THE SEDIMENTOLOGY, STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE LOWER CRETACEOUS VIKING FORMATION AT CAROLINE AND GARRINGTON, ALBERTA, CANADA

THE SEDIMENTOLOGY, STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE LOWER CRETACEOUS VIKING FORMATION AT CAROLINE AND GARRINGTON, ALBERTA, CANADA

BY

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ABSTRACT

The Lower Cretaceous (Albian) Viking Formation at Caroline and Garrington, Alberta contains two regionally extensive erosion surfaces, VE3 and VE4, separating three allocyclic members, B/C, D, and E. These erosion surfaces, along with two possible correlative conformities at lower stratigraphic levels, can be mapped over large areas of the Alberta Basin allowing for the creation of a Viking Allostratigraphy.

The basal allomember cored in the study area is informally termed B/C and is made up of burrowed siltstones deposited in an offshore marine setting. It is overlain by the regionally extensive ravinement surface VE3, which rises "steplike" towards the southwest. Allomember D, which overlies this unconformity, is composed of a shallowing upward succession of storm-dominated facies resulting from progradation of the shoreface towards the northeast. Allomember E is a complex succession of facies deposited over the regionally extensive ravinement surface VE4 during the final relative rise of the Boreal sea. Within Allomember E are up to six coarse grained, sheetlike beds sharply interbedded with marine shales. These interbeds are the result of basinward progradation of coarse sediment during periods of stillstand in the overall transgression, under the mixed influence of storms and tides. The coarse grained deposits

originated at "steps" in the VE4 topography, representing successive positions of the retreating paleoshoreline, and were swept basinward by tides and storms over older, stratigraphically deeper "steps" and newly deposited shales. The coarse grained interbeds in Allomember E become thinner and finer in any one vertical section, reflecting the continued transgression of the shoreline towards the southwest.

The boundaries of the Caroline and Garrington fields are determined by the extent of the sheetlike coarse grained deposits of Allomember E, and by the location of the post-depositionally determined oil-water contacts. Caroline and Garrington are producing from different stratigraphic intervals. Caroline is producing from a shale-encased coarse grained interbed termed E3 (the Viking "A pool" of industry). At Garrington, this interbed is very thin, muddy and therefore unproductive. The Garrington field, in contrast, is producing from the stratigraphically lower coarse grained interval (VE4-CM2), which directly overlies the VE4 surface.

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CHAPTER 1: INTRODUCTION

1.1 Geologic Problem of the Viking

Many shallow marine clastic sandbodies deposited during the Cretaceous in the Western Interior Seaway (W.I.S.) have received attention due to their tremendous economic importance as petroleum reservoirs. In Alberta, formations such as the Cardium and the Viking are important reservoirs; the Viking is estimated to contain 247.6 x 10^3m^3 of oil and 362 869 x 10^6m^3 of gas (ERCB, 1982, 1983). The abundance of cores and well logs has also allowed detailed sedimentological study of these sandbodies to be made. As a result, their depositional environments and sediment transport processes have been extensively discussed in the literature.

Many of the sandbodies deposited in the W.I.S. are made up of coarsening upward sequences completely enclosed by marine shales. Examples include the Shannon Sandstone of Wyoming (Spearing, 1976; Seeling, 1978; Shurr, 1984; Tillman and Martinsen, 1984), the Sussex Sandstone of Wyoming (Berg, 1975), the Mosby Sandstone of Montana (Rice, 1984) and the Cardium Formation in Alberta (Wright and Walker, 1981; Bergman and Walker 1987, 1988; Leggitt, 1987; McLean, 1987, Pattison, 1988) and the Duffy sandstone (Boyles and Scott, 1982). Other examples are given in Walker (1984, p. 164, Table 3). Various depositional environments and mechanisms have been proposed to explain the coarsening upward sequences. Amongst the most popular are:

1) offshore bars apparently deposited great distances from their nearest contemporaneous shoreline,

2) erosional remnants of former shallow marine sheet sands, and,

3) incised shorefaces.

To document any one of these postulated depositional environments it is necessary to define the boundaries of the sandbodies. This makes an educated estimation of the original extent and geometry of the sandbody possible, which, in turn aids in interpreting the original depositional environment. Once they are defined, it is possible to address the questions of whether sediment was transported offshore across the shelf, as would be the case in the offshore bar hypothesis, or whether the shoreface migrated back and forth across the basin in response to relative changes in sea level.

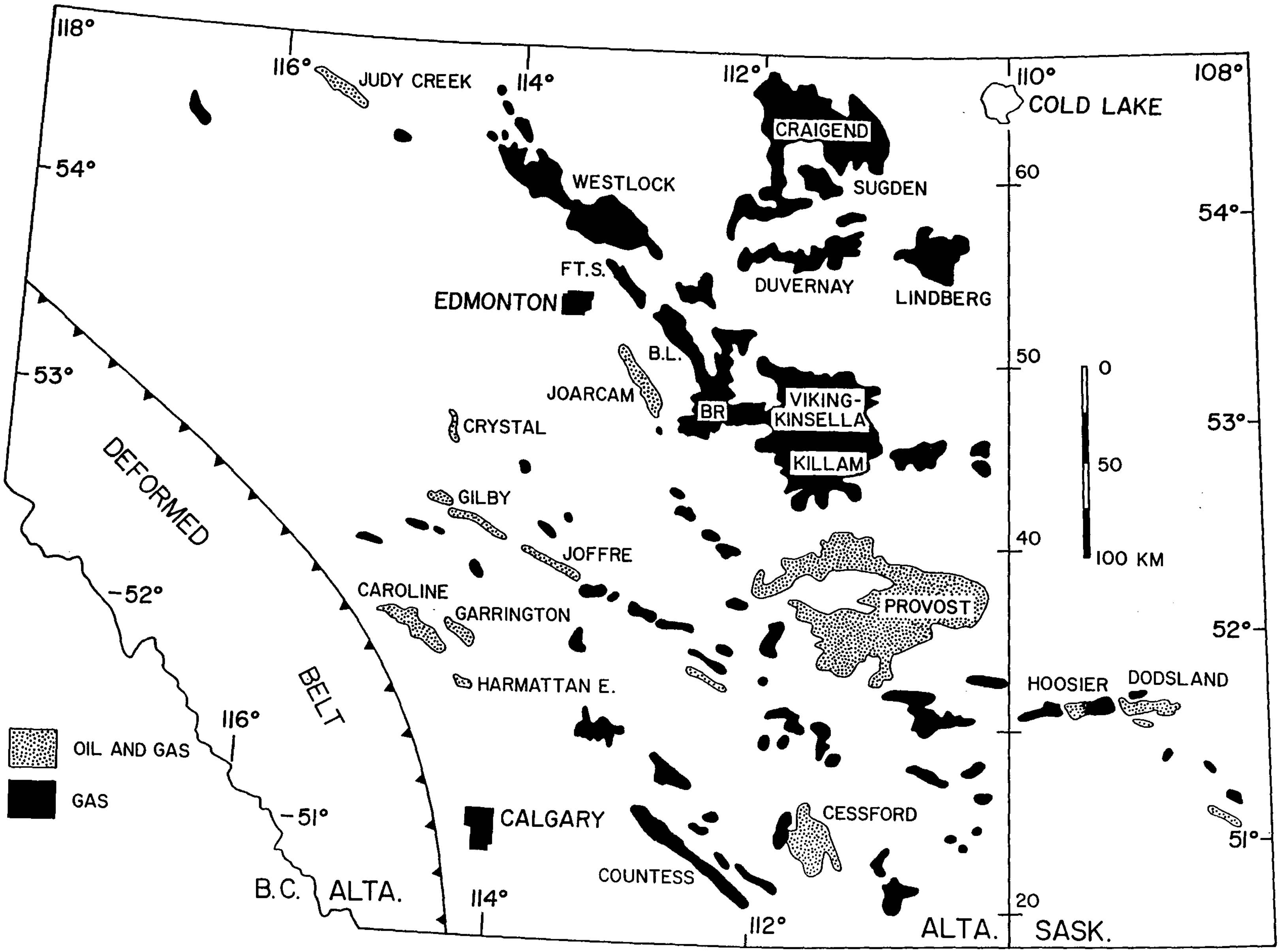
Many of the coarse clastic formations in the W.I.S. were initially interpreted to be offshore bars because: 1) they are encased in marine shales, 2) they lack features suggestive of a paleoshoreline (i.e., rooted horizons, paleosols, desiccation cracks), and 3) they appear to have been deposited 10's to 100's of kilometers from the nearest preserved paleoshoreline. In recent years, the idea that relative sea level change can cause major changes in basin configuration, particularly the position of the shoreline, has led to a reinterpretation of many of these coarse clastic units. When it was realized that shorelines can migrate large distances in response to relative changes of sea level, the offshore bar origin of many sand bodies became less attractive. For example, recently completed work on the Turonian-Coniacian Cardium Formation (Plint et al., 1986; Bergman and Walker 1987, 1988) has shown that sea level changes can be invoked to shift the shoreline back and forth across the basin. As a result, the Cardium Formation has been reinterpreted as a series of erosional remnants of original sand sheets, with incised shoreface deposits.

Recognition and documentation of bounding disconformities (erosion surfaces, omission surfaces etc.) and genetic depositional sequences is the key to recognizing sea level fluctuations. It is then possible to study the geometry of the allomembers (N.A.C.S.N., 1983) defined by the bounding disconformities. Once constructed, an allostratigraphy enables documentation of the effects of sea level changes on depositional patterns, from field to field across the basin, and through time.

The Late Albian Viking Formation of south-central Alberta is an example of a coarse grained clastic unit enclosed by marine shales initially thought to be deposited as a series of offshore bars (Gammell, 1955; DeWeil, 1956; Stelck, 1958; Koldijk, 1976). Viking fields such as Joffre and Joarcam appear to have been deposited tens of kilometers away from

Figure 1.1: Distribution map of Viking sandbodies in Alberta and Saskatchewan. The sandbodies have been delineated from hydrocarbon production estimates provided by the Energy Resources Conservation Board. Evidence of subaerial exposure (roots) has been found southwest of the Caroline field.

The Caroline and Garrington fields are located in the southwestern portion of the map and are oriented in a NW-SW linear trend. Map from Walker, in Downing and Walker (1988).


118°
116°
JUDY CREEK
114°
112°
110°
108°
COLD LAKE
CRAIGEND
SUGDEN
54°
60
54°
WESTLOCK
FT.S.
DUVERNAY
LINDBERG
EDMONTON
B.L.
50
0
53°
JOARCAM
BR
VIKING-
KINSELLA
CRYSTAL
KILLAM
53°
50
DEFORMED
GILBY
40
100 KM
JOFFRE
52°
CAROLINE
GARRINGTON
PROVOST
52°
HARMATTAN E.
HOOSIER
DODSLAND
BELT
116°
OIL AND GAS
GAS
51°
CALGARY
CESSFORD
51°
COUNTESS
B.C.
ALTA.
114°
112°
20
ALTA.
SASK.

the nearest known paleoshoreline at Crossfield, southwest of the Caroline field (Amajor, 1980). In recent years however, several researchers have documented the existence of erosion surfaces within what had previously been described as a continuous coarsening upwards sequence (Pozzobon, 1987; Downing and Walker; 1988; Power, 1988; Robb, 1985; Hein et al., 1986; Leckie, 1986; Leckie and Reinson, in press). Recognition of these erosion surfaces led many of these researchers to consider the role of sea level change in the deposition of Viking sands. The erosion surfaces and facies packages documented in the studies cited above were not correlated into other fields and hence the creation of a Viking allostratigraphy has not yet been possible.

Downing and Walker (1988) documented the existence of 3 erosion surfaces at Joffre and suggested that Joffre is an incised shoreface deposit created by a drop in relative sea level. An ensuing rise in sea level is thought to have removed any evidence of upper shoreface deposits or subaerial exposure. In order to test this hypothesis it is preferable to examine Viking fields closer to the possible paleoshoreline, because it is there that sea level changes will have the greatest and most noticeable effect on depositional patterns. The fields that meet this criterion are Caroline, Garrington and Harmattan East.

1.2 <u>Selection of the Study Area</u>

In 1987 and 1988, numerous studies were started at

McMaster University on different Viking fields in Alberta. One common aim in all of these studies was the documentation of bounding disconformities and the facies sequences which are bounded by them in each individual area. Correlation of the disconformities and facies packages between the areas was an additional aim, one which would enable the construction of a basin wide Viking allostratigraphy.

The Viking Formation at Caroline and Garrington (this study) ties together work on the Gilby A, Gilby B, and Willesden Green areas to the north (Boreen, 1989) and the Harmattan East area to the south (S.W.Hadley, pers. comm., 1989). The position of the study area is therefore strategically located to allow correlation between these areas and as such, aid in the creation of a Viking allostratigraphy. The study area is also intriguing in that several economic coarse grained reservoir rocks, (known informally as the Viking "A sands"), overlie the main sand, and are sharply interbedded with marine shales. The origin of these units has remained unresolved and therefore warrants further study.

The study area contains an excellent data base of cored wells and wireline logs allowing for good, detailed sedimentological correlation.

1.3 <u>Definition of the Problem</u>

This thesis will specifically attempt to answer the following questions:

1) are there bounding disconformities present in the study

area, and if so, what is their nature, extent and geometry,

2) how were the various facies deposited and under what sorts of relative sea level controls,

3) what are the origins of the coarse grained to conglomeratic Viking A horizons which are intimately interbedded with marine shales, and,

4) are the boundaries of the Garrington and Caroline oil and gas fields depositional or erosional.

CHAPTER 2: REGIONAL SETTING AND STRATIGRAPHY

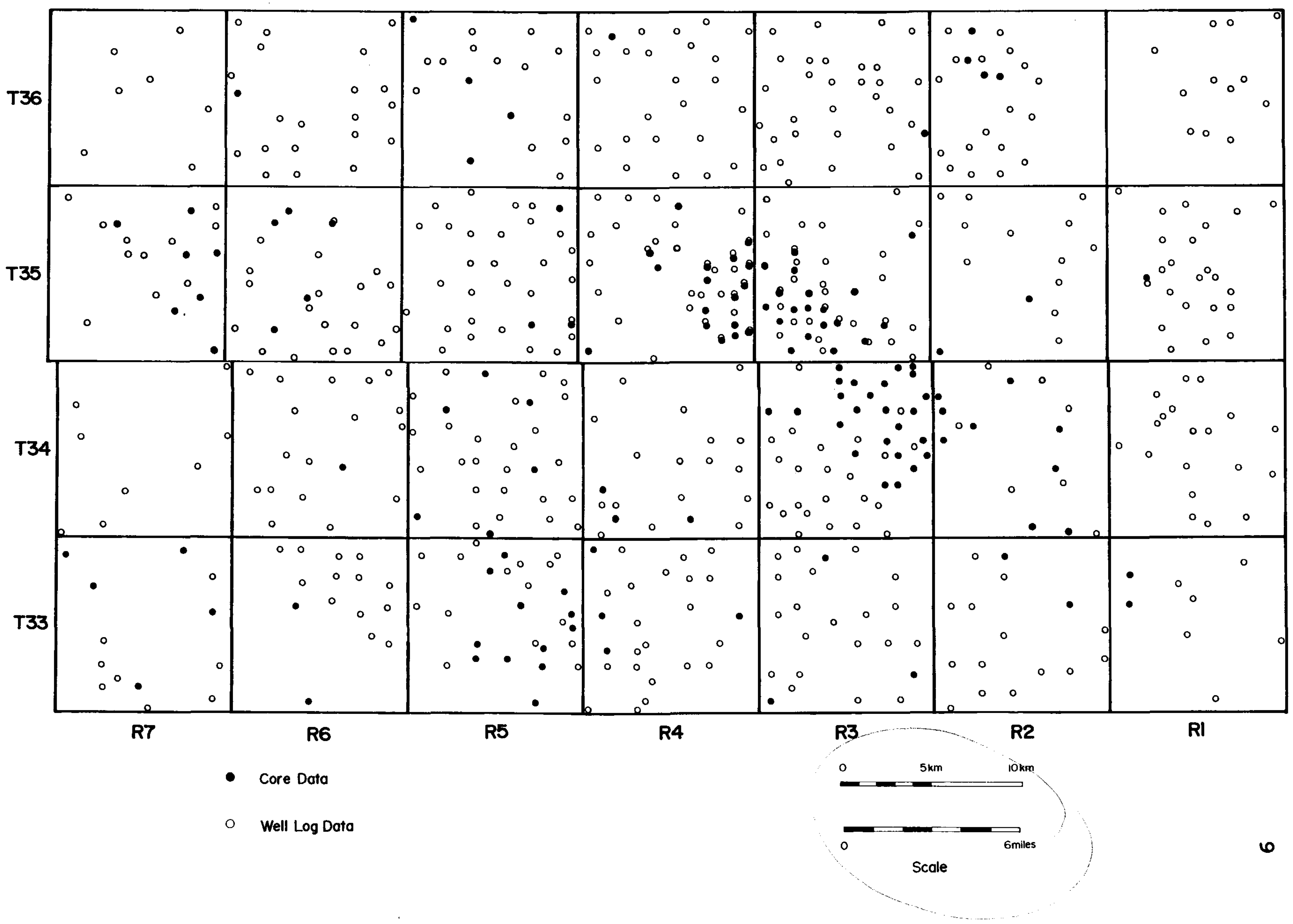
2.1 Study Area

The study area includes the oil and gas fields of Garrington and Caroline and covers the area T33-36, R1-7 W5 (Fig 2.1). Within this area, cores from the northwest part of Caroline (T 35-36, R 6-7) were examined on a reconnaissance basis whereas those from the remainder of the study area were examined in detail. The study area was chosen in order to tie into two ongoing studies in the adjoining areas; the Willesden Green, Ferrier, Gilby B and Gilby A fields to the north (Boreen, 1989), and Harmattan East to the south (S.W. Hadley, pers. comm., 1989).

