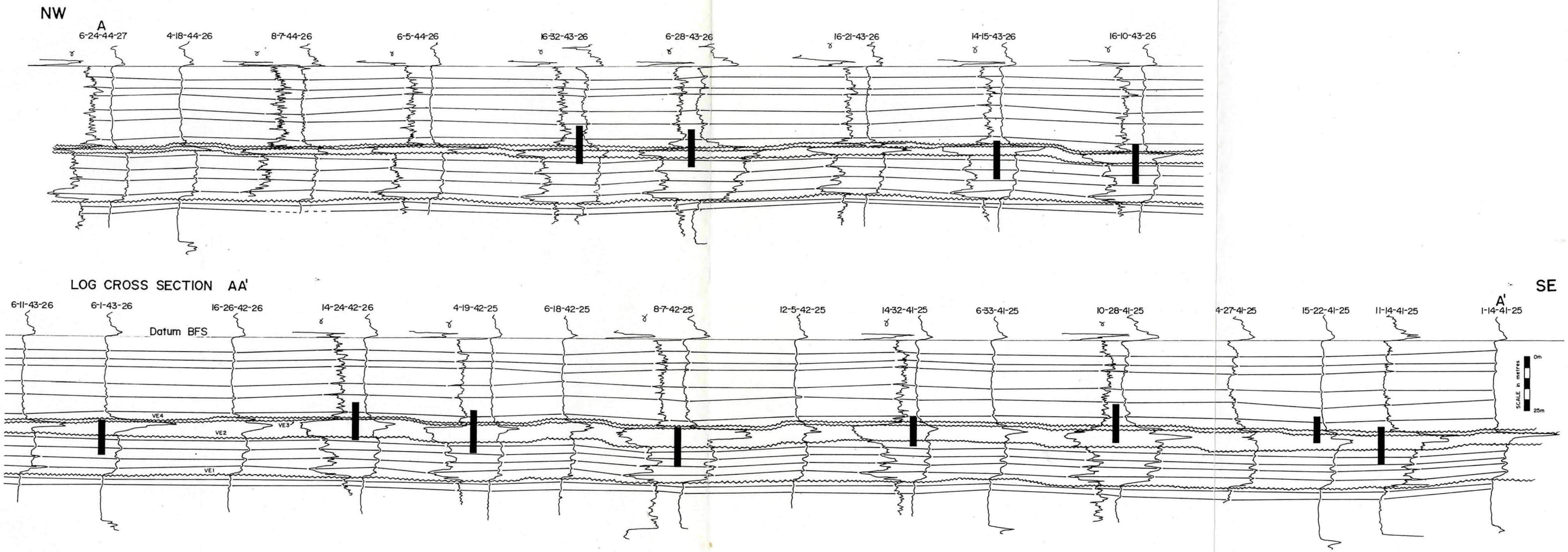
Log cross section AA' (Fig. 5.2) illustrates two main things: i) a progressive thinning of the VE2 to VE3 interval from southeast to northwest and ii) a progressive thickening of the VE1 to VE2 interval from southeast to northwest. VE2,3 and 4 mimic each other in that they tend to rise and fall as a group. VE1 usually mimics the other VE surfaces although to a quantitatively lesser extent. Core cross section A (Fig. 5.2a) also shows the progressive northwesterly thinning of the VE2 to VE3 interval. It also shows a thinning of the VE3 to VE4 interval between 6-28-43-26 and 14-15-43-26, and a thickening of the same interval between 8-7-42-25 and 14-32-41-25. Overall, both cross sections exhibit a stratigraphic drop of the Viking interval from northwest to southeast.

5.3 LOG CROSS SECTION BB' AND CORE CROSS SECTION B

Log cross section BB' (Fig. 5.3) and core cross section B (Fig. 5.3a) show the discontinuous nature of VE3. VE3 is not present in 10-31-40-25 but is definitely present in 6-14-41-

Figure 5.2   Log cross section AA'.

Figure 5.2a Core cross section A.


NW
A
6-24-44-27
4-18-44-26
8-7-44-26
6-5-44-26
16-32-43-26
6-28-43-26
16-21-43-26
14-15-43-26
16-10-43-26
LOG CROSS SECTION AA'
SE
6-11-43-26
6-1-43-26
16-26-42-26
14-24-42-26
4-19-42-25
6-18-42-25
8-7-42-25
12-5-42-25
14-32-41-25
6-33-41-25
10-28-41-25
4-27-41-25
15-22-41-25
11-14-41-25
A'
1-14-41-25
Datum BFS
VE4
VE3
VE2
VE1
SCALE in metres
0m
25m