2.2 Viking Stratigraphy

The Lower Cretaceous (Upper Albian) Viking Formation of central Alberta and Saskatchewan is a dominantly marine sandstone encased between two marine shales; the Joli Fou Formation below and the unnamed shales of the Colorado Group (hereinafter referred to as the Colorado shales) above. These three sediment packages make up the Lower Colorado Group, thought to be deposited during late Albian time (Williams and Stelck, 1975). The Viking Formation was first named by Slipper in 1918 for the sands of the Viking - Kinsella field of North-central Alberta and received formation status in the 1950's (Magditch, 1955; Stelck, 1958).

Figure 2.1: Base map of the Caroline and Garrington study area showing the distribution of wells and cores used in this study. All wells in this study are located west of the 5th Meridian.


T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
RI
Core Data
Well Log Data
0
5km
10km
0
6miles
Scale

The Viking Formation is equivalent to the Paddy Member of the Peace River Formation in North-west Alberta (Stelck and Koke, 1987), the Pelican Formation in North-east Alberta (Boethling, 1977), the Bow Island Formation in Southwest Alberta (Glaister, 1959) and the Silt Member of the Ashville Formation in Manitoba (Rudkin, 1964). It is correlative with the sands of the Newcastle Formation in North Dakota, the Muddy Sandstone of Montana and Wyoming and the 'J' Sandstone of Colorado (McGookey et al., 1972). The Viking Formation ranges from 15 to 45 m over much of central Alberta (Gammel, 1955) attaining a maximum thickness of 60 m near Calgary. It thins to the east and the northeast and 'shales out' completely near St. Paul, Alberta (Gammel, 1955).

Underlying the Viking Formation is the Joli Fou Formation, a dark grey, non-calcareous, fissile marine shale with bentonitic horizons and thin lenses of fine and medium grained sandstone (Wickenden, 1949). It represents the first deposits of the early Colorado Sea. It is 18 to 36 m thick in central Alberta but thins rapidly to the west (Leckie and Reinson, in press). This Formation is known everywhere in the Canadian Plains as the Joli Fou Formation except in southern Alberta where it merges with the overlying Viking Formation and is known as the Bow Island Formation (Glaister, 1959). The Joli Fou Formation is equivalent to the Skull Creek Formation in Montana, the Thermopolis Formation of Wyoming and the Kiowa Shale of Colorado and Kansas (McGookey et al.,

Figure 2.2: Stratigraphic relationships of the Viking Formation in the Western Interior Basin. Note that the Viking Formation is known in central Alberta and southern Saskatchewan.

<table>
<tr><th rowspan="2">EPOCH</th><th rowspan="2">STAGE</th><th colspan="3">FOOTHILLS</th><th colspan="5">ALBERTA PLAINS</th><th rowspan="2">SOUTH SASKATCH - EWAN</th><th rowspan="2">WYOMING</th><th rowspan="2">MONTANA & NORTH DAKOTA</th><th rowspan="2">COLORADO</th><th rowspan="2" colspan="2">S.W. MANI TOBA</th></tr>
<tr><th colspan="2">SOUTH -ERN</th><th>CENTRAL</th><th>SOUTH -ERN ALBERTA</th><th colspan="2">N.W. ALBERTA</th><th>N.E. ALBERTA</th><th>CENTRAL ALBERTA</th></tr>
<tr><td>UPPER CRETACEOUS</td><td>CENOMANIAN</td><td colspan="2">CROWSNEST VOLCANICS</td><td rowspan="2">LOWER BLACKSTONE FORMATION</td><td colspan="6">BASE OF FISH SCALE MARKER</td><td></td><td></td><td>GRANEROS FM.</td><td></td><td rowspan="4">ASHVILLE FORMATION</td></tr>
<tr><td rowspan="3">LOWER CRETACEOUS</td><td rowspan="3">LATE ALBIAN</td><td rowspan="3">BEAVERMINES FM.</td><td rowspan="3">BLAIRMORE GROUP</td><td rowspan="3">BOW ISLAND FORMATION</td><td colspan="2">LOWER SHAFTSBURY FM.</td><td>LOWER LABICHE FM.</td><td>LLOYDMINISTER SHALE</td><td>COLORADO SHALE</td><td>SHELL CREEK FM.</td><td colspan="2">MOWRY SHALE</td><td></td></tr>
<tr><td rowspan="2"></td><td rowspan="2">PEACE RIVER FORMATION</td><td rowspan="2">PADDY MBR.</td><td>PELICAN FM.</td><td colspan="2">VIKING FORMATION</td><td>MUDDY S.S.</td><td>NEWCASTLE S.S.</td><td>J. S.S.</td><td>SILT MEMBER</td></tr>
<tr><td colspan="3">JOLI FOU FM.</td><td>THERMOPOLIS SHALE</td><td>SKULL CREEK SHALE</td><td></td><td></td></tr>
</table>

1972; Robb, 1985).

Overlying the Viking Formation are the dark marine shales of the Colorado Group (Colorado shales) which reach thicknesses of up to 61 m (Simpson, 1975). Other informal names for this unit are the Lloydminister Shale (Tizzard and Lerbekmo, 1975) and the Unnamed Shale (Evans, 1970). The Colorado shales are equivalent to the Mowry and Graneros Formations in the American Great Plains (McGookey et al., 1972).

Capping the Colorado shales is the Base of Fish Scales (BFS) which marks the end of sedimentation in the Lower Cretaceous. This unit is present throughout the basin and gives a distinctive well log response. The BFS is used as a datum in this study. The stratigraphic relationships of the Joli Fou, Viking and Colorado shales are illustrated in Fig. 2.2.

2.3 Biostratigraphy and Chronostratigraphy

The lack of diagnostic foraminiferal assemblages within the Viking Formation makes an assignment of an exact date difficult. However, based on microfaunal evidence from the Joli Fou and the Colorado Shale, the Viking is assigned a mid-late Albian age (Stelck, 1958). The underlying Joli Fou belongs the *Haplophragmoides gigas* zone while the overlying Colorado shale belongs to the *Miliammina manitobensis* zone (Stelck, 1975). The exact contact between these two zones is unknown

(Caldwell et al., 1978).

Chronological dating using Potassium-Argon radiometric dates of bentonite horizons within the Viking Formation gives ages which range from 97 to 100 Ma (Tizzard and Lerbekmo, 1975; Amajor, 1980).

2.4 Structure

The study area is situated in the Alberta Foreland Basin of the Canadian Plains and lies (with the exception of the extreme south west portion (T33 R7)) east of the Foothills Deformed Belt. The Alberta Foreland Basin is a simple syncline which had developed by the end of Cretaceous time (Podruski et al., 1988). The Viking Formation is found on the north east limb (dipping to the west) of this syncline. Within the study area, the dip of the top of the Viking main sand (Viking B sand) increases marginally from 0.64° in the southwest corner to 0.66° in the northeast corner.

The deformed belt occupies the southwestern half of T33-R7. It formed during the Laramide Orogeny, from Maastrichtian to Paleocene time, and is therefore post Viking deposition (Podruski et al. , 1988). In the deformed part of the study area the effects of this orogeny include elongation of linear features such as pebbles, and numerous fault repeats, as seen from geophysical well logs.

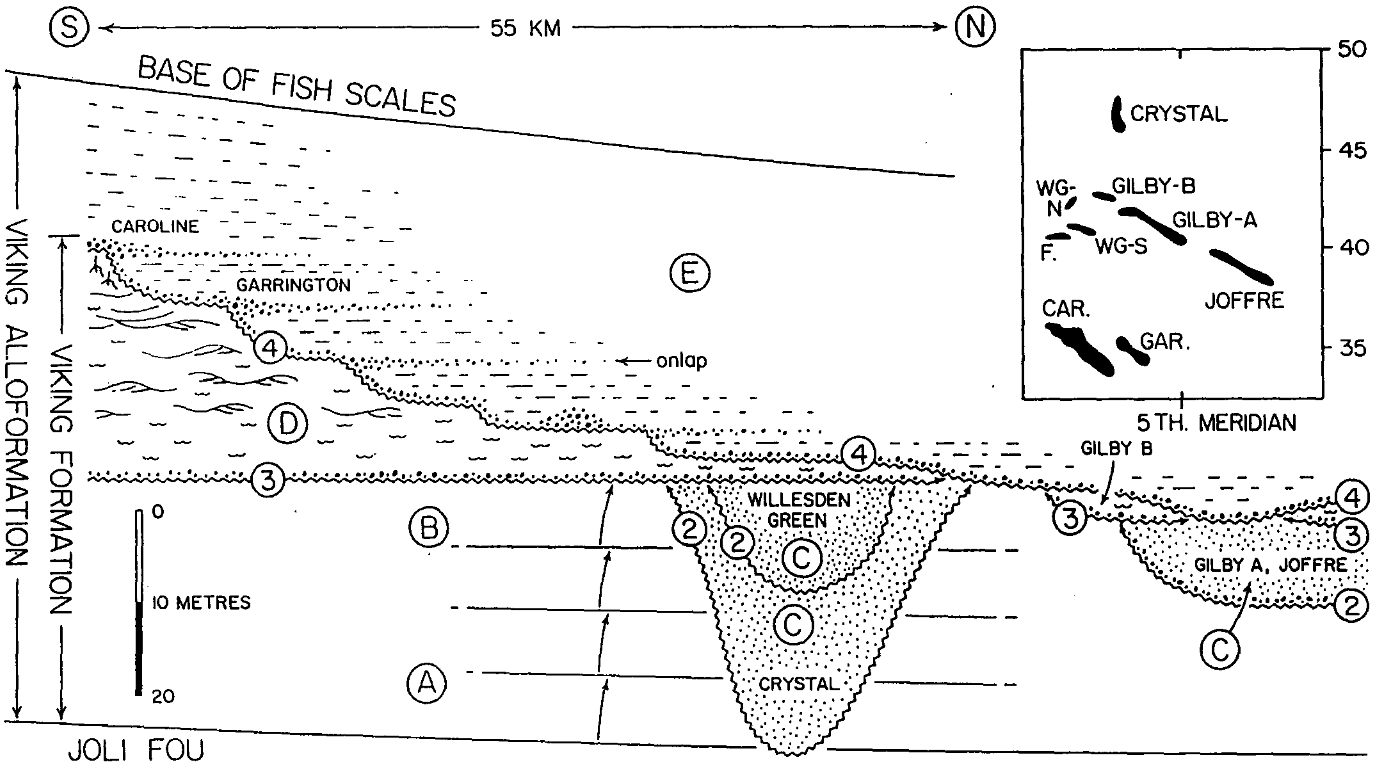
There do not appear to be any other major structural features (i.e. faults) in the bulk of the study area.

2.5 Internal Stratigraphy of the Viking Formation

Previous research on the Viking Formation has documented the existence of several erosion surfaces (Hein et al., 1986; Leckie, 1986; Downing and Walker, 1988; Leckie and Reinson, in press). However, these surfaces have not been correlated over the entire basin and their relationship to one another is unknown. Ongoing work at McMaster University involving the simultaneous study of overlapping areas across much of the basin has enabled the correlation of these erosion surfaces and their correlative conformities (A.D. Reynolds, pers. comm.). With this knowledge of the geometry, nature and extent of the bounding discontinuities an allostratigraphy has been constructed for the Viking formation.

The allostratigraphy proposed for the Viking Formation is restricted to an area between Harmattan East and Joffre and encompasses the fields of Harmattan East, Caroline, Garrington, Willesden Green, Gilby A, Gilby B, Joffre, and Crystal (Fig 2.3). Within this area 4 erosion surfaces defined as VE1 (Viking erosion surface 1) through VE4, and 5 allomembers, A to E, have been recognized and correlated. Work on the regional extent of these erosion surfaces is still ongoing. At present, the regional extent of VE2 is debatable and it is unresolved whether VE2 is present over wide areas of the basin, including the study area (A.D. Reynolds, pers. comm., 1989), or whether VE2 is present only as the base of the channels found at Willesden Green and Crystal (Boreen,

Figure 2.3: Allostratigraphic sketch of the Viking Formation. The sketch was constructed from regional cross sections between the Caroline and Crystal fields and shows a simplified interpretation of the Viking allostratigraphy. The circled letters refer to erosion surfaces (a circled 4 indicates VE4). From R.G. Walker (pers. comm., 1990).



S
55 KM
N
BASE OF FISH SCALES
CAROLINE
GARRINGTON
E
onlap
D
VIKING ALLOFORMATION
VIKING FORMATION
0
10 METRES
20
B
A
WILLESDEN GREEN
C
CRYSTAL
GILBY B
GILBY A, JOFFRE
JOLI FOU
CRYSTAL
WG-N
GILBY-B
GILBY-A
F.
WG-S
JOFFRE
CAR.
GAR.
5 TH. MERIDIAN
50
45
40
35

1989,). Figure 2.3, which outlines the general Viking allostratigraphy, favours the latter scenario, while many of the other figures in this study, including all of the cross sections, include a VE2 "pick". While it is clear that the "pick" identified as VE2 in these figures is a correlatable marker, its validity as a correlative conformity to VE2 is, at present, uncertain. An additional implication of this uncertainty is that if the VE2 surface is present within the study area, then the rocks found underlying the VE3 surface would comprise part of Allomember C. If, on the other hand the VE2 surface is not present, then the rocks underlying the VE3 surface would belong to Allomember B. Due to this uncertainty, this allomember will be described as Allomember B/C.