CORE CROSS SECTION A

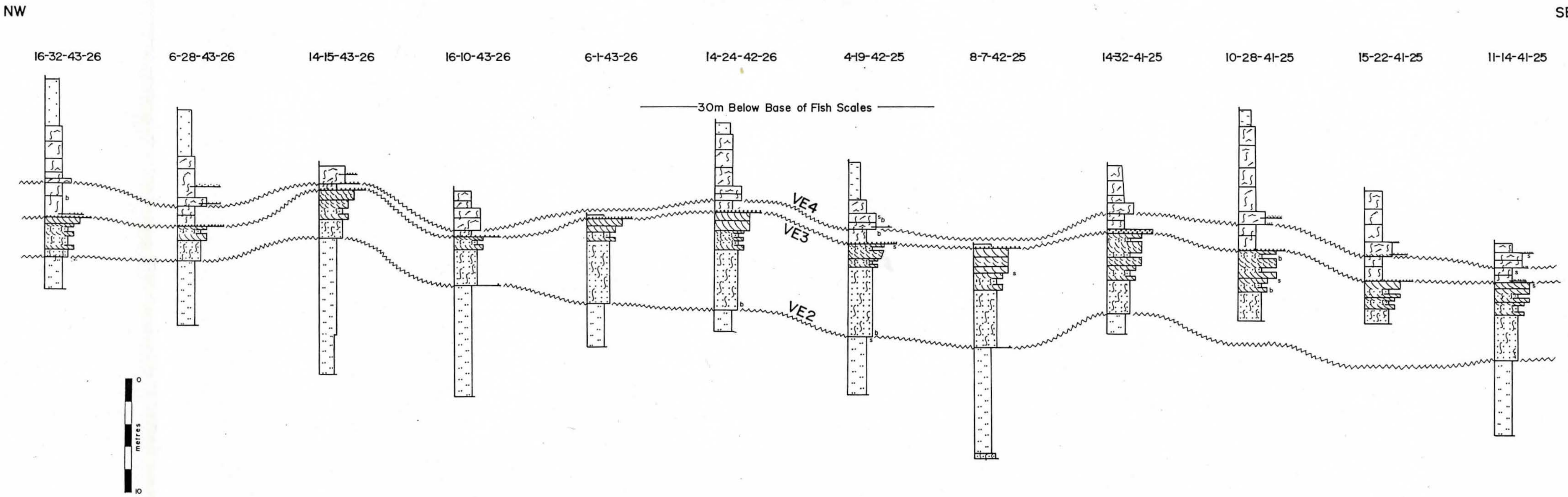
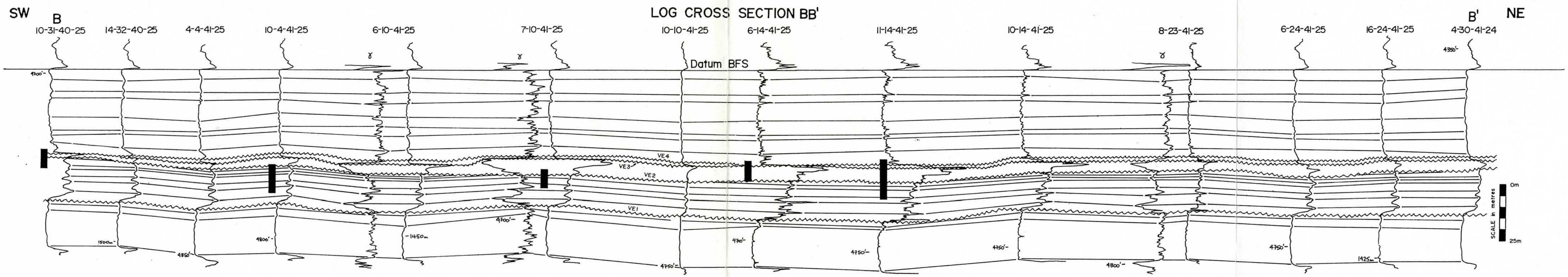
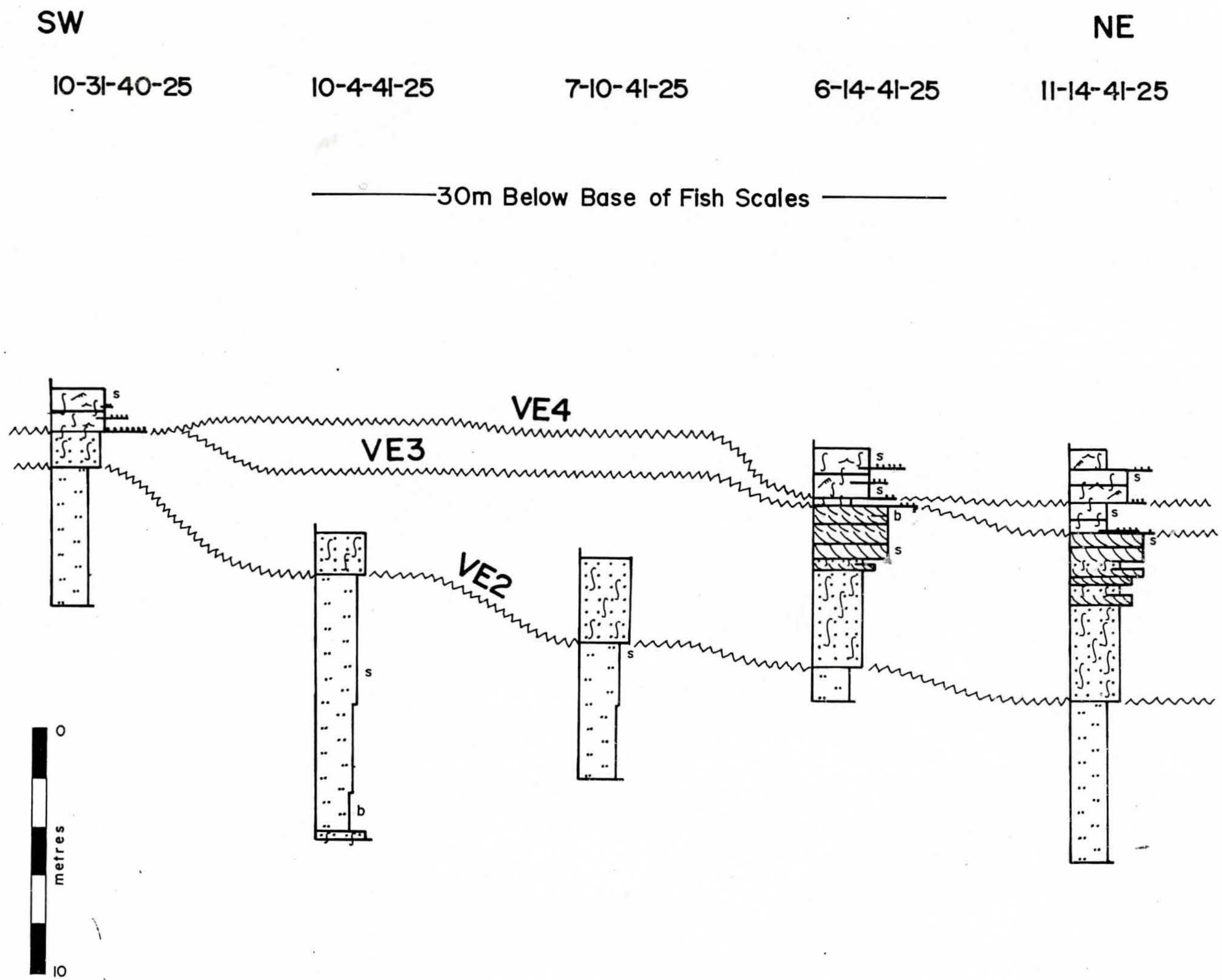


Figure 5.3   Log cross section BB'.

Figure 5.3a Core cross section B.


SW
B
LOG CROSS SECTION BB'
B'
NE
10-31-40-25
14-32-40-25
4-4-41-25
10-4-41-25
6-10-41-25
7-10-41-25
10-10-41-25
6-14-41-25
11-14-41-25
10-14-41-25
8-23-41-25
6-24-41-25
16-24-41-25
4-30-41-24
Datum BFS
VE4
VE3
VE2
VE1
SCALE in metres
0m
25m

CORE CROSS SECTION B



25. Cross section BB' shows VE3 developed between 10-31-40-25 and 14-32-40-25. There is no direct evidence for this, however similar well log responses in the Chigwell area support this correlation. The VE3 and VE4 correlations were problematic on cross section BB' because they did not follow the trend of other correlations. Difficulties were encountered in "hanging" the cores on the well log responses. Log cross section BB' shows an amalgamation of VE3 and VE4 at 6-14-41-25. This is due to the small scale of the figure. In reality, VE3 and VE4 are discernable at 6-14-41-25, however they are only centimetres away from each other. To illustrate this distinction, the distance between VE3 and VE4 has been exaggerated for 6-14-41-25 on core cross section B. Also note the thickening of the VE2 to VE3 interval between 6-10-41-25 and 7-10-41-25 and subsequent thinning of the same interval between 11-14-41-25 and 10-14-41-25 (Fig. 5.3). VE2 cuts out two underlying markers between 6-10-41-25 and 7-10-41-25 on the log cross section. VE1,2,3 and 4 follow the same undulation trends across both cross sections.

5.4 LOG CROSS SECTION CC' AND CORE CROSS SECTION C

Log cross section CC' (Fig. 5.4) shows a thickening of the VE2 to VE3 interval between 7-12-41-26 and 6-28-41-25 and a thinning of the same interval between 6-34-41-25 and

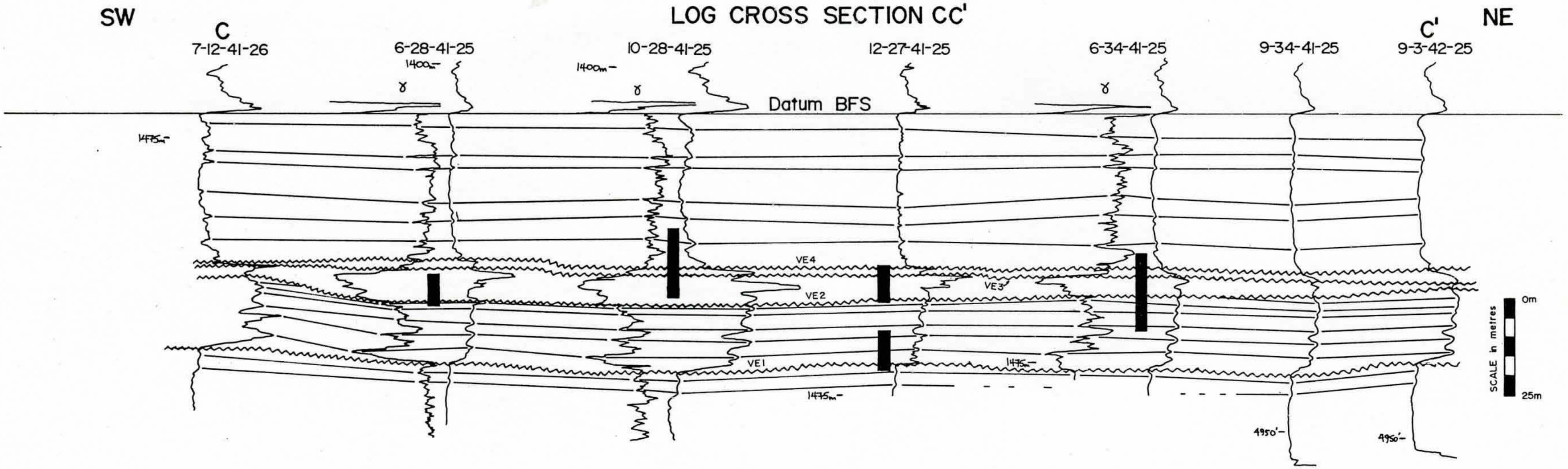
9-34-41-25. In both instances, VE2 cuts out underlying markers. VE3 and VE4 are essentially parallel to each other and progressively drop stratigraphically from southwest to northeast. VE1 shows minimal topography and undulates in a different manner than any of the other VE surfaces. Core cross section C (Fig. 5.4a) illustrates the southwest to northeast stratigraphic drop of VE3 and VE4 as well as the beginning of the thinning of the VE2 to VE3 interval between 12-27-41-25 and 6-34-41-25. The nature of VE1 can be seen on D in 12-27-41-25.

5.5 LOG CROSS SECTION DD' AND CORE CROSS SECTION D

Log cross section DD' (Fig. 5.5) demonstrates the VE surfaces cutting in to one another (especially in the wells southwest of 14-13-42-26). VE2 develops between 6-2-42-26 and 14-12-42-26 on DD' and the VE2 to VE3 interval thickens significantly between 14-12-42-26 and 14-13-42-26 (Fig. 5.5). Core cross section D (Fig. 5.5a) also illustrates both of the points above. The VE2 to VE3 interval then thins in the northeast between 7-19-42-25 and 11-20-42-25. This thinning is mostly due to a drop in VE3 rather than a rise in VE2, unlike the previous three cross sections. Core cross section D also hints at a thinning of the VE2 to VE3 interval towards the northeast between 4-19-42-25 and 6-19-42-25. VE2 cuts out underlying well log markers between 14-

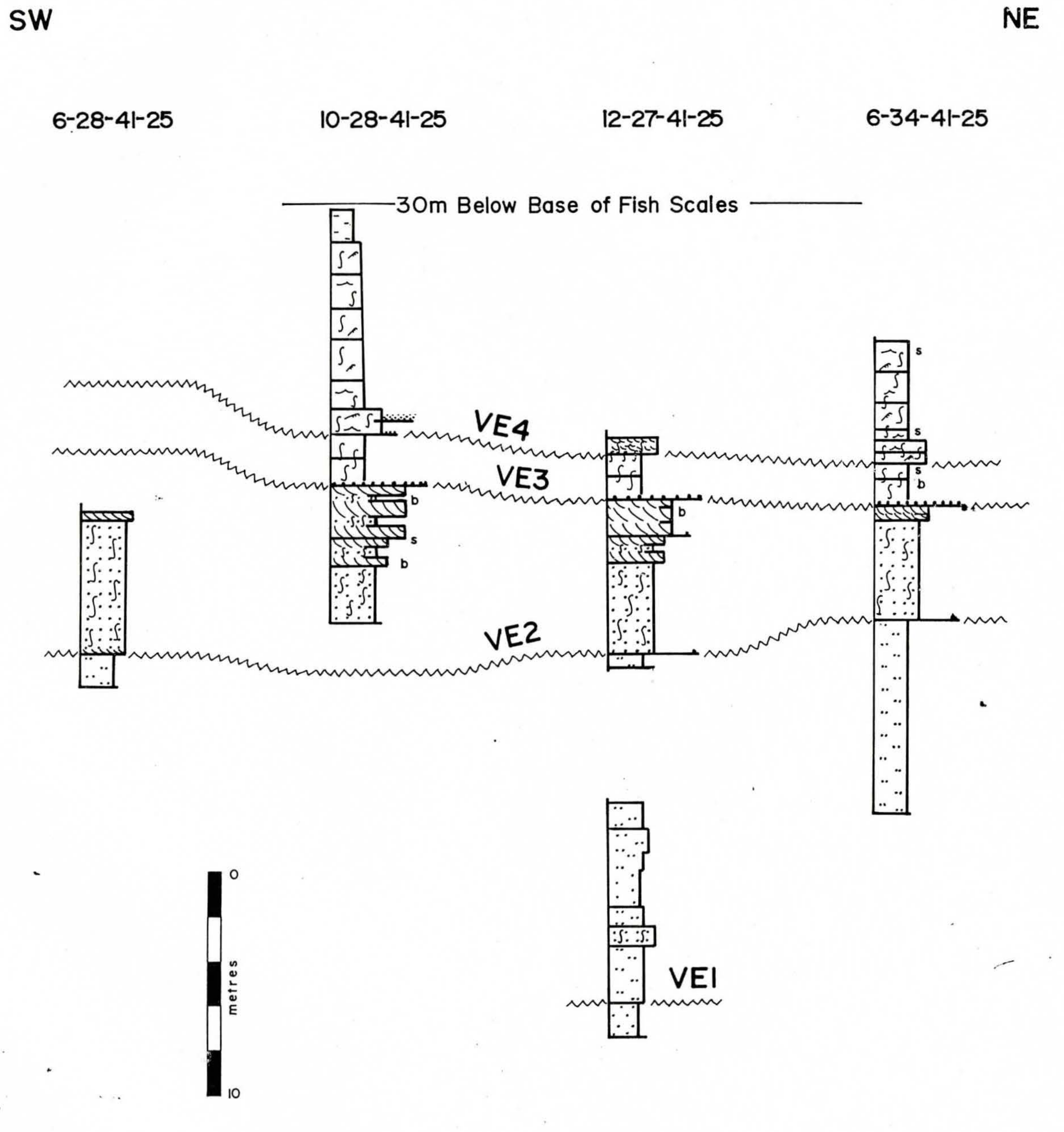
Figure 5.4   Log cross section CC'.

Figure 5.4a Core cross section C.



SW
LOG CROSS SECTION CC'
NE
C
C'
7-12-41-26
6-28-41-25
10-28-41-25
12-27-41-25
6-34-41-25
9-34-41-25
9-3-42-25
Datum BFS
VE4
VE3
VE2
VE1
SCALE in metres
0m
25m

CORE CROSS SECTION C



13-42-26 and 16-13-42-26 as well as between 4-19-42-25 and 6-19-42-25. The nature of the VE1 contact can be seen in 14-28-41-26 (Fig. 5.5a).