2.6 Stratigraphy at the Caroline and Garrington Fields

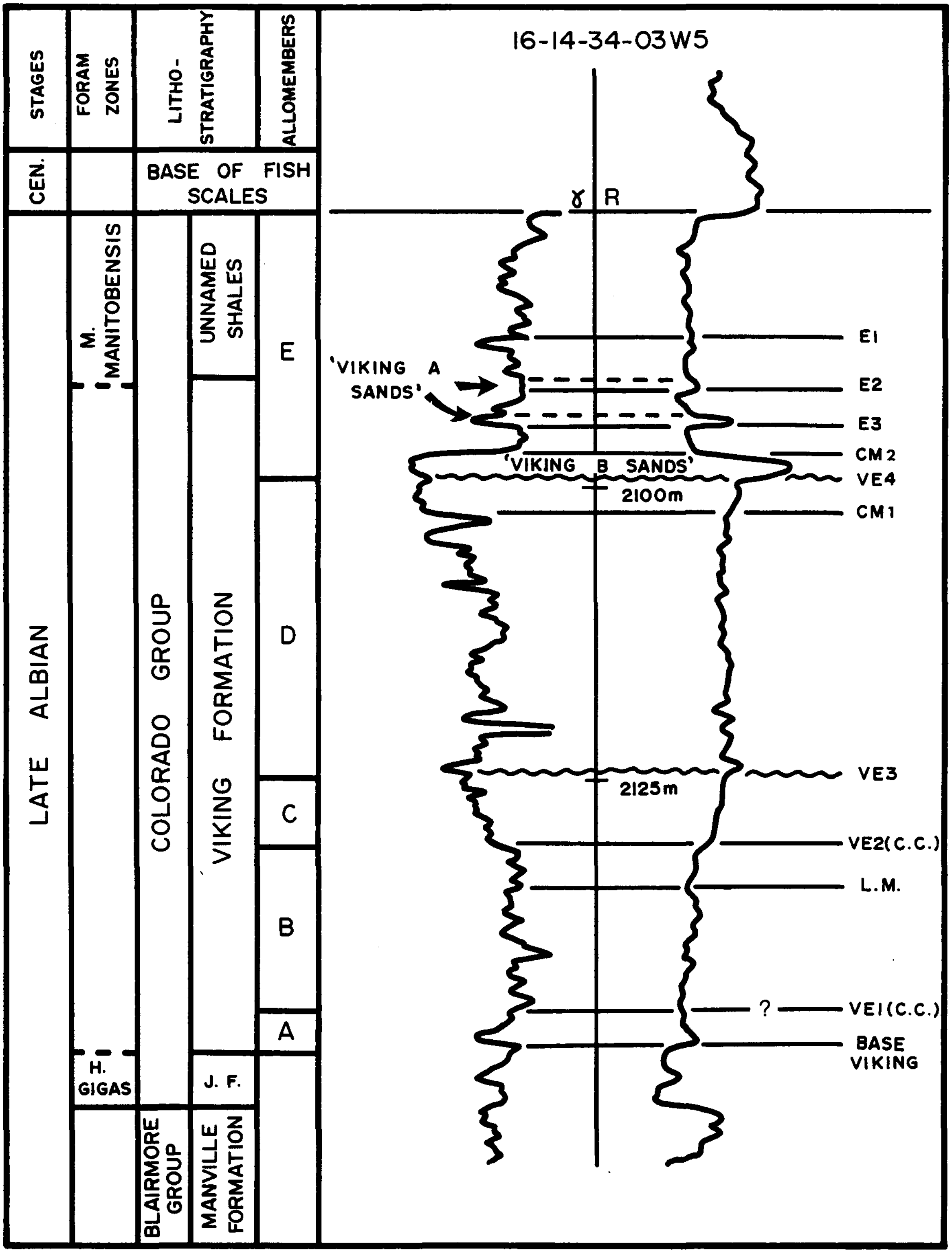
The Viking Formation ranges in thickness from approximately 54 m in the northwest corner of the map area to approximately 32 m in the southeast corner. Other researchers working to the north of the study area have defined the base of the Viking Formation at the inflection point on the first positive deflection of the resistivity log above the Joli Fou Formation (Downing and Walker, 1988; Power, 1988). This pick is made with difficulty in the study area because the Joli Fou Formation is very thin and begins to merge with the Viking Formation to become the Bow Island Formation. By correlation with wireline logs to the north of the study area a tentative estimate of the base of the Viking can be made but should be treated with caution. Three coarse grained sandstone and conglomerate bodies have been defined within the Viking Formation in the study area by previous researchers and have been given the informal names "A sand, A+ sand and the B sand" (Robb, 1985; Hein et al., 1986 and Leckie, 1986). These sand bodies are encased by marine shales and are overlain by Colorado shales. These sandbodies result in positive deflections on resistivity and negative deflections on gamma ray geophysical logs. As will be shown in a later section, there are actually more than three of the sandbodies present in the study area. The top of the Viking Formation has been defined as the top of the uppermost sandstone and conglomerate horizons (Robb, 1985; Hein et al., 1986). This pick is useful for industry because it denotes the upper petroliferous sands. The coarse grained horizons are encased by and overlain by marine shales of the Colorado group. In an allostratigraphic scheme (N.A.C.S.N., 1983), the top of the Viking Alloformation could be picked at the next bounding disconformity, which appears to be the BFS.

Although all 5 of the allomembers are present within the study area, only the uppermost 2 (members D and E) contain potentially economic lithologies and hence are commonly cored. Core penetrates the top of Member B/C only rarely. These relationships are illustrated in Figure 2.4.

2.7 Paleogeography

Sediments of the Lower Colorado Group were deposited during the Late Albian when the interior of North America was

Figure 2.4: Viking stratigraphy at Garrington. Different zonations are given in columns to the left. Abbreviations are as follows: Cen - Cenozoic, J.F. - Joli Fou Formation. The log and core picks given on the right hand side are those utilized in the construction of cross sections and isopach maps and are explained in the text. Some of the wells contain the additional log picks E4 and E5 which are not shown here. The terms CM1, CM2, and LM are valid for this study only and are not the same as those of Downing and Walker (1988).


STAGES
FORAM ZONES
LITHO- STRATIGRAPHY
ALLOMEMBERS
CEN.
BASE OF FISH SCALES
LATE ALBIAN
M. MANITOBENSIS
H. GIGAS
COLORADO GROUP
BLAIRMORE GROUP
UNNAMED SHALES
VIKING FORMATION
J. F.
MANVILLE FORMATION
E
D
C
B
A
16-14-34-03W5
γ R
'VIKING A SANDS'
'VIKING B SANDS'
2100m
2125m
E1
E2
E3
CM2
VE4
CM1
VE3
VE2(C.C.)
L.M.
?
VE1(C.C.)
BASE VIKING

inundated by seas advancing from the north and to some extent from the south (Williams and Stelck, 1975). The Joli Fou and Viking Formations were deposited as part of the Kiowa-Skull Creek Marine Cycle, a transgressive-regressive cycle which coincides with a Late Albian global rise and fall of sea level (Kauffman, 1984). Joli Fou shales were deposited during the greatest extent of transgression when the northern Boreal and Southern Gulfian seas had formed a continuous seaway across western North America (Williams and Stelck, 1975). The Viking Formation and its equivalent formations were deposited as a clastic wedge during a major regression related to a global sea-level drop at 97 Ma. (Vail et al., 1977; Haq et al., 1987; Kauffman, 1984). At this time the continuous seaway had been cut off to the south and was connected to the ocean only to the north (Williams and Stelck, 1975). Clastic material for these sandstone deposits was provided by the ongoing tectonic activity to the west (Caldwell, 1984). Bentonitic horizons found within the Viking Formation resulted from intermittent volcanism associated with the rising Cordillera.

Finally during Late Late Albian time, the second flooding of the Boreal Sea resulted in the deposition of the transgressive Colorado Shales and marked an end to Viking deposition.

2.8 Data Base and Study Method

The data base for this study consists of 139 measured cores and 584 logs within the study area shown in Figure 2.1.

The cored wells are listed in Appendix 1, along with the present depths of the cored intervals.

All cores were measured at the Alberta Energy Resources Conservation Board, Core Research Centre, in Calgary. Sedimentological studies consisted of detailed logging of sedimentary structures, biogenic structures and grain sizes (using a Can-Strat card). A facies scheme was established based on sedimentary and biogenic structures, and grain size. Detailed photos of individual facies and lithological contacts, as well as of continuous boxes of cores, were taken in Calgary.

Wireline logs used in this study consist exclusively of resistivity and gamma ray logs. Fairly good correlation is possible between the logs and core, although in some cases the level of resolution of the logs is not high enough to show all the detail present in core. The Base of Fish Scales (BFS) is a prominent and ubiquitous marker located above the Colorado shales and is therefore used as the datum for all stratigraphic cross sections. The BFS represents a condensed section and is thought to have been deposited in a deep water, offshore setting. It is therefore considered to have been deposited on as smooth and flat a surface as can be reasonably be reconstructed.

Core lithologs, core photos and well logs not included in this thesis are stored at McMaster University under the care of Dr. R.G. Walker and are available for examination upon request.

CHAPTER 3: VIKING LITERATURE REVIEW

3.1 Introduction

The Viking Formation was first named in 1918 by Slipper after the discovery of the gas bearing sands of the Viking-Kinsella area. It achieved Formation status in 1958 (Stelck, 1958). Since that time the Viking Formation has received considerable attention, inspired in part by its economic importance; the Viking has estimated in place reserves of $247.6 \times 10^3 m^3$ of crude oil and $362\ 869 \times 10^6 m^3$ of raw gas (Energy Resources Conservation Board, 1983, 1984). The origin of the coarse sands and conglomeratic horizons making up much of the Viking Formation has been controversial due largely to their stratigraphic position between the marine shales of the Joli Fou Formation and the Colorado shales. Many depositional scenarios have been invoked by researchers and include: a) regressive and transgressive shoreline deposits, b) storm surge deposits, c) turbidites, d) nearshore complexes of beaches, barrier islands and offshore bars and e) tidal current ridges.

3.2 Early Research

Much of the early research on the Viking Formation concluded that shelf processes were responsible for transporting coarse material great distances into the offshore shelf environment. Both Beach (1955) and Roessingh (1959) suggested that turbidity currents were responsible for the offshore transport of pebbles and could explain the widespread occurrence of pebble beds and their poorly sorted character.

Koldijk (1976) argued that powerful storm-driven currents were more likely to have deposited the pebble beds offshore and suggested that the fields were then localized into 'bars' by shoaling processes acting over local topographic highs. Many other authors have invoked an offshore depositional setting via storm-currents (Stelck, 1958; Tizzard and Lerbekmo 1975; Reinson et al., 1983). Evans (1970) invoked tidal currents to explain the unusual orientation of the Dosland-Hoosier field in Saskatchewan. Tides were also suggested to have influenced the upper part of the Viking at Caroline (Leckie, 1986).

3.3 Recent Interpretations, Incorporating the Role of Sea Level Changes

Most recent investigations of the Viking Formation have incorporated the role of sea level changes in the interpretation of the distributions of Viking sands. One of the earliest proponents of this view was DeWiel (1956) who suggested that the Viking Formation was formed in a nearshore environment and that the distribution of Viking reservoir facies could be explained by lateral displacements of the shoreline. Other early Viking researchers also incorporated the role of sea level changes into their interpretations (Bullock, 1950; Gammel, 1955; Glaister, 1959; Lerand and Thompson, 1976).

Since the introduction of the concepts of seismic stratigraphy (Vail et al., 1977), sedimentologists have been reinterpreting the rock record with emphasis on depositional sequences and their bounding unconformities or correlative conformities. A depositional sequence has been defined in this context as "a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities" (Mitchum et al., 1977, p. 53). Implicit in these concepts is the role of changing sea level and the resulting shifts in the shoreline which create major disconformities. These concepts enable a logical explanation for the complex sedimentological features and stratigraphic breaks of previously 'problematic' sandbodies such as the Cardium Formation (Plint et al., 1986; Bergman and Walker 1987, 1988) and more recently, sandbodies within the Lower Cretaceous Mowry Shale (Davis and Byers, 1989).

Amajor (1980) conducted a regional study of the Viking Formation in Central Alberta and southwest Saskatchewan and concluded that at the beginning of Viking time, deltas supplied sediment during a relative still stand. Following this, he hypothesized, there was a gradual rise of sea level, during which the loci of sand deposition shifted landward (to the southwest) with time. He also subdivided the Viking Formation into 3 chronostratigraphic intervals using widespread bentonitic horizons. He reasoned that the basal interval was deposited farthest offshore and each succeeding interval was deposited closer to the southwest.

Beaumont (1984) conducted another regional study and presented a similar scenario for Viking deposition. Like Amajor (1980), he reasoned that there was a major basinward shift in the shoreline during earliest Viking time due to a major drop in sea level. As a result streams were able to transport pebbles and coarse sand across the subaerially exposed former shelf. Sea level then rose gradually throughout the remainder of Viking time during which the coarse material was redistributed across the shelf and localized by shelf processes into the various Viking fields. Thus while Beaumont (1984) did invoke sea level changes to account for Viking deposition, he still called for an offshore depositional setting for the Viking fields and did not discuss the problem of how the 'shelf hydraulic regime' actually formed the long narrow sand bodies.

Reinson et al. (1983) studied the Caroline and Joffre Viking fields, and invoked offshore transport of coarse material by strong density currents. They also suggested basinwide changes in the depositional settings due to sea level changes.

Leckie and Reinson (in press) conducted a regional study of the Viking Formation of central and southern Alberta, the Peace River Formation of northwestern Alberta and the Boulder Creek Formation of northeastern British Columbia and documented several major unconformities within an overall basinwide transgressive phase. They suggested that sea level rise was punctuated by at least 2 major lowstands during which most of the Viking fields were deposited.

Other more local studies of various Viking fields have also called for multiple sea level changes to explain the sedimentological characteristics and erosional breaks within the individual fields. Downing and Walker (1988) documented 3 erosion surfaces in their study of the Joffre field and suggested that the coarse grained material making up the field was a remnant shoreface created during a fall in base level. A subsequent transgression is thought to have removed any evidence of an upper shoreface and beach deposits. Power (1988) also concluded that both regressive and transgressive changes in sea level were responsible for the sediment distribution at the Joarcam field. Leckie (1986) suggested that the deposition at Caroline occurred during a sea level fall during which time the shoreline prograded into the basin and was followed by a rapid transgression. Hein et al. (1986) also invoked sea level changes in the deposition of the Caroline, Garrington and Harmattan East fields. Other local studies which have incorporated sea level changes into their conclusions include those of Raddysh (1988) at Gilby, Pozzobon (1987) at Eureka (Saskatchewan) and Raychaudhuri (1989) at Chigwell. None of these studies, with the exception of Raychaudhuri (1989) was able to correlate the local unconformities with those documented elsewhere across the basin. Thus the creation of a Viking allostratigraphy has not been possible until very recently.

Those Viking studies relating to Caroline and Garrington will be elaborated in section 3.4.

3.4 Previous Work in the Caroline and Garrington Area

It has only been within the last decade that attention has been given to the sedimentology and depositional environments of the Viking Formation within the study area. All of the researchers who have studied these fields concluded that they were deposited in a nearshore to shelf environment.

Reinson et al. (1983) suggested that the fine grained sands in the Caroline area were deposited as part of a prograding shoreface in a nearshore environment and that an erosional break recording a major shift in the depositional conditions separated these 'shoreface' sandstones from the overlying coarse grained sandstones and conglomerates. They recognized the enigmatic nature of these upper conglomerates, particularly those encased completely by marine shales (the "A sands" of industry) and postulated that they may have been deposited by bottom currents and subsequently remolded by tides.

Robb (1985) studied the sedimentology and diagenesis of the Garrington field and suggested that the lower portion of the Viking Formation was deposited as part of a prograding shoreface. However he suggested that the conglomeratic layer which caps these sands was introduced by sediment gravity flows and then reworked by strong geostrophic flows and remolded into large sand waves and dunes by strong marine currents. Although not a major theme of his work, he did allude to sea level changes in explaining the presence of at least 2 thin coarse grained to conglomeratic units encased in the shales. He suggested that they were the result of minor regressive episodes within the overall marine transgression responsible for deposition of the Colorado shales.

Hein et al. (1986) conducted a more regional study of the Caroline, Garrington and Harmattan East fields and suggested that submarine cut and fill scour features into the underlying prograding clastic wedge were the result of a fall in base level. Conglomerates were then deposited on these erosive features mainly from conglomeratic sediment gravity flows and then reworked by shelf processes. A marine transgression then resulted in the deposition of shale. The authors also invoked minor oscillations in sea level to explain the presence of coarse grained conglomeratic beds totally encased by marine shales, but did not expand on that idea.

Leckie (1986) suggested that the Viking Formation at Caroline could be explained as an overall regressive-transgressive couplet. The lower fine grained clastic wedge was a result of deposition of a prograding shoreface during sea level fall or still stand with a high sediment supply while the upper coarse grained conglomeratic units and intervening shales were deposited under transgressive conditions. He noticed a sharp contrast between the styles of sedimentation between the regressive and transgressive deposits indicating that the lower unit was dominated by storm deposits while the overlying deposits contained a more tidal signature. He attributed this to a change in basin configuration after the rise of sea level. He suggested that a regional rise in sea level transgressed and reworked previously deposited sediment and that tidal currents remolded these deposits into their present configuration. Leckie also attributed the 'Viking A' sands to minor episodes of regression or still stand within the overall transgression but similarly did not elaborate.

In their regional study mentioned previously, Leckie and Reinson (in press) documented the stratigraphic position of the Caroline field with respect to the fields far to the northwest. They indicated that the Caroline field was part of a clastic wedge which overlay a progradational wedge in which the Viking fields to the northwest were located. He called these progradational wedge cycles 1 and 2 and indicated that a major transgressive depositional break occurred between them. This was the first study in which the rocks of the Caroline area were tied in to a more extensive Viking allostratigraphy.

CHAPTER 4: FACIES DISCUSSION

4.1 Introduction

Facies are defined on the basis of grain size, physical structures, and biological structures. This section will include descriptions of each facies found within the study area and a preliminary interpretation of the depositional environment for each.

Within the study area, most cores only penetrate the top two Viking allomembers (D and E). The next lowest member (B/C) was cored in a few locations.

A regional facies scheme which encompasses each of the different members and defines fourteen Viking facies has been developed to describe the formation over a large part of west central Alberta (McMaster Viking study group, pers. comm., 1989). Of these, nine have been recognized by the author within the study area, and an additional facies has been documented. The facies discussion employed here will generally follow the stratigraphic order of the facies, commencing with the oldest deposits. Some of these facies are repetitive and have been documented in underlying members elsewhere (A.D. Reynolds pers. comm., 1989) and therefore the numbering of facies for the regional study is different from that employed here.

4.2 Facies Descriptions and Preliminary Interpretations

Facies 1 - Burrowed Muddy Siltstone

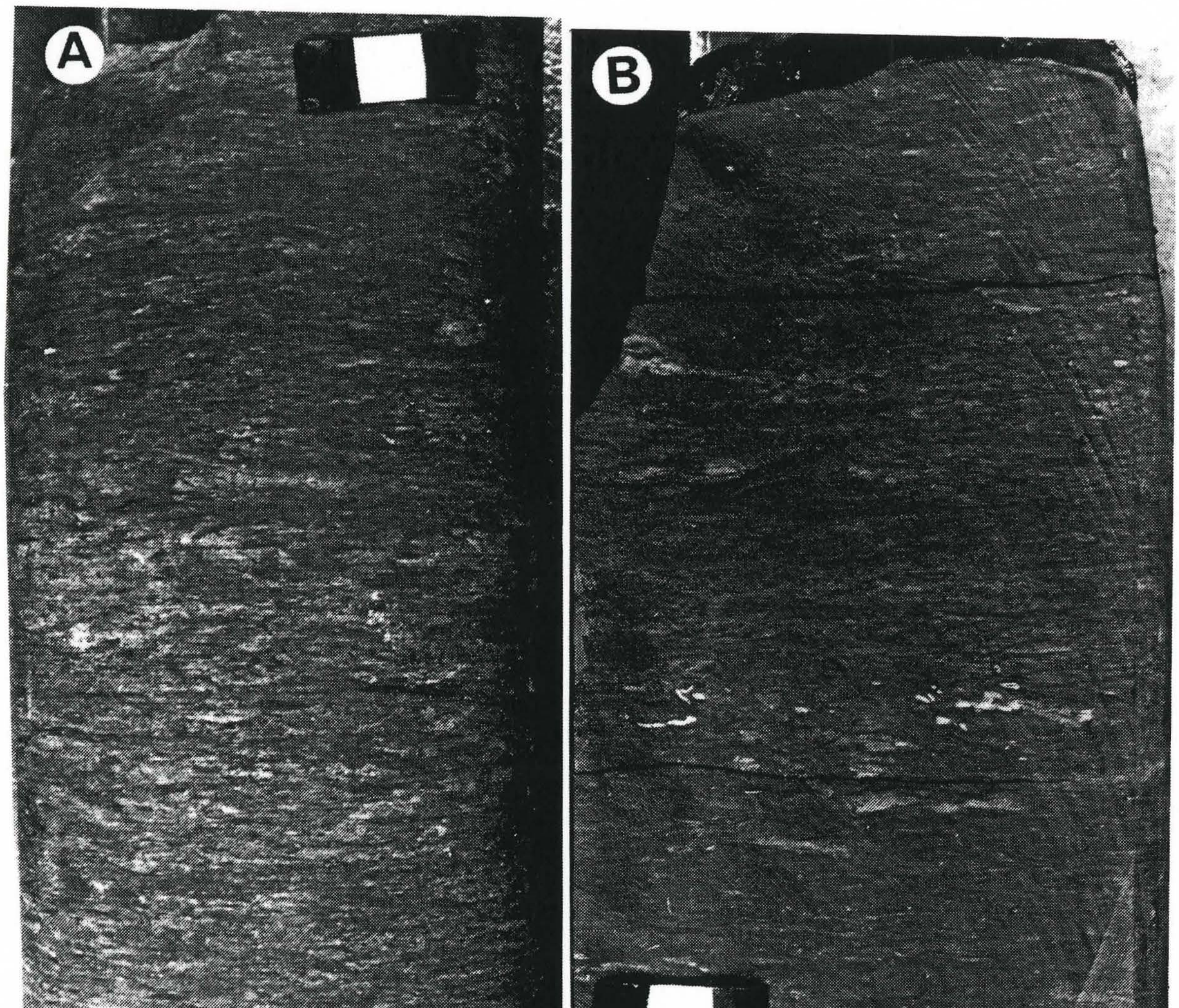
Description: This facies is composed of extensively burrowed mud, silt and minor amounts of fine grained sand (Fig. 4.1). It was observed in only a few cores within the study area, and is up to 2 m thick. Rare, very thin laminae or lenses of silt and very fine grained sand are preserved in places. *Helminthopsis* is pervasive in this facies; *Terebellina* is also present, although not as abundantly. A thin matrix-supported pebble veneer (clast size up to 0.8 cm) always caps this facies. Within the study area, this is the lowermost Viking facies observed in core. It lies unconformably below the burrowed and laminated sandy mudstones (Facies 2) and hence below the VE3 erosion surface.

Preliminary Interpretation: Based on the very fine grain sizes present, the pervasiveness of burrowing and the presence of marine trace fossils, along with the lack of any sedimentary structures, this facies is interpreted to have been deposited in a marine offshore environment, well below fair-weather wave base. Storms may have brought in small amounts of sand and silt to an otherwise low energy environment. Burrowers then reworked these deposits during fair-weather.

Figure 4.1: Facies 1 - Burrowed Muddy Siltstone.

a) Note that extreme burrowing has resulted in a churned mixture of sand, silt and mud.
Helminthopsis **burrows are present. Well 6-29-36-2; Depth 1927.7 m; Scale bar is 3 cm long.**

b) This example shows a higher percentage of mud than the previous example. Rare *Terebellina* **and** *Helminthopsis* **burrows are visible. Well 4-32-36-4; Depth 2203.0 m; Scale bar is 3 cm long.**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Facies 2 - Burrowed and Laminated Sandy Mudstone

Description: This facies is composed of mudstone, siltstone, and very fine to fine grained sandstone interbedded at the cm. scale (Fig. 4.2). It is up to 12 m thick. Sandy beds make up less than 50 % of the total thickness and range from about 0.5 to 15 cm in thickness; most are less than 10 cm. The sandstone beds may have sharp or burrowed bases and graded or burrowed tops. Thin sand 'pods' and 'lenses' are common within a bioturbated, muddy background. The sand commonly contains organic rich laminae. Burrowing is always evident within this facies and ranges in density from sparse to extensive. Trace fossils are abundant, and include *Chondrites, Helminthopsis, Planolites, Teichichnus, Terebellina, Zoophycos,* as well as less abundant *Ophiomorpha* and *Skolithos*. Sedimentary structures are commonly difficult to discern, but include gently undulating stratification with occasional low angle truncations (with wavelengths of about 10-15 cm), parallel lamination and climbing ripple-form stratification.

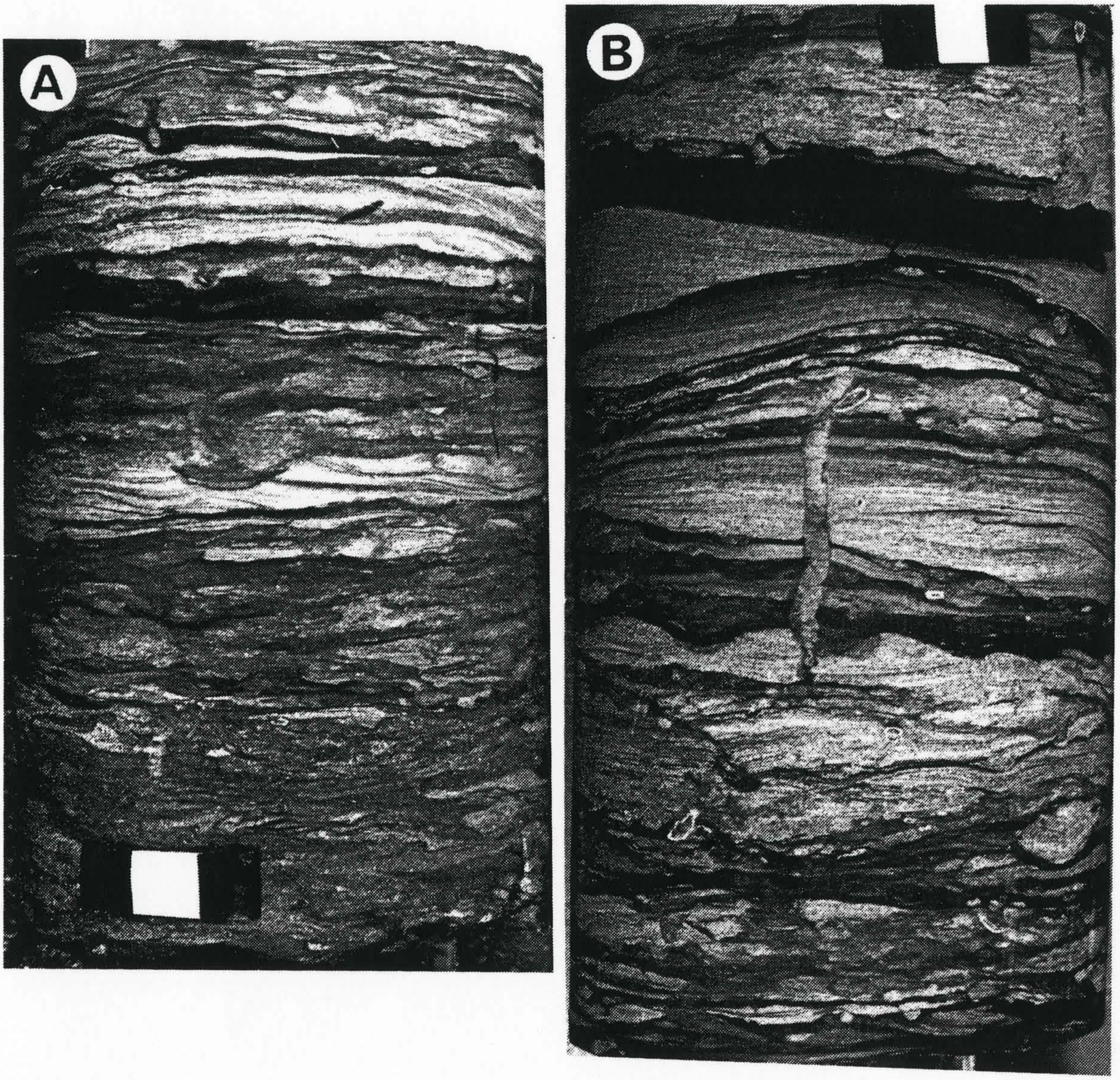
Other features associated with this facies are rare thin pebble stringers (clast sizes generally less than 1 cm), mud rip up clasts, sideritized mud bands, pyrite nodules, siderite nodules and organic-rich bands.

This facies is commonly transitional with the overlying hummocky cross stratified sandstone facies. In many of the cores, the sandstone beds show a slight thickening toward the

Figure 4.2: Facies 2 - Burrowed and Laminated Sandy Mudstone.

a) Thin, fine grained sand and silt beds in a burrowed, muddy background are typical of this facies. Some disruption of bedding due to burrowing is evident. *Planolites, Terebellina, Helminthopsis,* **and** *Chondrites* **trace fossils are present. Well 6-29-36-2; Depth 1925.8 m; Scale bar is 3 cm long.**

b) Note the preservation of thin sand and silt beds in a muddy, burrowed background. Trace fossils are abundant and include *Skolithos, Terebellina,* **and** *Chondrites.* **Well 14-17-35-1; Depth 1864.0 m; Scale bar is 3 cm long.**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top of the facies. The lower contact was observed in only four cores, in which case the facies directly overlies the VE3 erosion surface.

Preliminary Interpretation: The abundance of silt and mud in this facies, the abundance of burrowing and the presence of marine trace fossils interpreted to be of a mixed *Cruziana-Skolithos* ichnofacies suggests that this facies was deposited in a marine, offshore shelf setting. The sharp lower contacts and gradational tops suggest that the sandstone beds are the result of sporadic high energy conditions in an otherwise quiet environment. These features suggest a storm-dominated shelf setting.

Facies 3 - Hummocky Cross Stratified Sandstone

Description: This facies consists of clean, very fine to fine-grained sandstone interbedded with silty shales and siltstones (Fig. 4.3). This facies ranges in thickness from 1.4 m to 7.2 m (average thickness 5.0 m) and sandstone beds comprise 50% to 80% of the thickness.

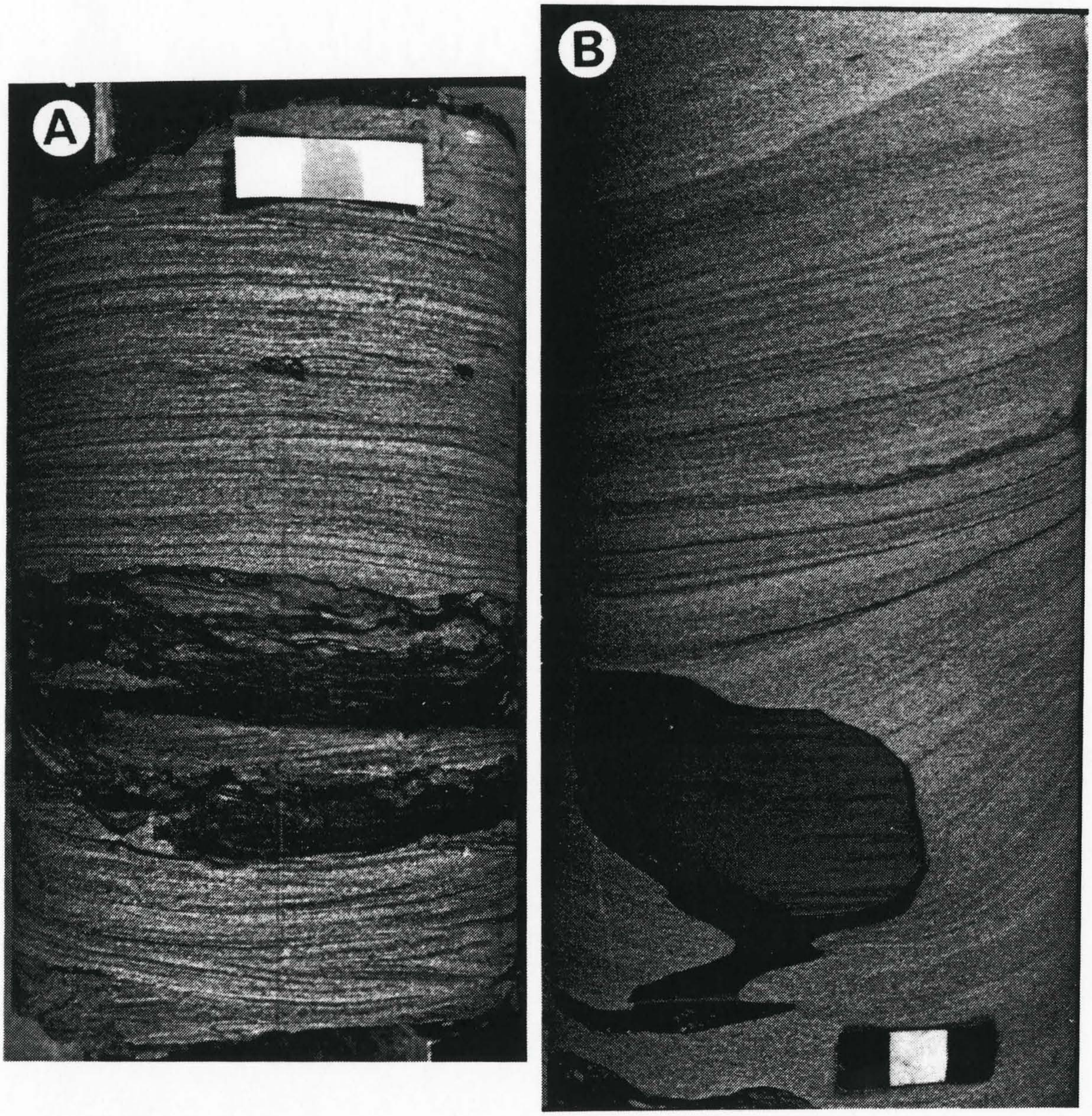
Sandstone beds vary in thickness from approximately 10 cm to 2.0 m, increasing upward through a given section. They are typically sharp based with sharp or burrowed tops. The prominent internal stratification is made up of parallel to sub-parallel laminae which may be slightly curved, dip gently (less than 15 cm), and show low angle, inclined intersections. Low angle climbing rippleform stratification is found in the upper portions of some sandstone beds. Other features found within the sandstone interbeds are organic rich laminae ("coffee grounds"), thin mud drapes, mud clasts, siderite rip-up clasts and pyrite nodules. Thin pebble horizons in the sandstone, with clasts up to 1.7 cm, are present in a few of the cores.