5.6 LOG CROSS SECTION EE' AND CORE CROSS SECTION E

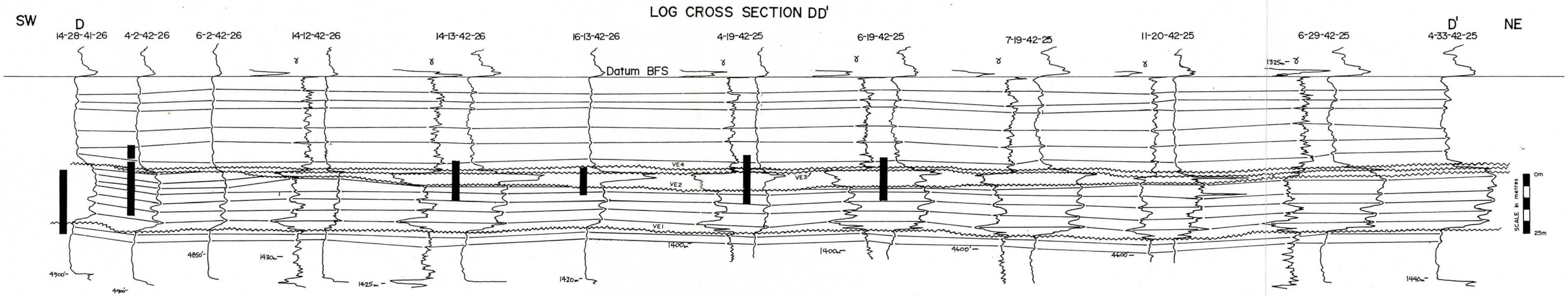
Log cross section EE' (Fig. 5.6) shows a marked increase in the VE2 to VE3 interval thickness between 3-14-42-27 and 8-34-42-26 and VE2 cuts out an underlying well log marker. The interval stays relatively thick until it thins again between 10-1-43-26 and 16-7-43-25 where VE2 cuts out two underlying well log markers. VE1,3 and 4 stay approximately flat and parallel across the length of the cross section. VE3 gets cut out by VE4 between 10-1-43-26 and 16-7-43-26. Core cross section E (Fig. 5.6a) illustrates the slight rise and parallel nature of VE3 and VE4.

5.7 LOG CROSS SECTION FF' AND CORE CROSS SECTION F

Log cross section FF' (Fig. 5.7) shows an increase in the VE2 to VE3 interval thickness between 6-18-43-26 and 6-28-43-26 that continues northeast and begins to thin again between 6-34-43-26 and 11-35-43-26. VE3 also develops between 6-18-43-26 and 6-28-43-26 and disappears between 6-34-43-26 and 11-35-43-26. VE2 cuts out underlying well log markers between 6-11-43-27 and 6-18-43-26 as well as between

Figure 5.5 Log cross section DD'.

Figure 5.5a Core cross section D. <u>Note:</u> "X"ed areas represent missing core.



LOG CROSS SECTION DD'
SW
D
D'
NE
14-28-41-26
4-2-42-26
6-2-42-26
14-12-42-26
14-13-42-26
16-13-42-26
4-19-42-25
6-19-42-25
7-19-42-25
11-20-42-25
6-29-42-25
4-33-42-25
Datum BFS
VE4
VE3
VE2
VE1
SCALE in metres
0m
25m

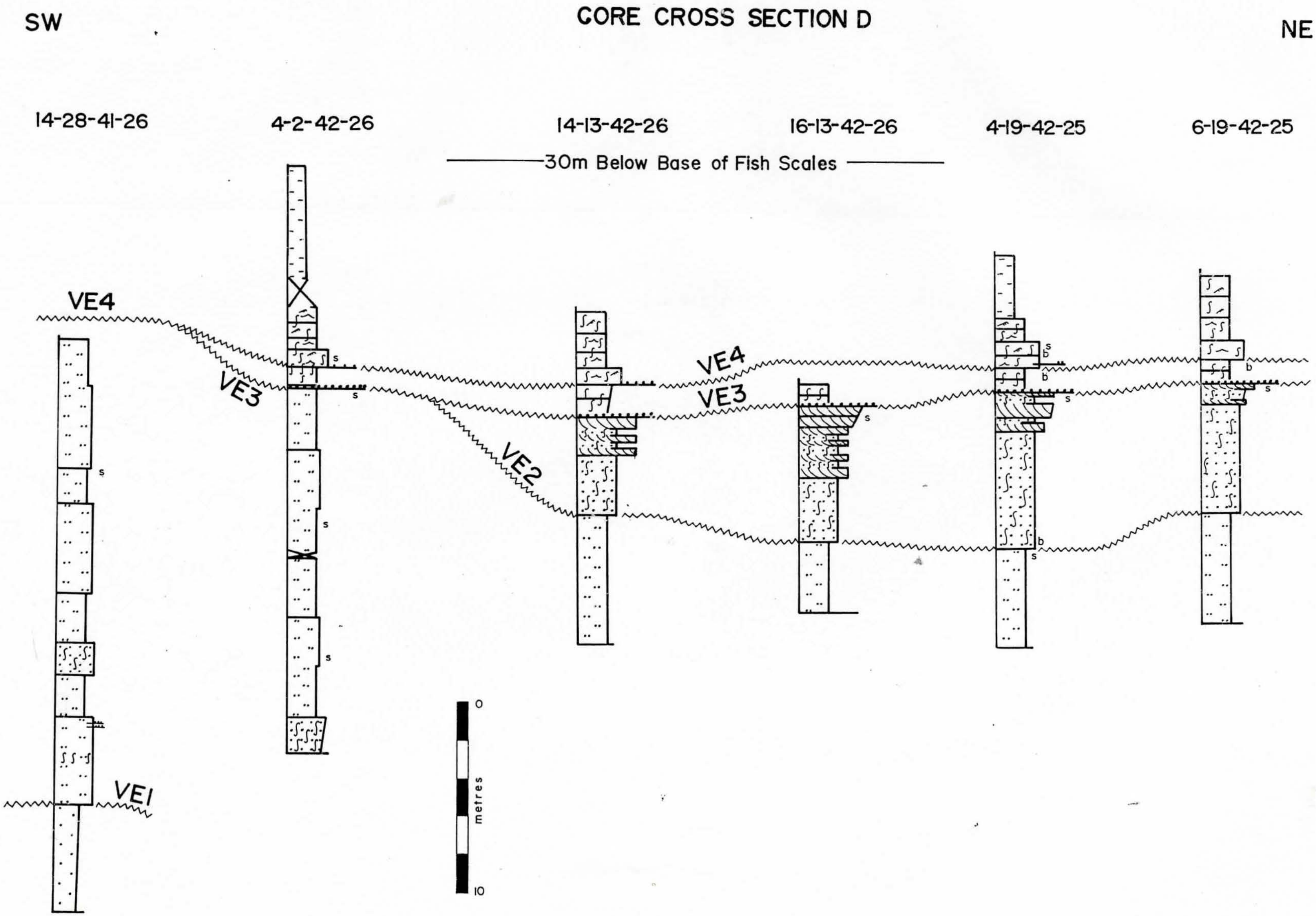
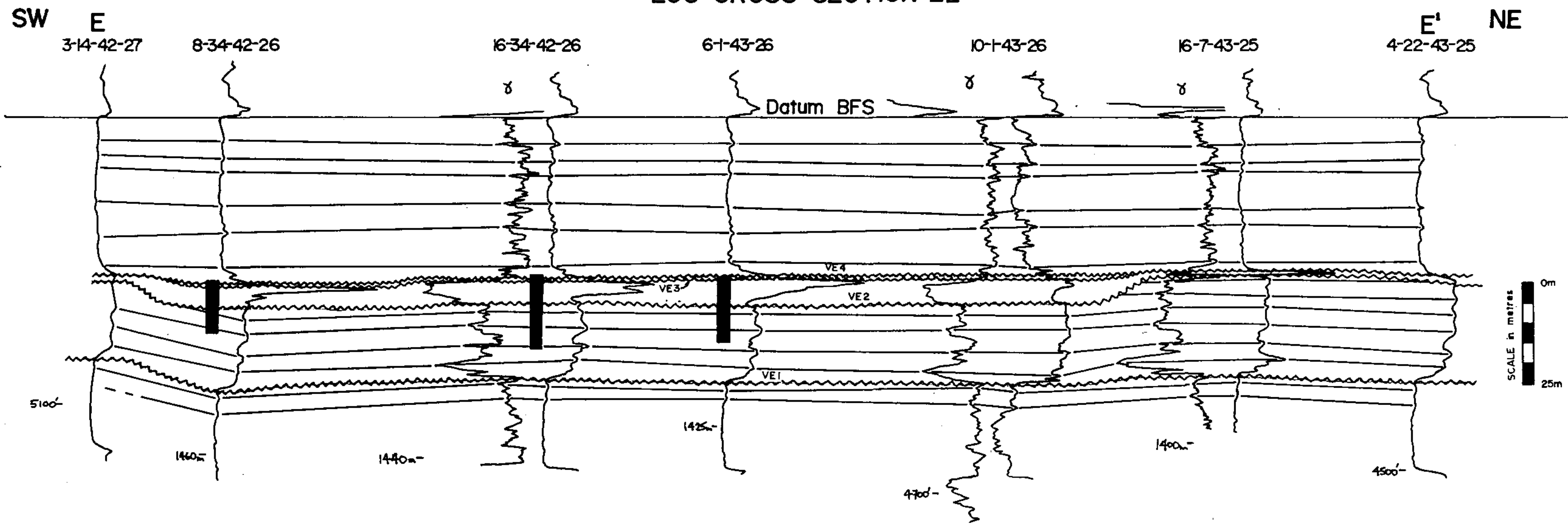