The sandy mudstone and siltstone interbeds range from a few cm to 30 cm. Their appearance is a function of the amount of sand and silt present, as well as the degree of burrowing. Consequently, the interbeds may be quite sandy and mottled due to intense burrowing. Alternatively, they may contain continuous, very thin, sharp based graded sandstone beds, discrete sandstone pods and sandstone lenses where burrowing is less intense, or may be dark and homogeneous where little to no burrowing is involved. The moderately burrowed sandy mudstone interbeds are very similar in appearance to the underlying Facies 2 (burrowed and laminated sandy mudstones). Generally, the sandy mudstone interbeds become less burrowed towards the top of the facies. Sideritized mud beds, syneresis cracks, organic laminae, and thin pebble veneers or scattered pebbles with clast sizes less than 1.0 cm are also found in some of these interbeds. Trace fossils are common and generally decrease in abundance towards the top of the facies. In the sandy mudstone beds, trace fossils are quite prevalent and include *Chondrites, Helminthopsis, Planolites, Skolithos, Terebellina,*

Figure 4.3: Facies 3 - Hummocky Cross Stratified Sandstone.

a) Note the alternation between fine grained sand beds and thin, mildly burrowed muddy interbeds. The sandstone beds in this example exhibit low angle parallel lamination and hummocky cross stratification. Well 6-19-34-2; Depth 2069 m; Scale bar is 3 cm long.

b) This example shows a thick, fine grained sandstone interbed (> 20 cm) with hummocky cross stratification. Note the large sideritized mud rip up clasts in the lower portion. Well 14-4-36-5; Depth 2354.9 m; Scale bar is 3 cm long.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Teichichnus and *Zoophycos*. Within the sandstones, trace fossils are less common but include *Ophiomorpha* and *Teichichnus*. There is a gradational change upwards from trace fossils of a mixed *Cruziana-Skolithos* ichnofacies to one dominated by traces of a *Skolithos* ichnofacies.

This facies gradationaly overlies Facies 2 (burrowed and laminated sandy mudstones) and is usually gradationally overlain by Facies 4 (swaley cross stratified sandstones). However, it has also been observed immediately beneath the VE4 erosion surface in cores where Facies 4 is absent. Because Facies 3 is transitional with the underlying Facies 2, its lower contact is taken to be the first appearance of a sandstone bed greater than 15 cm in thickness which is followed by a predominance of sandy beds over muddy beds.

Preliminary Interpretation: The parallel to sub-parallel, gently undulating stratification with low angle laminae intersections is interpreted to be hummocky cross stratification (HCS). HCS is accepted to be a characteristic product of storm wave activity below fair-weather wave base (Harms et al., 1975) and is thought to be the result of a combination of unidirectional flows generated by waning storms and, oscillatory storm wave action (Dott and Bourgeois, 1982; Walker et al., 1983; Swift et al., 1983).

Based on the presence of HCS, its interbedded nature and its stratigraphic position on top of laminated and burrowed sandy mudstones, Facies 3 is interpreted to have been deposited below fair-weather wave base and above storm wave base. Furthermore, the increase in thickness of the sand beds upwards, the decrease in burrowing structures and the change from a *Cruziana* dominated to a *Skolithos* dominated ichnofacies indicate a decrease in water depth upwards through the facies.

Facies 4 - Swaley Cross Stratified Sandstone

Description: This facies consists of clean, well sorted, very fine to fine sandstone (Fig. 4.4). Mudstone and siltstone interbeds are rare to absent, comprising less than 10% of the total thickness. The facies varies in thickness from 1.5 m to 12 m (average thickness of 5.2 m). The dominant sedimentary structures are parallel to sub-parallel, gently inclined laminations (less than 15°) which are truncated by overlying laminae in places. The laminations are usually well defined by comminuted plant debris ('coffee grounds') but very faint laminations, as well as sandstone beds lacking any discernable stratification, are also common. Low angle, asymmetrical ripple-form stratification is also present to a minor extent in some of the cores.

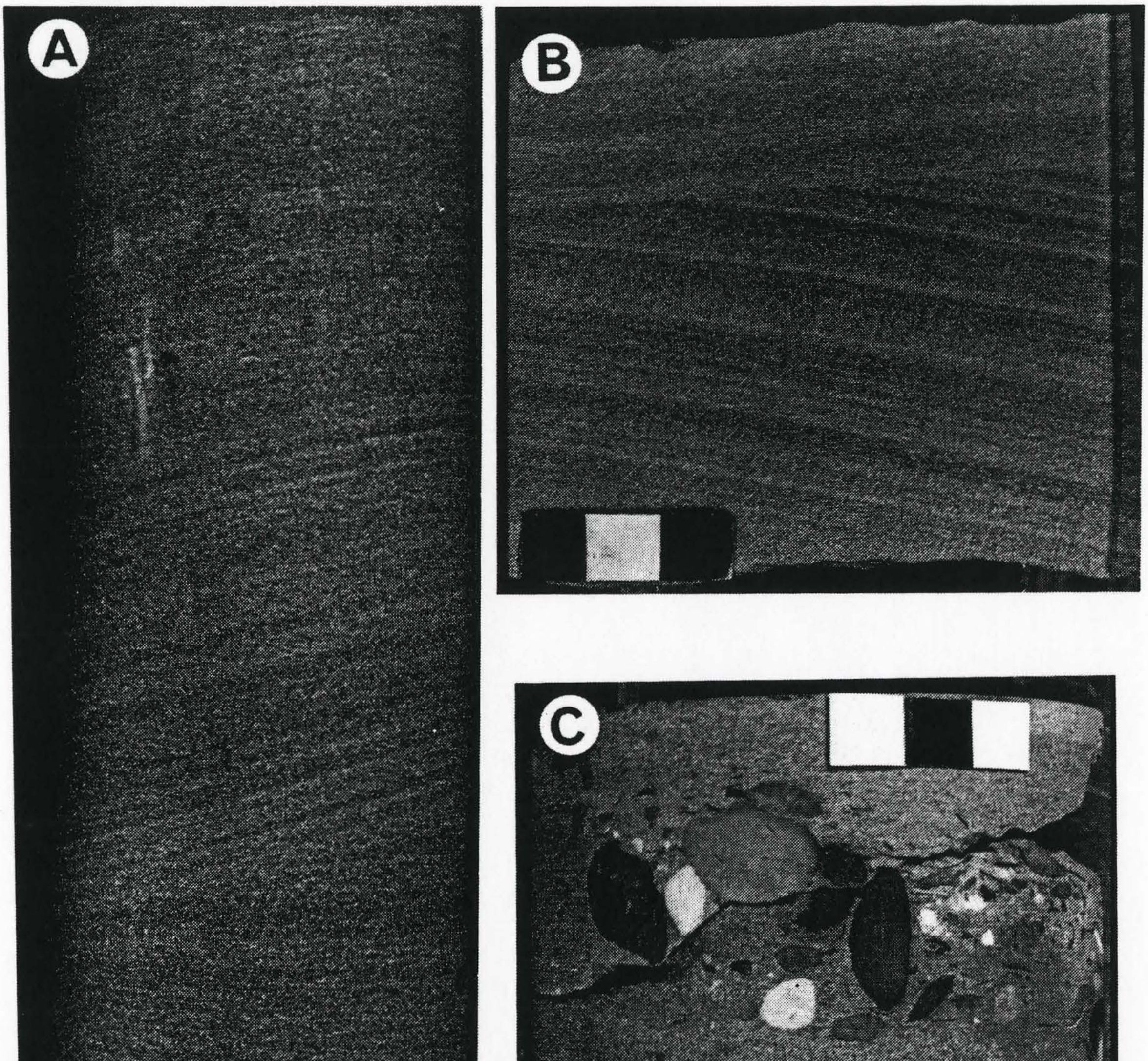
Other features associated with this facies are rare scattered pebbles, thin bands of scattered pebbles and thin matrix-supported conglomerate beds in which the matrix is clean and very fine to fine grained. Clasts are always smaller than 2.0 cm. Thin sideritized mud beds, siderite rip-up

Figure 4.4: Facies 4 - Swaley Cross Stratified Sandstone.

a) Note the uninterrupted thickness of fine grained sand with swaley cross stratification. Well 7-24-33-5; Depth 2462.2 m; Scale bar is 3 cm long.

b) This example shows the low angle truncation of stratification characteristic of SCS. Well 6-29-34-5; Depth 8320 ft.; Scale bar is 3 cm long.

c) Horizons of pebbles (up to 2 cm in diameter) within a fine grained sand matrix. This is a common variation of Facies 4. Well 11-23-34-2; Depth 6518 ft.; Scale bar is 3 cm long.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clasts, mud clasts, and thin organic-rich laminae ('coffee grounds') are also common. Pyrite nodules are rare but where present are in association with siderite rip-up clasts. Deformed bedding and steep scourfills are present in several cores. Calcified *Lingula* shells as well as mud-filled internal mold casts of *Lingula* are present along bedding planes in places. Burrowing within the sand is rare; where present it results in a faint mottling and partial destruction of sedimentary structures. Recognizable trace fossils are rare but *Ophiomorpha* has been observed within the sands. *Macaronichnus* was observed in only one of the cores examined. Similarly, the mudstone and siltstone interbeds show relatively little evidence of burrowing or trace fossils; where present, these include *Terebellina, Teichichnus,* and *Arenicolites.*

This facies occurs stratigraphically above Facies 3 (interbedded HCS sandstone), and immediately beneath the VE4 erosion surface. It is distinguished from the underlying unit by having sandstone bed thicknesses greater than 1.5 m and by containing substantially fewer mudstone or muddy siltstone interbeds.

Preliminary Interpretation: The parallel to sub-parallel, gently inclined laminations with low-angle scours are interpreted to be swaley cross stratification, a structure indicative of storm-dominated shoreline settings at shallower depths than HCS (SCS; Leckie and Walker, 1982; Rosenthal and Walker, 1987). Its presence, along with other features such as marine trace fossils of a *Skolithos* ichnofacies and the thick bedded nature of the sand, indicates a shallow marine shoreface setting probably above storm wave base. This interpretation is corroborated by the stratigraphic position on top of interbedded HCS sandstone. The total absence of rooted horizons indicates that deposits of the upper shoreface and beach are absent, thereby restricting deposition to the lower and middle sections of the shoreface.

Facies 5 - Cross Bedded Sandstone with Abundant Mud Rip Up Clasts

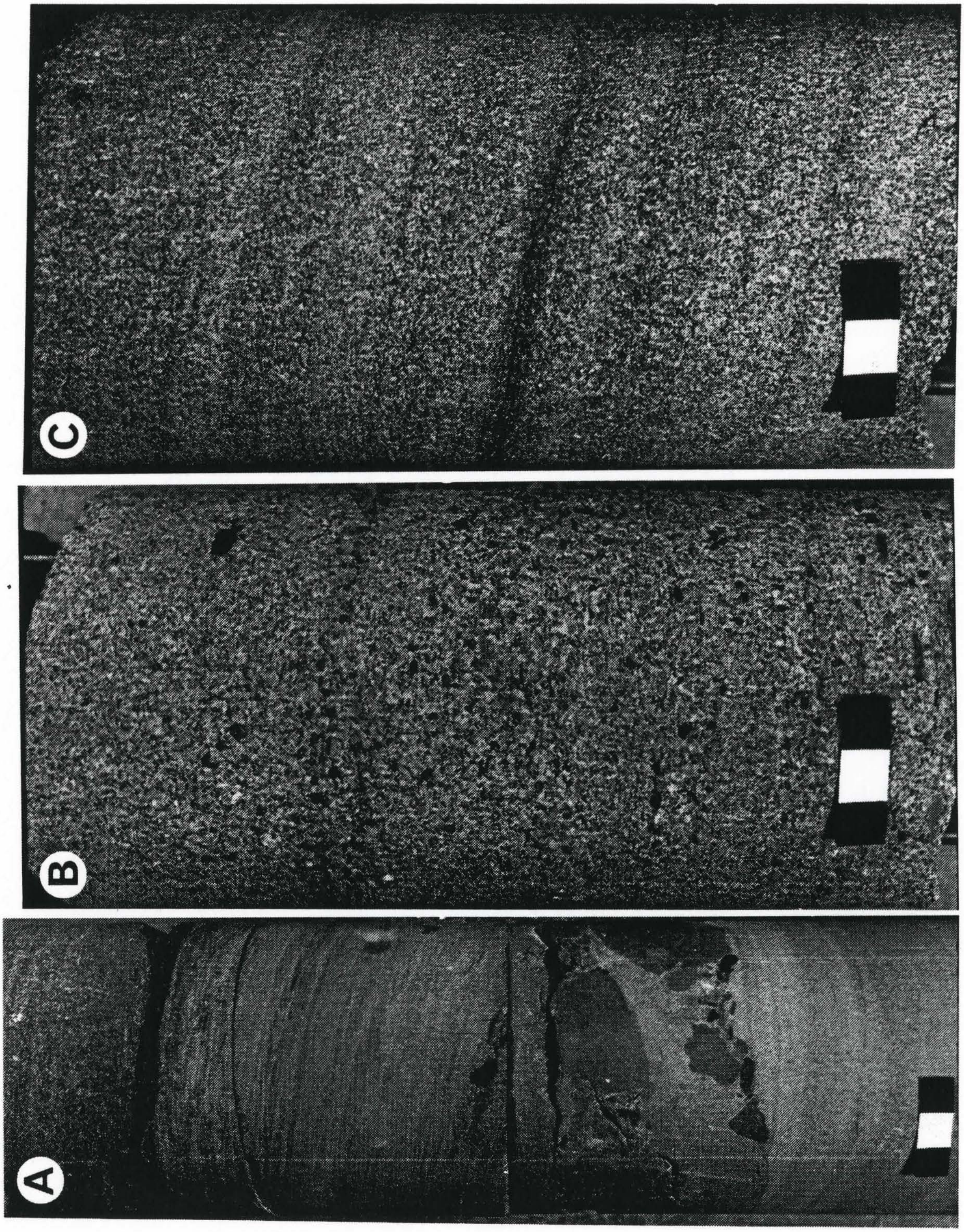
Description: Facies 5 is composed of coarse grained (from ML/FU to coarse granular), cross bedded sandstone with abundant mud rip-up clasts (Fig 4.5). It was observed in only one core within the study area (9-22-33-5W5) and has a thickness of 5.3 m. The cross beds are always less than angle of repose (12°-15°), are approximately planar and are unidirectional. No coset boundaries or low angle truncations were observed. There is an overall fining up within the upper 4.5 m of this facies, from coarse grained granular sandstone to MU/CL sandstone. There are also several abrupt grain size changes across stratification planes. The lower meter of this facies is composed of fine grained sideritized sand with an abundance of siderite nodules (up to 8 cm in diameter),

Figure 4.5: Facies 5 - Cross Bedded Sandstone with Abundant Mud Rip Up Clasts.

a) The basal portion of this facies is sharply overlying Facies 3. It is characterized by fine grained, sideritized sand with abundant siderite rip up clasts (up to 8 cm in diameter) and weakly developed, low angle cross stratification. Well 9-22-33-5; Depth 2431.4 m; Scale bar is 3 cm long.

b) Note the coarse granular sandstone with small mud rip up clasts and low angle, unidirectional cross beds. Well 9-22-33-5; Depth 2430.5 m; Scale bar is 3 cm long.

c) This example is from within the top meter of the facies and shows fine to medium grained sandstone with unidirectional, low angle cross stratification. Well 9-22-33-5; Depth 2427 m; Scale bar is 3 cm long.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mud drapes, mud rip up clasts and granules.

Facies 5 sharply overlies Facies 4 (swaley cross stratified sandstone) and occurs immediately beneath the VE4 erosion surface. None of the surrounding cores contain this facies.

Preliminary Interpretation: This facies is interpreted to be a channel fill deposit based on the substantial thickness of unidirectional cross bedded medium to coarse grained sand, the overall fining up of grain sizes, the abundance of siderite clasts, mud rip ups and mud drapes, particularly at its base, and the sharp, erosive contact with the underlying swaley cross stratified sandstone. This unit is not included with Facies 7 (pebbly cross stratified sandstone) because of the greater abundance of mud and siderite rip-up clasts, the striking unidirectionality of the cross beds, the lack of cross beds exhibiting angle of repose cross bedding and the lack of any discernible coset boundaries.

Facies 6 - Conglomerate

Description: This facies consists of poorly sorted, chert pebble rich rocks with more than 25 % of its components made up of clasts greater than 2 mm in diameter (Fig. 4.6). The facies varies in thickness from several cm to greater then 3 m and averages 1 m. Conglomerates exist in a wide range of styles ranging from a matrix supported conglomerate to a very tight clast supported conglomerate. Conglomerates are present with both normal and inverse grading but most commonly are structureless. They were noted with crude imbrication and stratification in a few cores. Stratification is defined by clast size variations, by clast alignment, by mud drapes and by sandy horizons. Stratification range in orientation from flat lying and parallel, dipping at low angles and in rare cases at high angles.

The pebbles are rounded and clasts are usually 1.0 to 2.5 cm in diameter (max 5.5 cm.). The matrix is poorly sorted and ranges from a granular muddy matrix to a coarse grained granular matrix. Many of the conglomerates show a change of matrix in the last 5-10 cm from a poorly sorted sandy matrix to a muddy matrix speckled with granules and sand grains. Conglomerates with muddy matrixes do occur interbedded with those having a more granular matrix.

Burrowing is negligible in this facies; it was noted in a few of the cores with a muddy matrix and a low clast density in which case rare *Skolithos, Arenicolites* and *Ophiomorpha* burrows were observed.

This facies commonly overlies Facies 4. The contact between these two facies is very sharp and appears erosive. It also occurs interbedded with cross bedded pebbly sandstone (Facies 7) and pebbly burrowed mudstone (Facies 8) in the coarse grained interval overlying Facies 4 and in the upper coarse grained intervals (Viking "A sands") encased by marine shales.

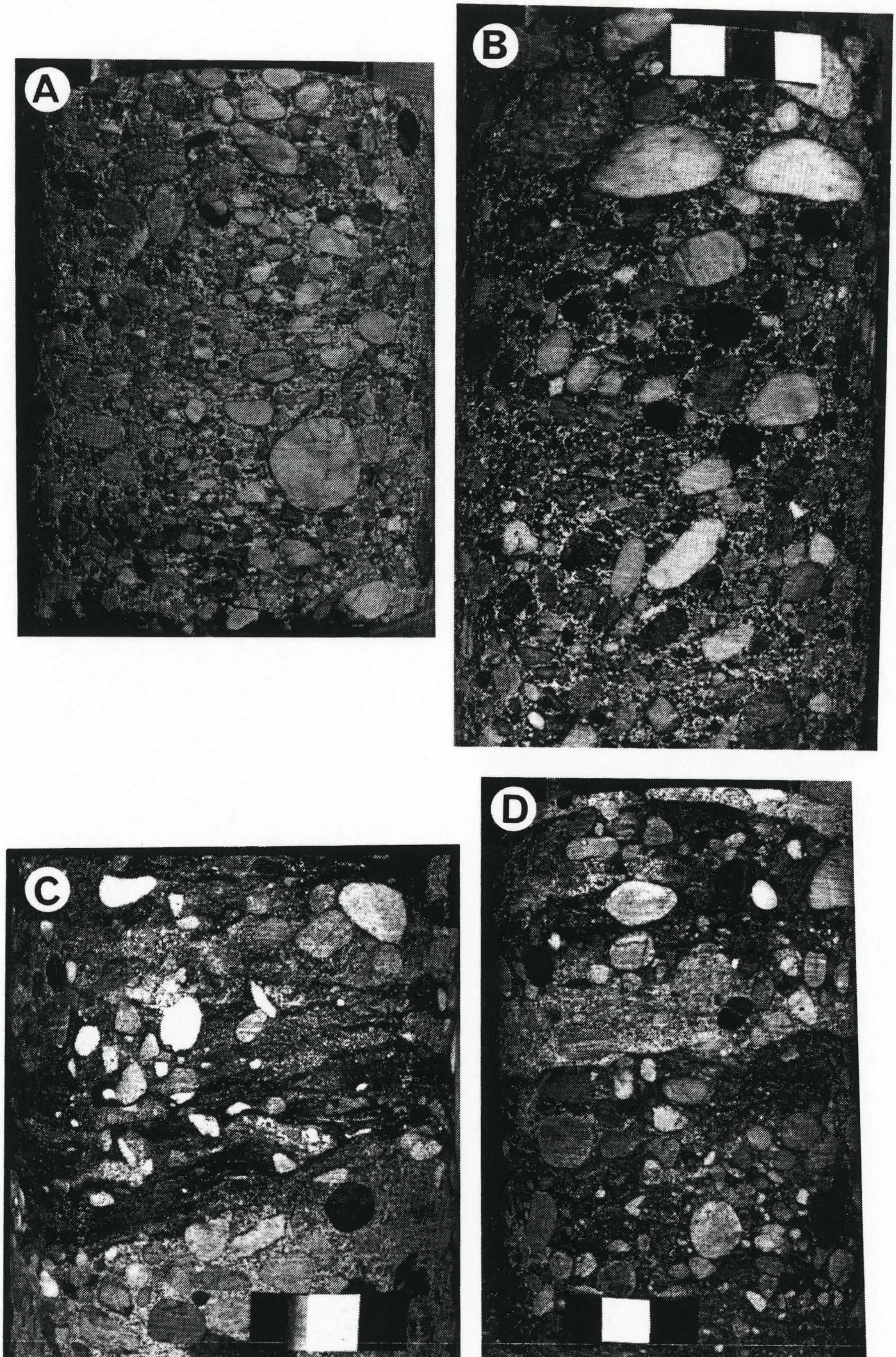
Figure 4.6: Facies 6 - Conglomerate.

a) Poorly sorted, massive conglomerate. Well 7-24-33-5; Depth 2460.7 m; Scale bar is 3 cm long.

b) Reverse grading with a slight clast imbrication. Well 6-26-34-3; Depth 2102.8 m; Scale bar is 3 cm long.

c) Mud drapes are a common feature of many of the conglomerates as is shown in this example. Well 8-24-35-4; Depth 2169.5 m; Scale bar is 3 cm long.

d) Banded conglomerate. This example shows conglomeratic bands with a poorly sorted sandy matrix and a gritty mud matrix. Well 6-14-34-5; Depth 7853.9 ft.; Scale bar is 3 cm long.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Preliminary Interpretation: The conglomerate facies is interpreted to have been deposited in an open shelf setting. The presence of intervening mudstone laminae and superimposed, amalgamated beds indicate that this facies was not deposited as a single event. In addition, the presence of crude stratification and imbrication, as well as this facies association with pebbly cross stratified sandstones, suggests deposition by traction currents. The source of the pebbles is, at this point, speculative.

The exact depositional environment and mechanisms of deposition is enigmatic and cannot be determined without considering the conglomerates intimate relationship with Facies 7 and 8. For this reason interpretation of this facies will be considered more fully in a later section.

Facies 7 - Pebbly Cross Stratified Sandstone

Description: Facies 7 consists of poorly sorted pebbly cross stratified sandstone with grain sizes ranging from medium grained to pebble sized of up to 3 cm in diameter. The clast abundance can vary between 1 % and 25 % of the total volume. The thickness of this facies ranged from several cm up to 5.5 m and averaged about 60 cm.

Four major types of stratification occur within this facies. High angle cross stratification with laminae dipping at angles of up to 30° is the most common. It was often difficult to differentiate between tangential cross stratification and planar cross stratification in a 3 or 4 inch core, but evidence of both types was found. The tangential cross stratification has tangential tosets and increases in angle upwards. Planar cross stratification, in contrast, remains at a relatively constant angle. Both types were commonly observed in sets about 10 cm thick. Low angle cross stratification with dip angles at less than 12° are another common form of stratification within this facies. Compound cross stratification was also present in a number of cores. This stratification type involves two scales of cross stratification; low angle master bedding surfaces (4-12°) and high angle cross stratification (15-30°) bound by the master bedding surfaces. The last form of cross stratification observed is crudely defined parallel bedding with individual cross-sets generally less then 10 cm thick. This last form was not observed in many of the studied cores. The cross stratification in this facies are most commonly defined by grain size segregations. Possible bi-polar cross stratification was observed in several beds, but this is equivocal.

Other features associated with this facies are abundant irregular mud drapes, mud rip up clasts, siderite mud rip up clasts and sideritized horizons. Disruption of sedimentary structures and incorporation of mud as a result of burrowing is also a common feature of this facies. Trace fossils *Arenicolites* and *Skolithos* were rarely observed. A thin

Figure 4.7: Facies 7 - Pebbly Cross Stratified Sandstone.

a) Compound cross stratification is present in this example. Note the set of high angle cross beds bounded by a set of lower angle master bedding surfaces. Well 13-8-35-6; Depth 8922 ft.; Scale bar is 3 cm long.

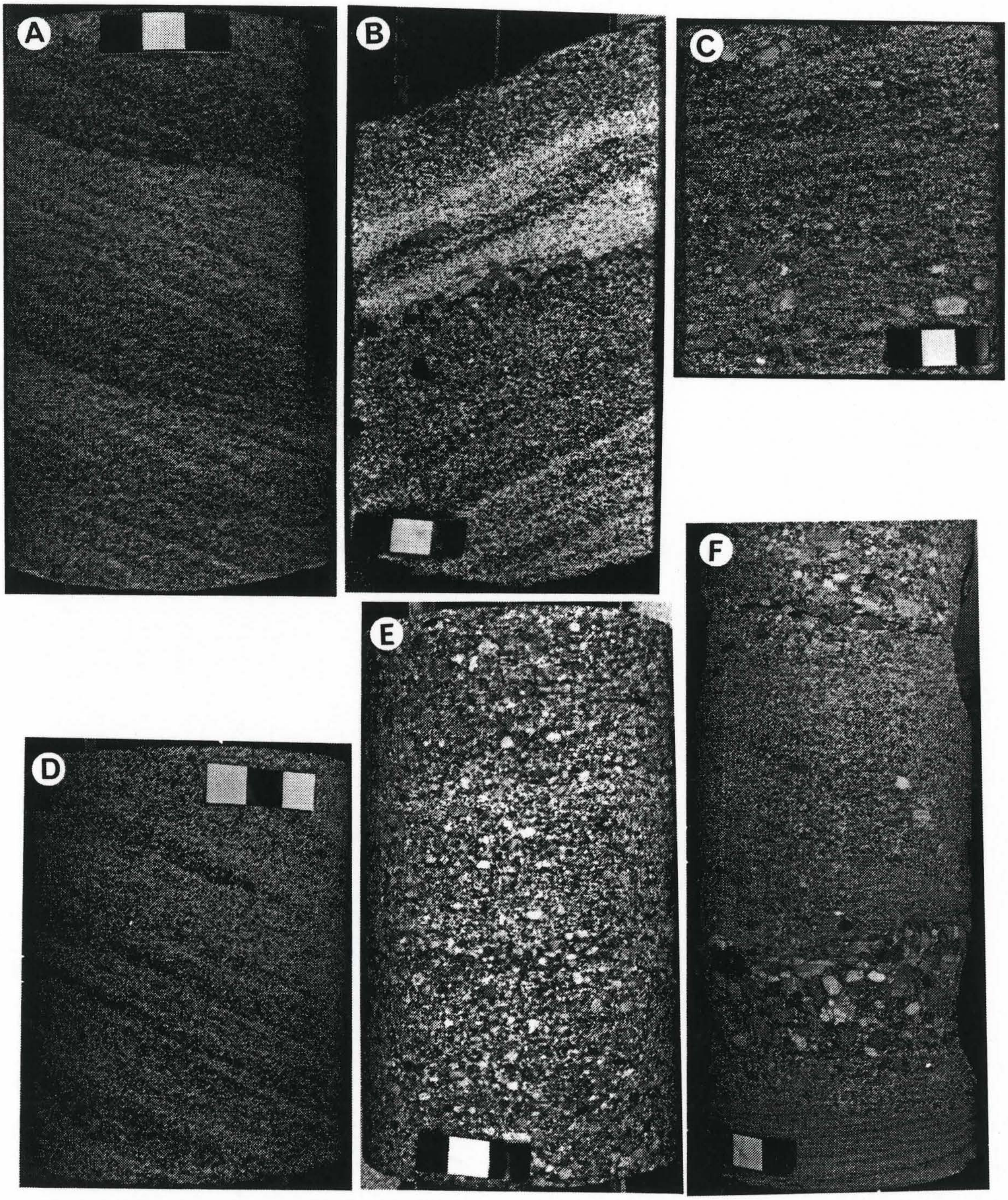
b) This example shows 2 styles of cross stratification at different dip angles as well as grain size segregations across stratification planes. Well 16-28-33-6; Depth 2524.5 m; Scale bar is 3 cm long.

c) Faintly laminated, low angle cross bedding in a pebbly sandstone with a decrease in abundance of clasts upwards. Well 7-4-35-3; Depth 2109.8 m; Scale bar is 3 cm long.

d) High angle cross bedding in a coarse grained sandstone with granules. Well 12-5-34-4; Depth 2346.9 m; Scale bar is 3 cm long.

e) Granular sandstone with little, if any development of cross stratification. Well 6-6-35-4; Depth 2384.5 m; Scale bar is 3 cm long.

f) Pebbly cross stratified sandstone banded with conglomeratic horizons. Well 8-7-35-3; Depth 2132 m; Scale bar is 3 cm long.


A
B
C
D
E
F

(<10 cm) horizon of sideritized mud penetrated by *Arenicolites* burrows are commonly present at the base of this facies, especially where the pebbly cross stratified sandstone is encased by shales.

This facies occurs in association with the conglomeratic facies and the pebbly burrowed mudstone facies, all of which erosively overlie the swaley cross stratified sandstone facies. Facies 7 can be found in any of the coarse grained interbeds encased by shales either making up the entire interbed or interbedded with conglomerate or pebbly burrowed mudstone.

Preliminary Interpretation: The cross stratification present indicates deposition by traction currents. These currents must have been quite strong at times to transport pebbles of 3 cm, however the presence of abundant muds drapes indicate that they were interrupted from time to time by periods of quiescence. The presence of large mud rip up clasts and the poorly sorted nature indicate a short transport distance.

Facies 8 - Pebbly Burrowed Mudstone

Description: This facies is composed of a generally structureless mixture of mud, sand and pebbles (Fig. 4.8). The thickness of this facies is variable and ranges from several cm to about 90 cm. Pebbles are not usually very abundant, are generally less than 1 cm in diameter, are poorly sorted and randomly oriented. Pebbles sometimes occur in distinct horizons in which case there appears to be a banding of 'speckled' mud and thin conglomeratic horizons. The proportion of sand present varies from random specks in a mud matrix to that of a dirty, muddy cross stratified sandstone with abundant mud drapes. Burrowing is often extensive and has resulted in a very churned, mottled appearance with occasional sand lenses and pods. In some cases there is very little disruption due to burrowing and thin silt laminae and faint, relict cross stratification was observed. Trace fossils are common and include *Arenicolites, Skolithos,* and *Planolites.*

This facies occurs stratigraphically above the swaley cross stratified facies in all the coarse grained horizons. It occurs in association with the conglomerate and cross bedded pebbly sandstone facies as interbeds with either sharp or gradational bases. When this facies occurs in the upper coarse grained horizons encased in marine shales it often rests sharply on a thin sideritized mud horizon with sand-filled *Arenicolites* and *Skolithos* burrows.