SW
CORE CROSS SECTION D
NE
14-28-41-26
4-2-42-26
14-13-42-26
16-13-42-26
4-19-42-25
6-19-42-25
30m Below Base of Fish Scales
VE4
VE3
VE2
VE1
metres
0
10

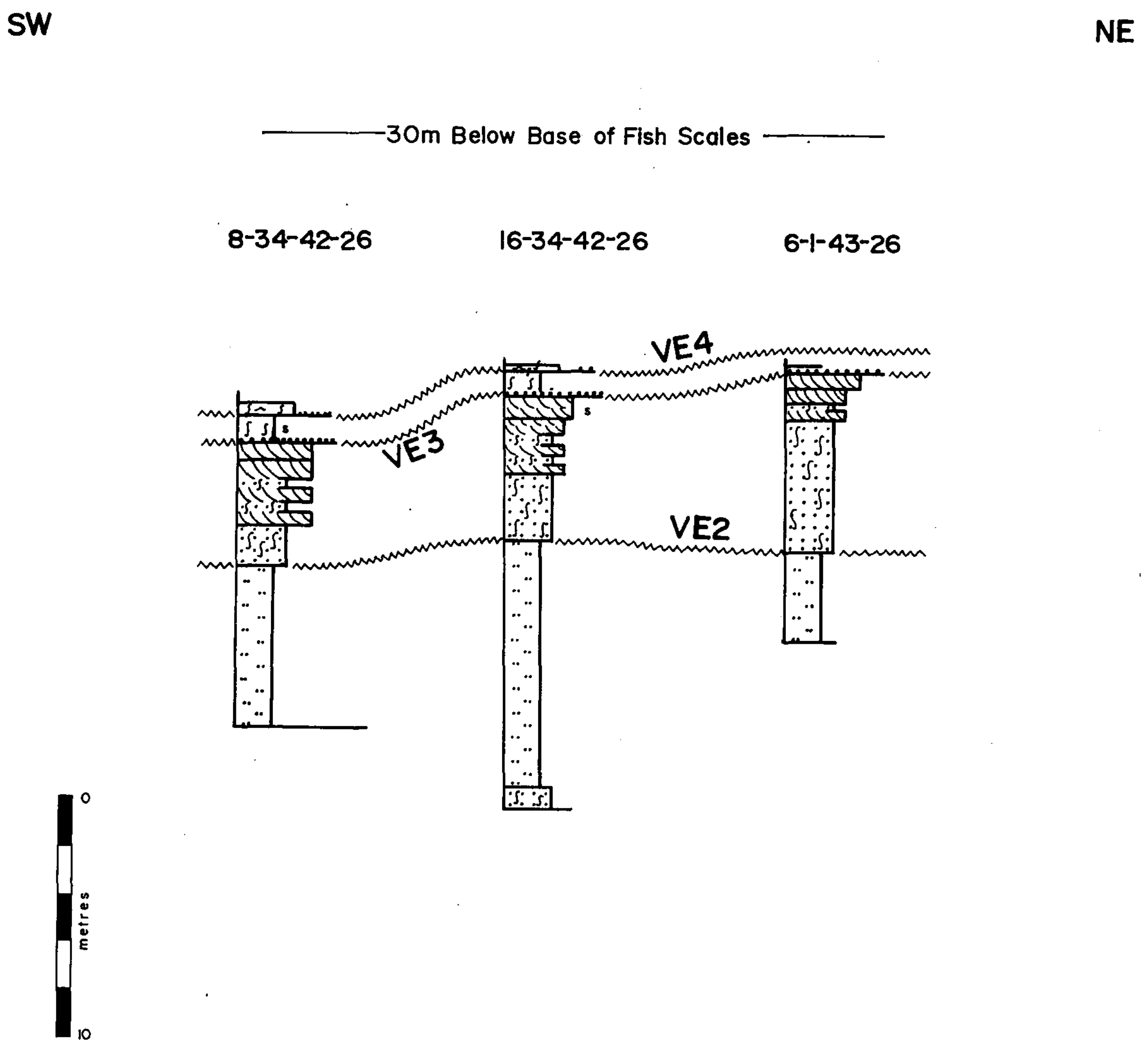
Figure 5.6 Log cross section EE'.

Figure 5.6a Core cross section E.

LOG CROSS SECTION EE'



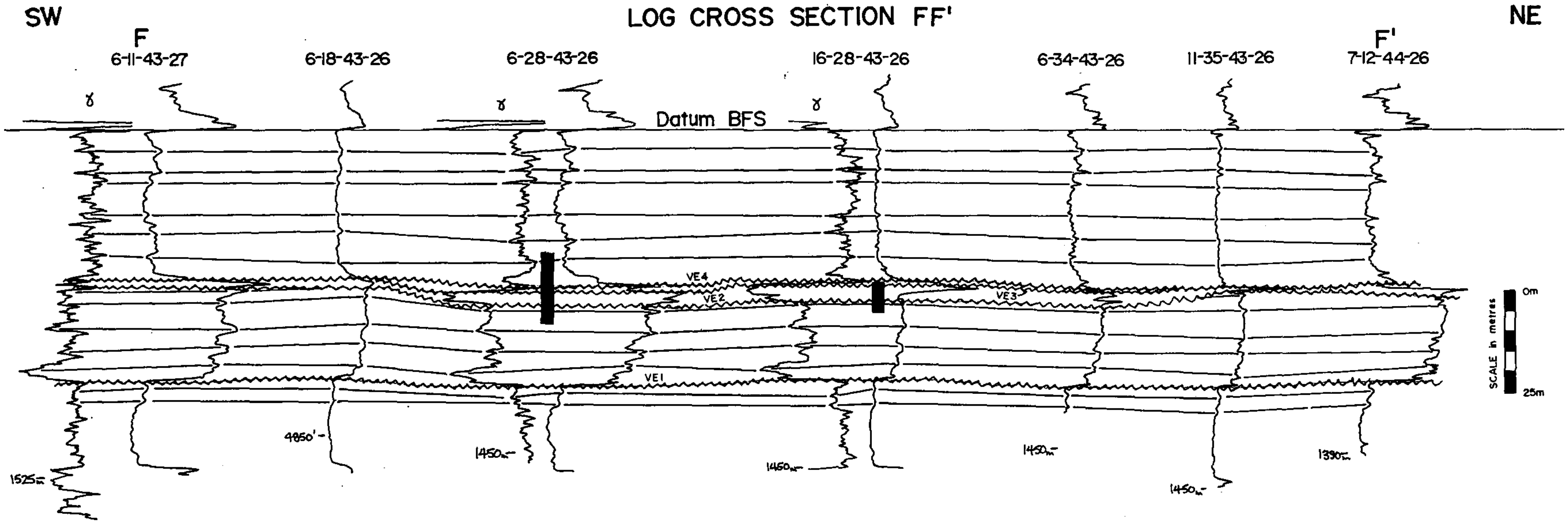
CORE CROSS SECTION E



6-34-43-26 and 11-35-43-26. The VE2 to VE3 interval thickness is less here than in the other cross sections. VE1 and VE4 are relatively flat and parallel. Core cross section F (Fig. 5.7a) demonstrates the small rise of VE2,3 and 4 between 6-28-43-26 and 16-28-43-26.

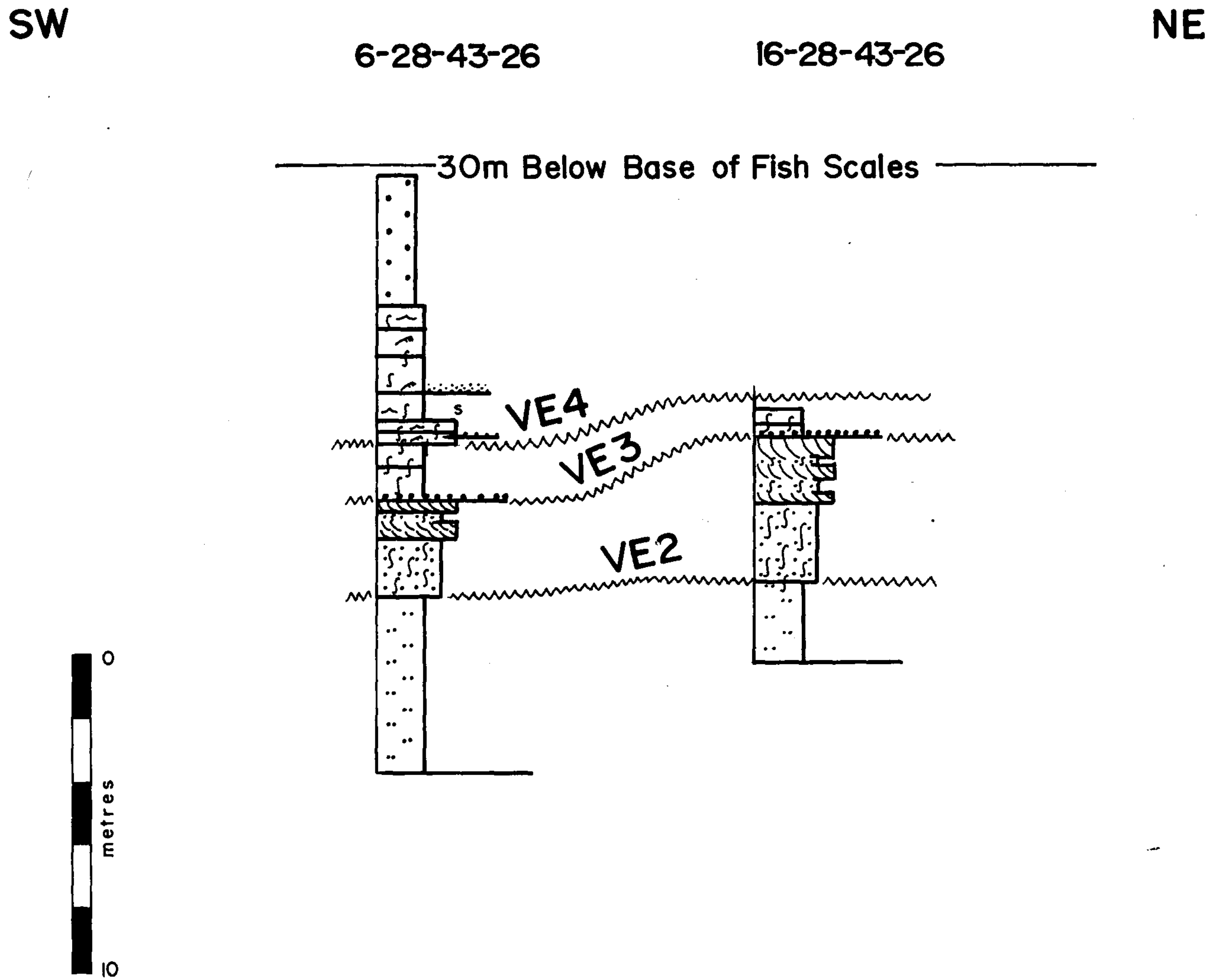
Figure 5.7   Log cross section FF'.

Figure 5.7a Core cross section F.



SW
LOG CROSS SECTION FF'
NE
F
F'
6-11-43-27
6-18-43-26
6-28-43-26
16-28-43-26
6-34-43-26
11-35-43-26
7-12-44-26
Datum BFS
VE4
VE2
VE3
VE1
4850'
1450m
1525m
1390m
SCALE in metres
0m
25m