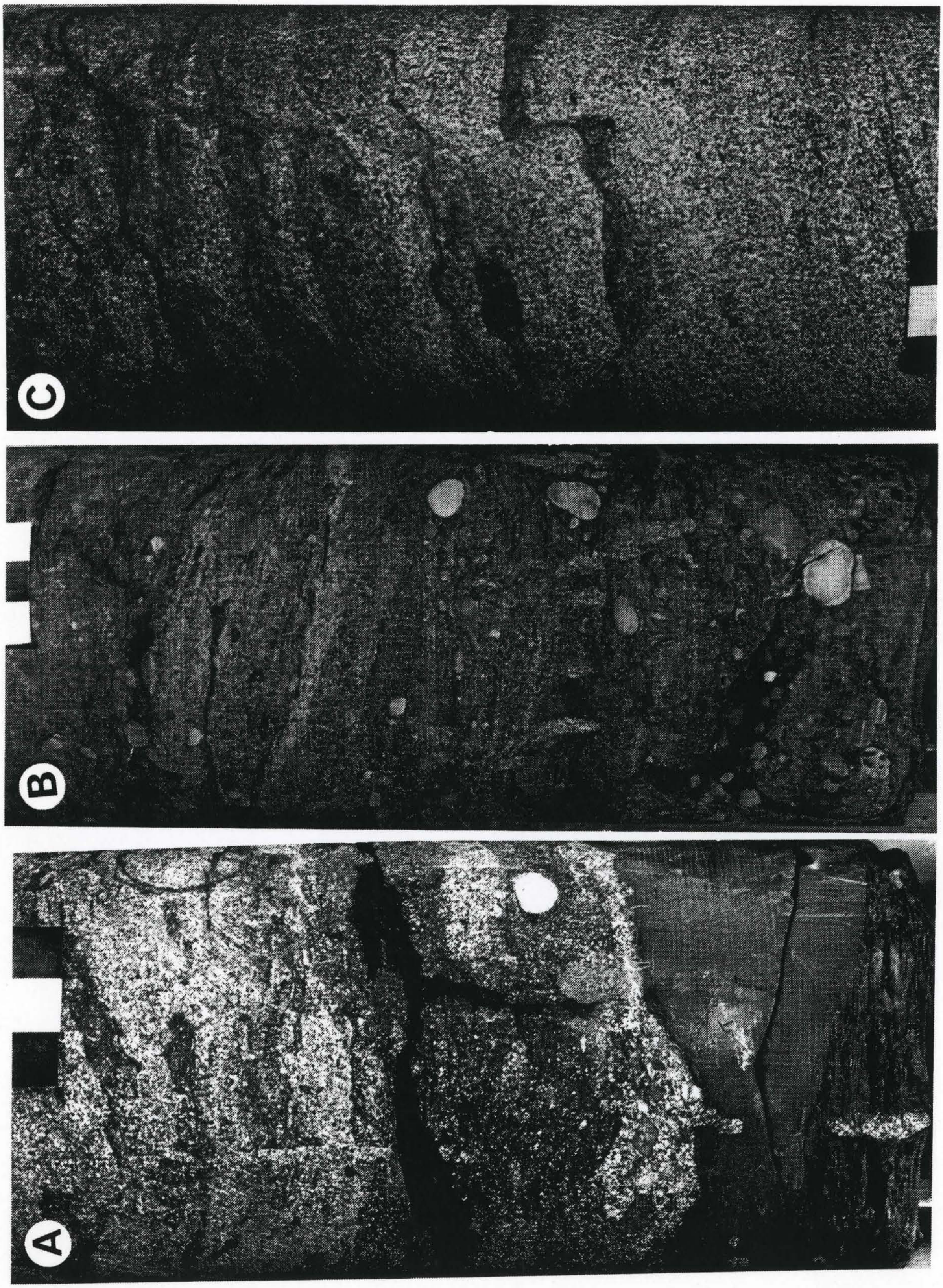
Preliminary Interpretation: The presence of pebbles, occasional preservation of lenses or beds of cross stratified sandstone and rare banding of conglomeratic horizons suggests that this facies is genetically related to Facies 6 and 7. This is further supported by the fact that this facies is often interbedded with Facies 6 and 7. The presence of coarse grained material burrowed in with mud is indicative of

Figure 4.8: Facies 8 - Pebbly Burrowed Mudstone.

a) Burrowed pebbly granular sandstone and mud overlying a sideritized mudstone horizon. Note the presence of sand filled *Arenicolites* burrows which penetrate the underlying sideritized horizon. Well 11-31-33-4; Depth 2392.8 m; Scale bar is 3 cm long.

b) This example contains numerous pebbles in a burrowed muddy sandstone. Vertical *Arenicolites* and *Skolithos* burrows are present. Well 11-31-33-4; Depth 2392.8 m; Scale bar is 3 cm long.

c) Burrowed sandy mudstone gradationally overlying a granular sandstone. Note the presence of unbioturbated mud drapes near the top of the sandy horizon. Well 6-12-35-4; Depth 2210 m; Scale bar is 3 cm long.


A
B
C

alternating periods of high and low energy. During periods of low energy, burrowers were able to disrupt sedimentary structures and mix in mud with the coarse grained material.

The similarity of the chert pebbles and poor sorting of Facies 6, 7 and 8 suggest that they may have shared a common sediment source.

Facies 9 - Black Shale

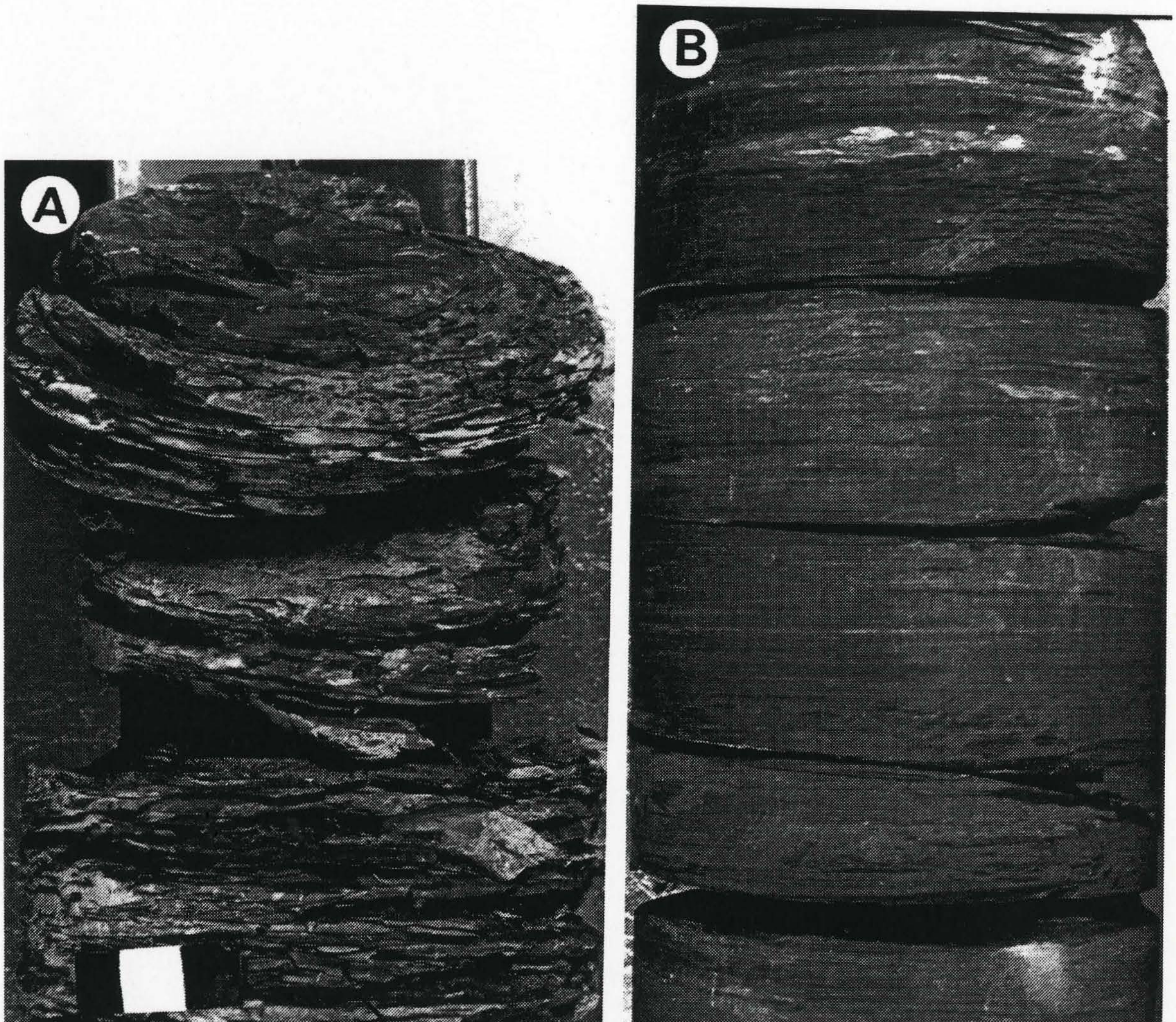
Description: This facies is composed of dark gray or black shale with very small amounts of sand and silt in the form of sand laminae and thin sand beds (≤5 cm) (Fig. 4.9). Sand accounts only for 1 to 2 % of the volume. The facies has an average measured thickness of 6.5 m (range from 1.5 - 14.0 m), but because it is the uppermost facies (and its top contact was not cored), this figure does not reflect the true thickness of the facies. The predominant feature of facies 9 is its homogeneous dark grey to black colour broken only by very thin, fine to medium grained sand stringers, rare very thin mottled sand beds and thin (2 - 20 cm) sideritized mud beds. These sideritized mud horizons are, in places, found beneath a mottled sand bed. The shale facies varies in its degree of cohesiveness from quite fissile and friable to very cohesive and blocky.

Disruption of the beds by burrowers is very minor to non-existent as indicated by the abundance of very thin sand and silt laminae. Mottling due to some degree of burrowing has been observed within some of the sand beds. The only trace

Figure 4.9: Facies 9 - Black Shale.

a) Cohesive, blocky black shale with occasional delicate, fine grained sand laminae. Well 16-5-35-3; Depth 2117 m; Scale bar is 3 cm long.

b) Very fissile black shale. Well 6-32-36-2; Depth 1894 m; Scale bar is 3 cm long.


A
B

fossils observed is *Planolites*, but these are rare.

Facies 9 is the uppermost cored facies within the study area but also occurs separating several of the coarse grained horizons made up of facies 6, 7 and 8. Correlations from wireline logs and observation in core south of the study are (S.W. Hadley, pers. comm., 1989) indicates that Facies 9 is overlain by the Base of Fish Scales.

Preliminary Interpretation: The predominance of clay and silt, and the lack of burrowing structures indicates that deposition occurred in a low energy, stressed environment. The minor presence of several marine burrowers (*Planolites* and *Arenicolites*) points to a marine origin. It is therefore concluded that Facies 9 was deposited below wave base in a marine setting. The thin sand beds present are thought to be the result of distal storm events.

Facies 10 - Paleosol

Description: Facies 10 is composed of organic rich, friable, crumbly, dark brown, partially lithified clay, silt and sand sized detritus. It has been found in only one core within the study area (Fig. 4.10) although several Viking cores to the south are reported to contain similar deposits (S.W. Hadley, pers. comm., 1989). The measured thickness of this facies is 74 cm. The facies seemed to become more friable and browner in colour upward. In addition, there are a few traces of roots within this facies, and extending down into the

Figure 4.10: Facies 10 - Paleosol.

This example is deep brown in colour, very crumbly and has a high organic content. The lower right hand corner may contain a small root. Well 7-4-33-6; Depth 2733.8 m; Scale bar is 3 cm long.

underlying mudstones.

Facies 10 overlies, and scours down into a slightly sandy, organic rich mudstone which in turn overlies a cross stratified pebbly sandstone. It underlies VE4, however the cored interval does not extend down into SCS, so the relationship of this facies to the typical sandier upward succession of Allomember D is uncertain. This facies is sharply overlain by a thick package of coarse grained lithologies belonging to Facies 6, 7 and 8.

Preliminary Interpretation: The very friable nature of this facies, its organic rich, poorly sorted nature, its brown colour, and the presence of roots strongly indicate that it is a paleosol or ancient soil. This, in turn, indicates subaerial deposition.

4.3 Contacts

Two surfaces have been recognized in core which can be mapped regionally and are thought to be the erosion surfaces VE3 (Viking Erosion Surface 3) and VE4.

These surfaces were correlated on wireline logs over the entire study area as well as by the McMaster Viking research group over much of the Alberta Foreland Basin. In addition, they appear to be erosive in core, because they sharply separate rocks of very different sedimentary characteristics. It was from the regional correlations that the contacts were identified as being VE3, which separates Allomembers B/C and D, and VE4, separating Allomembers D and E.

4.3.1 Viking Erosion Surface 3 (VE3)

VE3 is the lower of the two erosion surfaces recognized from core. It was rarely cored due to the lack of economic deposits at that stratigraphic level within the study area.

When penetrated by core, VE3 is a sharp, yet subtle break between two different style of mudstones (Facies 1 and 2) and is marked by a thin layer of scattered pebbles (up to 1.5 cm in diameter) and granules. Facies 1 (section 4.2, this chapter), situated below the VE3 contact, is a dark, heavily burrowed mudstone without a great deal of sand and silt. In contrast, Facies 2, which lies above the contact, has a higher percentage of sand and silt, and is less intensely burrowed. As a result it contains many thin sand beds without appreciable disruption due to burrowing.

Figure 4.11 illustrates these features, especially the different characteristics of the mudstones above and below the thin layer of scattered pebbles thought to represent VE3.

4.3.2 Viking Erosion Surface 4 (VE4)

VE4 is ubiquitous within the Garrington and Caroline area as it separates the coarsening upward succession of Allomember D and the petroleum bearing coarse grained facies (Facies 6,7 and 8) which make up part of Allomember E.

VE4 in core is marked by a very sharp contact. The facies below the contact is commonly the swaley cross stratified sandstone facies, or less commonly the hummocky cross stratified sandstone facies. Above the contact, the facies

Figure 4.11: Viking erosion surface 3 (VE3). This contact separates Facies 1 from the overlying Facies 2. It is characterized by a thin pebble veneer. The contact marks the allostratigraphic boundary between Allomember B/C and Allomember D.

a) Well 4-32-36-4; Depth 2201.4 m; Scale bar is 3 cm long. VE3 is indicated by the arrow.

b) Well 6-29-36-2; Depth 1926.8 m; Scale bar is 3 cm long.