CORE CROSS SECTION F



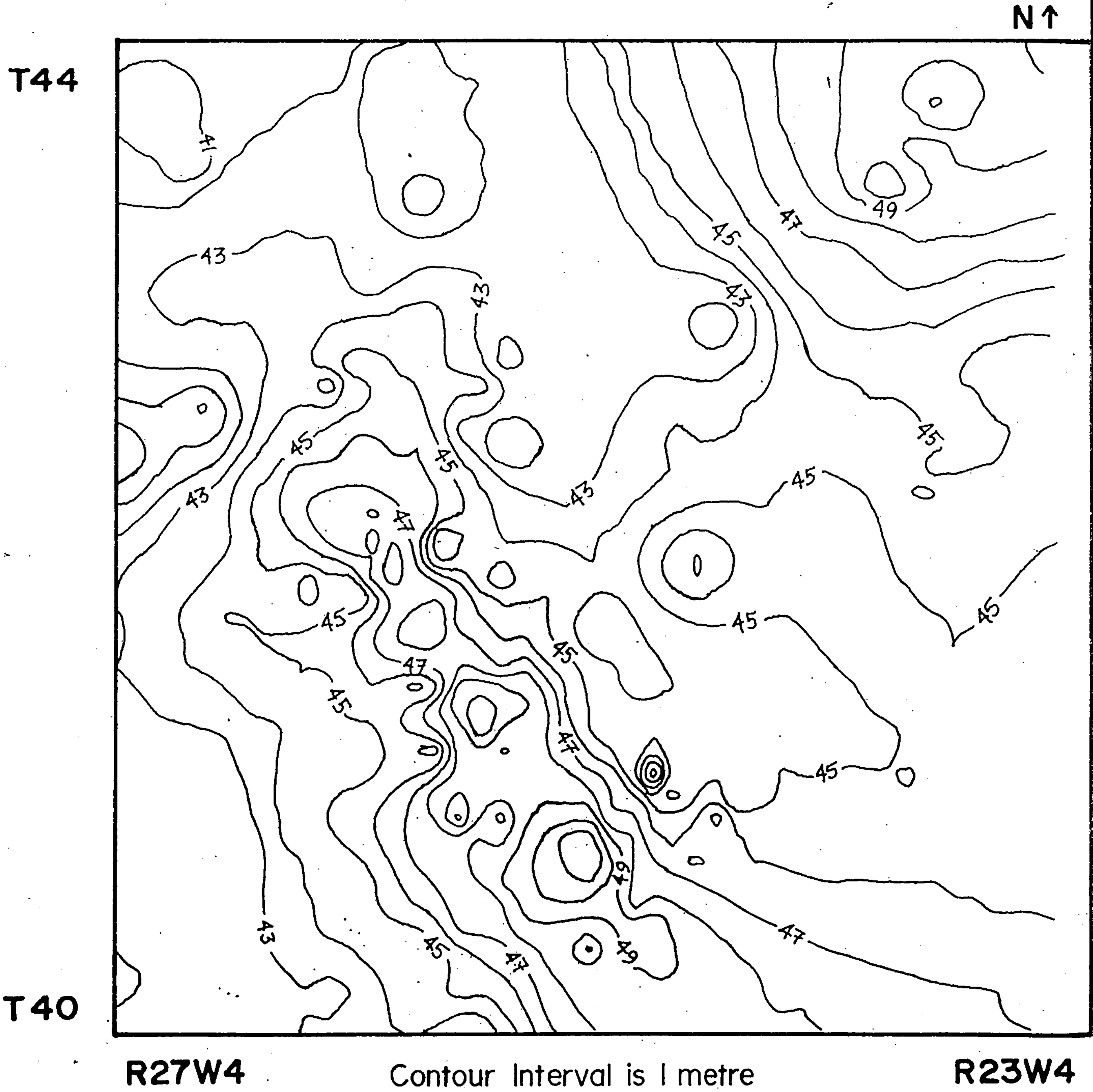
CHAPTER 6: ISOPACH MAP

6.1 ISOPACH MAP

The trends of the log and core cross sections presented in chapter 5 generally show that the major topography is associated with VE2. For this reason, an isopach map from "Base of Fish Scales" to VE2 was created in order to generate a plan view of the scour defined by VE2 (Fig. 6.1). The long linear nature of Chigwell is nicely defined by this map. The VE2 surface drops down from the southwest, is deepest in the middle of the field and then rises again towards the northeast. The data points were scarce towards the far southwest and northeast (Fig. 6.2) and so the contours there should be dealt with cautiously. The isopach map (Fig. 6.1) shows a VE2 scour that rises on either side (i.e. to the southwest and the northeast).

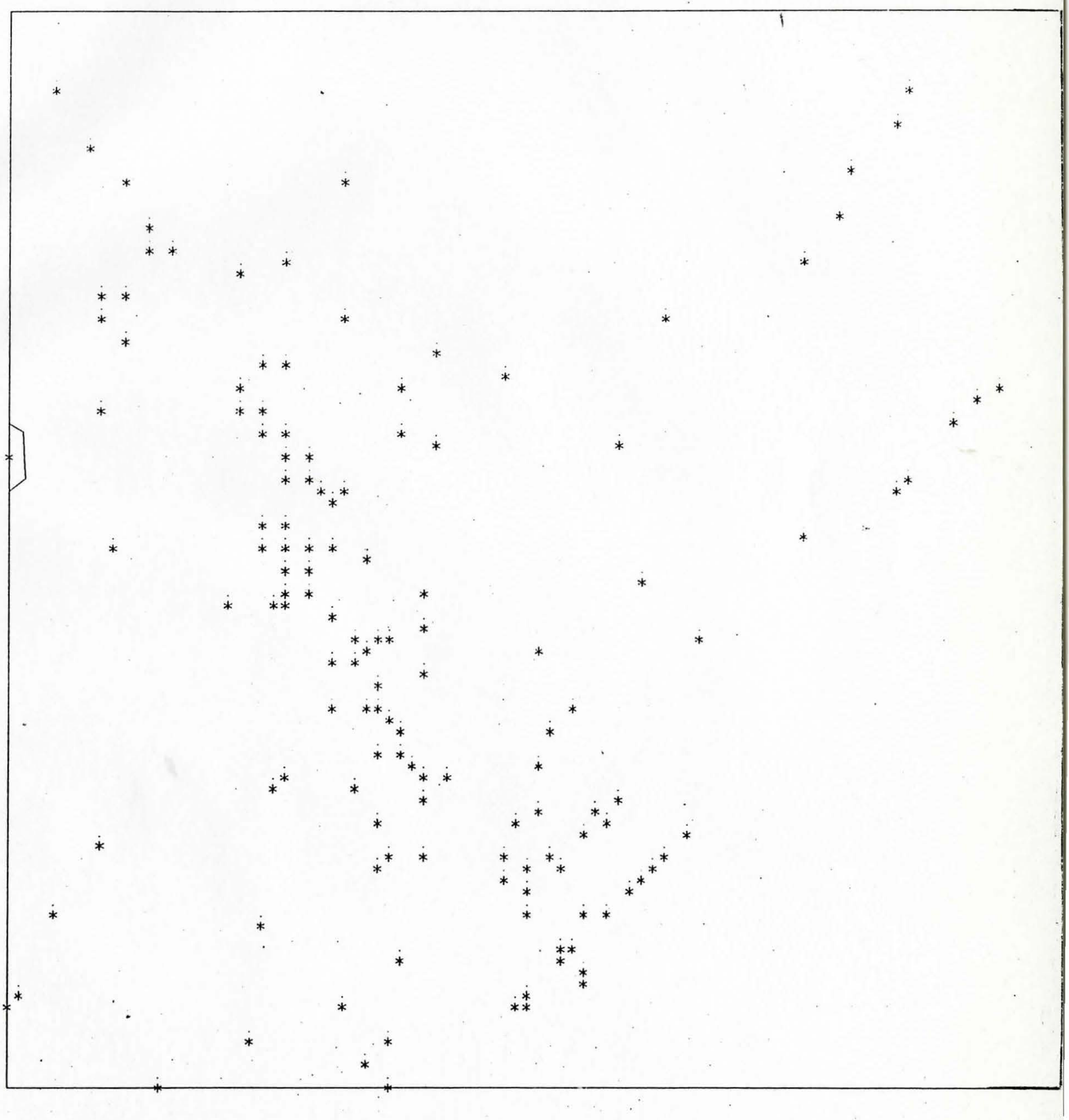
Figure 6.1 Isopach map of the "Base of Fish Scales" to VE2 interval.

CHIGWELL STUDY AREA



Contour Interval is 1 metre

Figure 6.2 Locations of data points used in the creation of Figure 6.1. <u>Note:</u> The scale, township and range boundaries are the same as for Figure 6.1.



CHAPTER 7: INTERPRETATIONS AND CONCLUSIONS

7.1 INTRODUCTION

The Viking sediments at Chigwell can be interpreted on three separate scales: i) on the scale of the facies themselves, ii) on the scale of facies associations in the context of the erosional bounding surfaces and iii) an overall summary of the depositional history at Chigwell. A discussion on the scale of the facies has been given in chapter three. A discussion on the other two scales is given below.

7.2 FACIES SEQUENCE AND EROSION SURFACE INTERPRETATIONS

7.2.1 Introduction

The facies associations/sequences were described in detail in chapter 4. Therefore, the sequences will only be alluded to briefly here.

7.2.2 Allomember A

Facies 1 and 2 are associated with allomember A and so it is postulated that they were deposited in a deep offshore, quiet water marine setting.

7.2.3 VE1 Surface

VE1 is rarely cored and so little is known for sure about it. For this reason, the nature of VE1 will not be addressed.

7.2.4 Allomember B

Facies 3 and 4 are associated with this allomember. There may be four smaller sanding/shallowing upward cycles within allomember B. This is interpreted as representative of the aggradation of four cycles on the sea floor during the deposition of allomember B. If this is the case, then there are major implications for the palaeoshoreline equivalent to allomember B at Chigwell (i.e. perhaps three minor regression/transgressions within allomember B ?). The position of this palaeoshoreline, however, is unknown.

7.2.5 VE2 Surface

Of the four erosional bounding surfaces observable at Chigwell, VE2 is the only one that shows any significant topography. The VE2 scour shows approximately 7 metres of relief (Fig. 6.1). The scour is nearly symmetrical with a slight hint of a shallower profile on the southwest side of the field (Fig. 6.1). This VE2 surface could have arisen in four ways: i) open shelf erosion, ii) tidal scour, iii) shoreface incision or iv) non-marine erosion. Essentially the open shelf and non-marine erosion hypotheses can be ignored (Bergman and Walker, 1988). This leaves two possibilities: 1) tidal scour and 2) shoreface incision. There are pros and cons for both ideas. It should be noted that scale is not a problem. Both tidal scouring and shoreface incision can account for the size of Chigwell. The presence of glauconite, the relative symmetry of the scour and evidence of tidal scouring in other Viking fields (Leckie, 1986) support the tidal scour origin of the VE2 surface. The major problem affiliated with the tidal scour origin is the sediment that sits directly on VE2. If the tidal processes were strong enough to be eroding underlying strata, then they were also undoubtedly strong enough to be creating large tidal cross bed sets on the VE2 surface. The observations made in this study showed only one example of cross beds lying directly on VE2 (6-28-41-25). There is little evidence to support a shoreface incision to account for the VE2 scour except perhaps for the recognition of other shoreface incision scours in the Viking (Downing and Walker, 1988) and the Cardium (Bergman and Walker, 1988; Pattison, 1988; Raddysh, 1988). Most of the evidence for a shoreface incision cutting VE2 is derived from the sediments that lie between VE2 and VE3. Note: An interpretation for the apparent rise of VE2 towards the northwest has not been attempted.

7.2.6 Allomember C

Facies 4 and 5a are associated with this allomember. Generally, the basal portions are dominated by facies 4 with increasing amounts of facies 5a upwards in the allomember. Allomember C usually both sands and coarsens upwards. In addition, more primary sedimentary structures are preserved upwards. The enigmatic nature of VE2 prompts two hypotheses in order to explain the sedimentology of allomember C: i) a tidal sand ridge hypothesis and ii) a prograding shoreface hypothesis.

If allomember C represents an offshore tidal sand ridge, then this would explain the glauconite associated with the lower parts of the allomember C sequence, as glauconite is stable in a shelf/slope type of environment. What the tidal hypothesis does not explain is how the sediment got offshore, the sanding/coarsening upwards of the allomember and the heavily bioturbated nature of facies 4 that makes up the bulk of the lower allomember C sequence. As previously mentioned above, only one example of cross beds sitting directly on VE2 was encountered. Furthermore, the mud drapes associated with allomember C are rare and no solid evidence of cyclicity (spring/neap cycles) or re-activation surfaces were observed.

If allomember C were deposited as a prograding shoreface, then this would solve the problem of having to get the sediment offshore. In a shoreface interpretation, it is not necessary to transport sediment offshore since the sediment would be being supplied directly to the shoreface itself. Cores that are thought to be representative of channel facies have been recognized in the Viking just northwest of Chigwell in the Ferrybank gas field, although the orientation and exact stratigraphic position of the channel(s) is/are unknown (A.D.Reynolds, pers.comm., 1989). This may prove to clear up a problem at Chigwell that Downing and Walker (1988) encountered at Joffre. The southwest-northeast oriented core cross sections (chapter 5) show a general trend of preservation of more of the coarser end of facies 5a along the southwest side of the field. This could perhaps imply a sediment source from the southwest that fed a Chigwell palaeoshoreline, in this shoreface model. Although not diagnostic of shoreface environments, the ichnogenera in allomember C could be found in lower to upper shoreface settings (Frey and Pemberton, 1984).

7.2.7 VE3 Surface

The VE3 surface is thought to have been cut by a marine transgression. The facies 6c conglomerates lie directly on VE3 and are interpreted as representative of a transgressive lag or veneer. Facies 6c is officially a part of allomember E.

7.2.8 Allomember E

Facies 6c and 7a are associated with this allomember. As mentioned above, facies 6c is thought to represent a transgressive lag deposit. The interpretation of facies 7a is the same as outlined earlier in section 3.8.

7.2.9 VE4 Surface

The VE4 surface is also believed to have been cut as a result of a marine transgression.

7.2.10 Allomember F

Allomember F is comprised of only facies 7b and so the interpretation of the allomember is the same as given in section 3.9.

7.3 OVERALL SUMMARY AND CONCLUSIONS

7.3.1 Introduction

Based on the discussion above, a tentative depositional history for the Viking interval at Chigwell can be summarized.

7.3.2 Summary and Conclusions

This field study has resulted in the following summary:

i) Allomember A was deposited in a quiet water, low energy offshore marine environment.

ii) VE1 was probably created during a sea level lowstand/stillstand.

iii) A marine transgression, and therefore a relative rise in sea level, took place and allomember B was deposited in an offshore environment, equivalent to unrecognized palaeoshorelines. The four allomember B sanding upward sub-cycles may be related to three minor regressions that may have taken place during deposition of allomember B.

iv) A regression of the seas (drop in relative sea level) ocurred allowing the VE2 scour to be formed. Whether the scour is of tidal or shoreface incision origin has not been resolved. The sediments that fill the VE2 scour (allomember C) appear to be the result of a prograding shoreface as opposed to an offshore tidal sand ridge.

v) A marine transgression created the VE3 suface. The transgression eroded any non-marine and beach sediments that may have once been a part of allomember C. A transgressively deposited conglomerate lag was smeared over the VE3 surface.

vi) A regression allowed the development of a palaeoshoreline at Harmattan (Hadley, pers.comm., 1989). Intermittent storms on this palaeoshoreline carried sediment into the basin and the waning storm flow deposits were deposited at Chigwell as allomember E (minus the conglomerate which is associated with the VE3 surface).

vii) Another marine transgression takes place and cuts the VE4 flooding surface. VE4 probably eroded some of allomember E below it. The allomember F sediments were deposited in an offshore marine environment. Occasional cross beds, graded pebble beds and current to combined flow to wave rippled beds of allomember F, suggest that perhaps offshore tidal sand bars and storm processes were active.

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