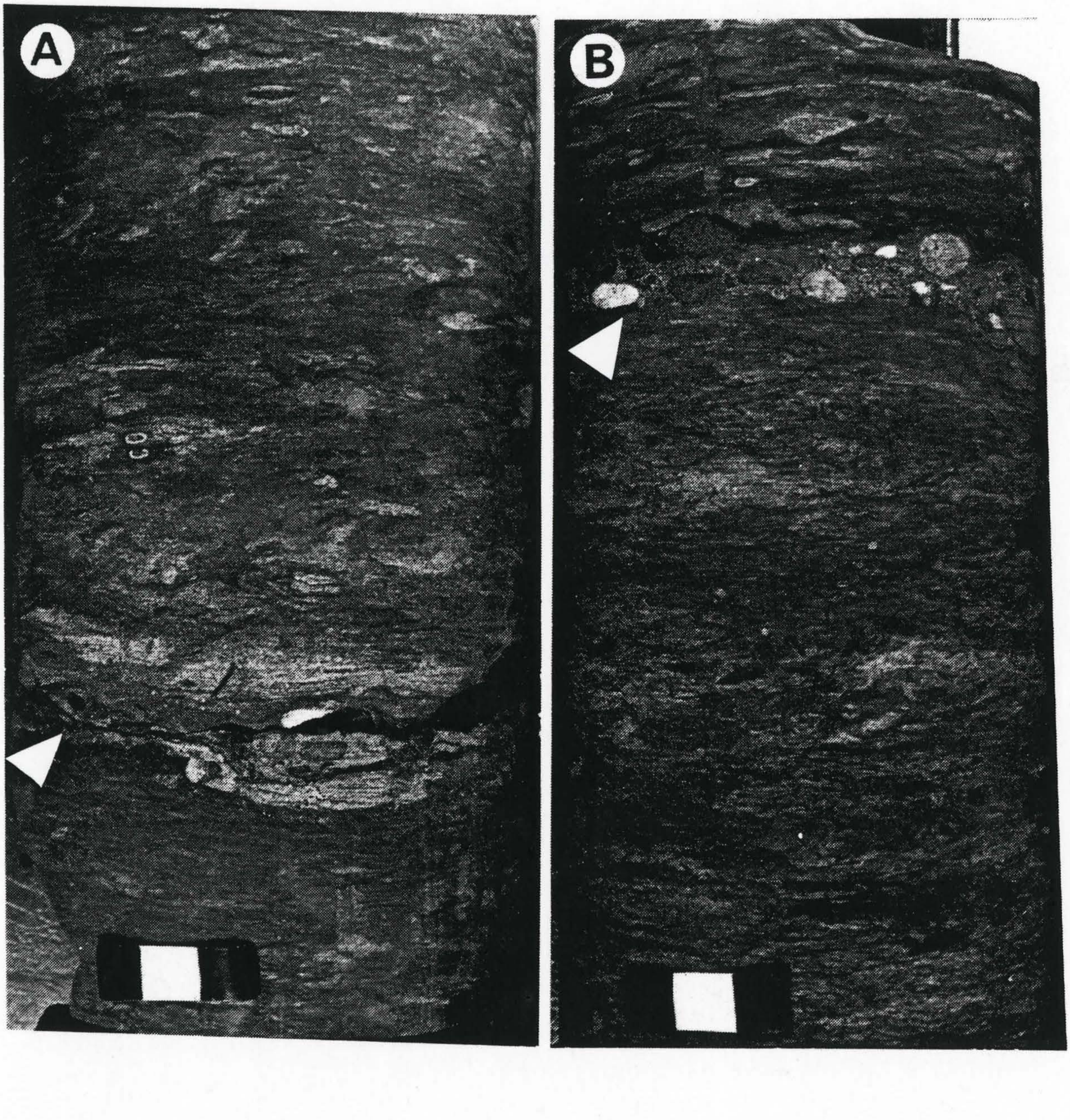
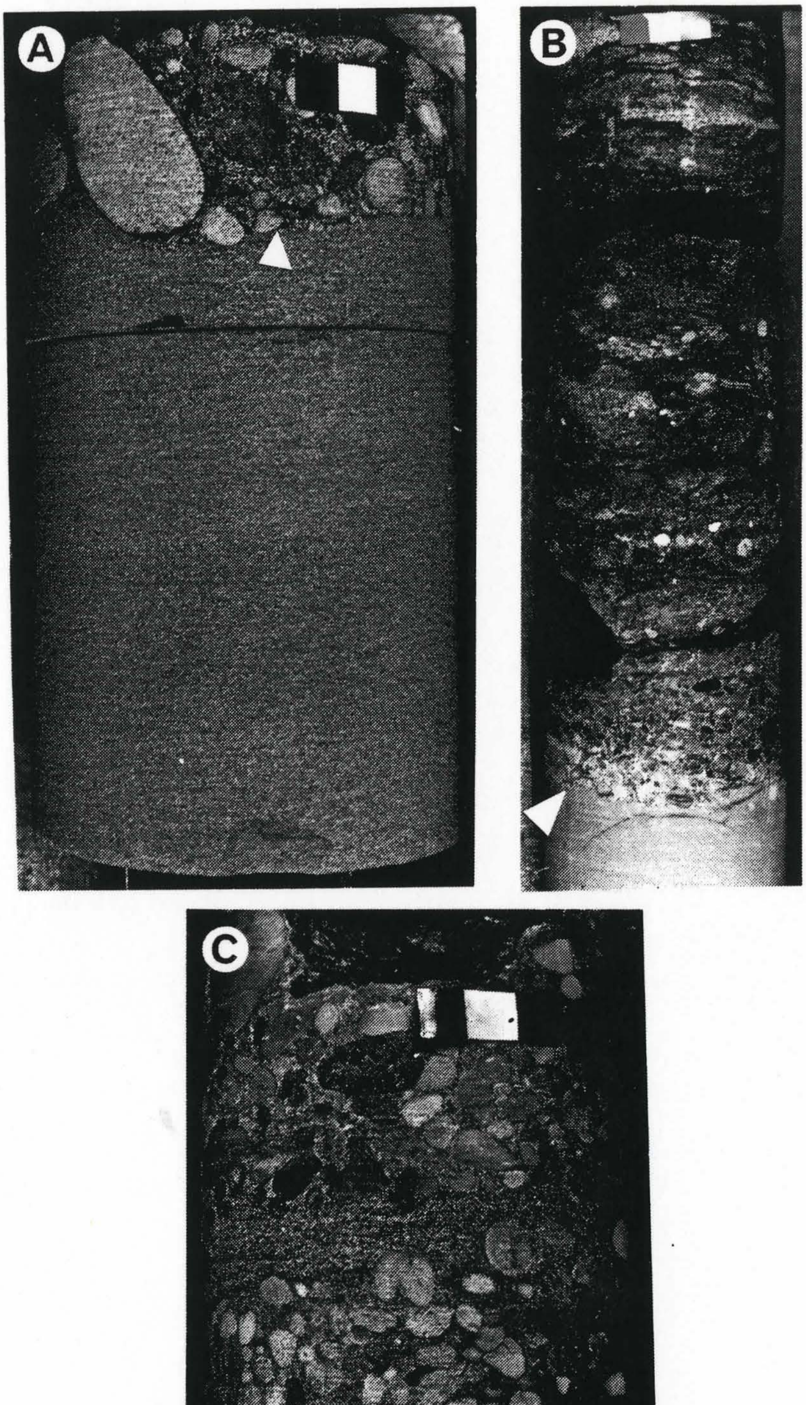

A
B

Figure 4.12 Viking erosion surface 4 (VE4). This surface typically separates Facies 4 below from either Facies 6, 7, or 8 above. It is always knife sharp and is usually overlain by pebbles up to 6 cm in diameter. The surface separates Allomember D from Allomember E.

a) SCS sandstone is sharply truncated by the VE4 surface (indicated by arrow) and is overlain by conglomerate. Well 6-13-34-3; Depth 2083 m; Scale bar is 3 cm long.

b) SCS sandstone beneath the VE4 surface is overlain by conglomerate which grades upwards into pebbly burrowed mudstone. Well 10-3-34-4; Depth 7537.4 ft; Scale bar is 3 cm long.

c) Well 14-9-35-3; Depth 2116.7 m; Scale bar is 3 cm long. VE4 is indicated by arrow.


A
B
C

are conglomerate, or pebbly cross stratified sandstones, or pebbly burrowed mudstones (Facies 6, 7 and 8 respectively). VE4 most commonly manifests itself by pebbles of Facies 6, sitting sharply on an undulating surface which truncates laminae of the underlying swaley cross stratified sandstone. These features in core indicate that VE4 is clearly erosive.

Figure 4.12 illustrates the VE4 surface and shows the sharp nature of the contact.

4.4 Vertical Facies Sequences

The previously described facies have been numbered sequentially in the order of their stratigraphic appearance, with Facies 1 being the lowest stratigraphic facies and Facies 9 being the highest. Exceptions to this are Facies 10 which was only found in one core in the study area and occurs stratigraphically beneath Facies 6, and Facies 6,7 and 8, all of which are higher than Facies 4, and 5 but which may occur in any one of a number of positions with respect to Facies 9 and each other. The facies were found to consistently occur in a number of associations with respect to the regional erosive contacts, VE3 and VE4, just described. These erosive contacts allow the definition of three allomembers (NACSN, 1983), where an allostratigraphic unit is defined as "....a mappable stratiform body of sedimentary rock that is identified on the basis of its bounding disconformity.". Of the three allomembers (B/C,D, and E) present in the study area, only Allomember D is complete in the sense that both

Figure 4.13: Idealized vertical facies sequence at Caroline. The facies sequence shown is based on the cored well 10-33-34-5, but incorporates features characteristic of other Caroline wells. Note the relatively thick coarse grained interbeds in Allomember E. The legend should be referred to for all the following core cross sections.

IDEALIZED FACIES SEQUENCE AT CAROLINE

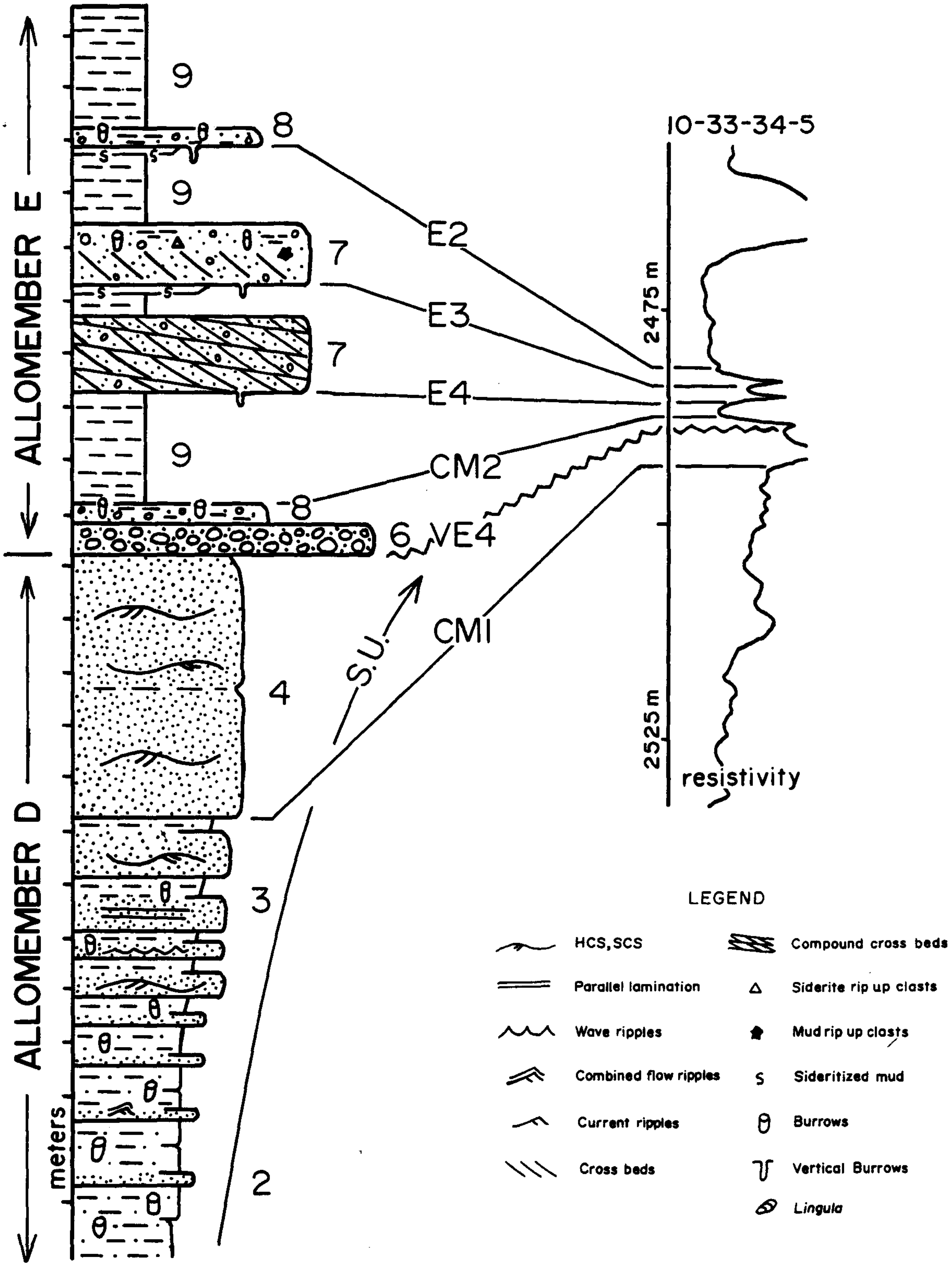
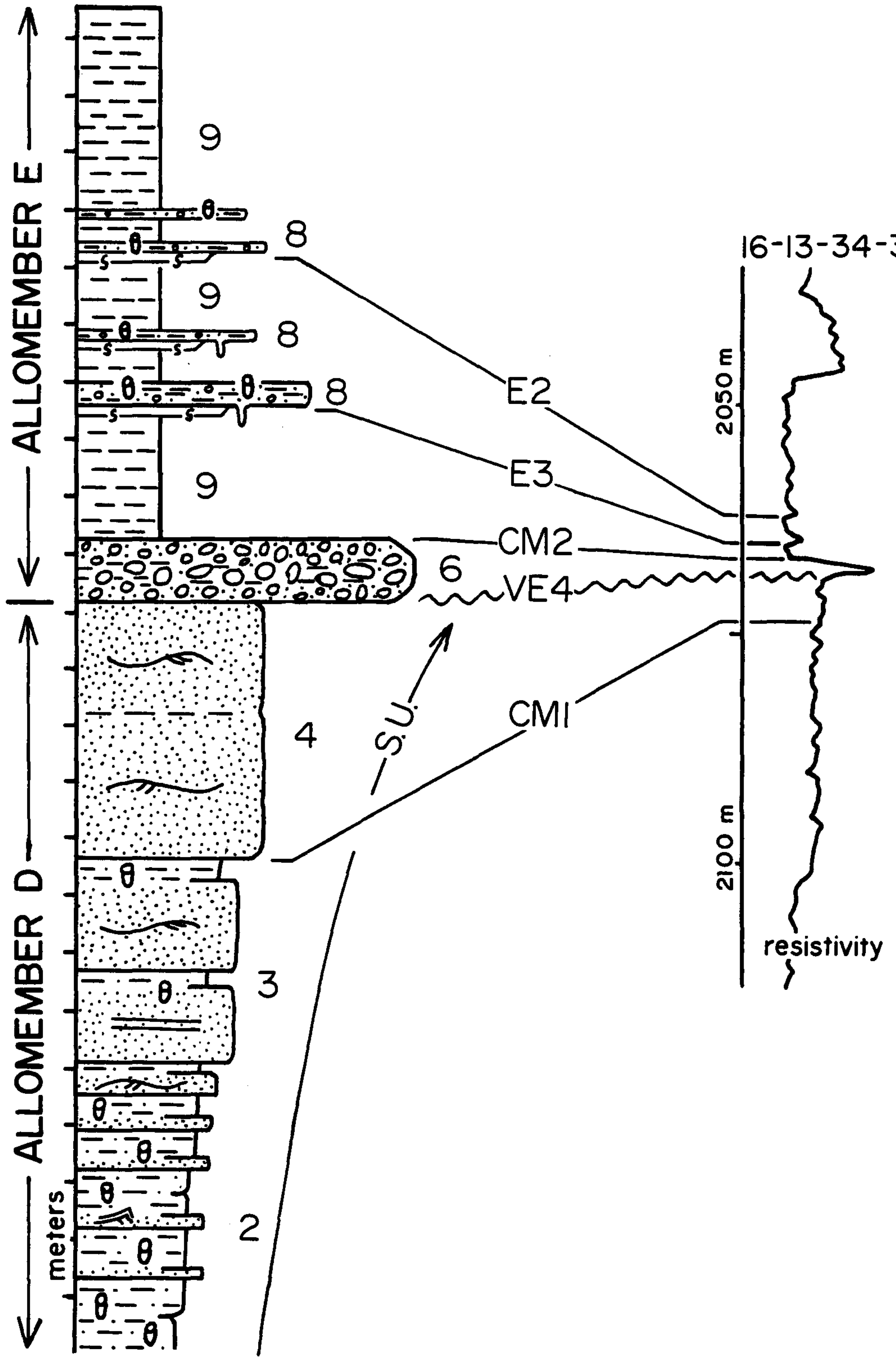


Figure 4.14: Idealized vertical facies sequence at Garrington. This figure is based upon well 16-13-34-3, but is believed to be representative of other Garrington cores. Note that the sandier upwards sequence in Allomember D is very similar to that found at Caroline. The interbeds in Allomember E are quite thin compared to those at Caroline and are generally made up of pebbly burrowed mudstone.

IDEALIZED FACIES SEQUENCE AT GARRINGTON



its top and bottom bounding disconformity have been recognized in core. The lower bounding disconformity of Allomember B/C (VE2), and the upper bounding disconformity (BFS) of Allomember E have not been cored and are inferred from wireline correlation.

The vertical facies succession within each of the three allomembers is similar for all of the cores across the study area with variations existing in the thickness of individual facies. These variations will be discussed in the following chapter. The following discussion will concentrate on describing the generalized vertical facies sequence in the three superimposed allomembers. It will be shown in the next chapter that the vertical facies sequence from one end of the map area to the other changes in a gradational and predictable way. Wells which characterize both the Caroline and Garrington field will be included in Figure 4.13 and 4.14 respectively.

4.4.1 Allomember B/C

Allomember B/C is the deepest of the allomembers present and is incomplete as the bounding disconformity (VE2) marking its base is never penetrated in core. This allomember was only penetrated three times in the study area and typically measured less than one meter in thickness. When cored, it consisted solely of burrowed muddy siltstone (Facies 1). Figure 4.15 shows the contact between Allomember B/C and Allomember D in core.

Figure 4.15: Allomember B/C - D contact. Well 6-12-36-3; Depth 1991.5 m; Core is 3 inches in diameter. This shows the VE3 surface separating Allomember B/C and D. Facies 1 is overlain by a thin, diffuse layer of pebbles marking the VE3 surface (indicated by arrow). This is then overlain by Facies 2 of Allomember D.

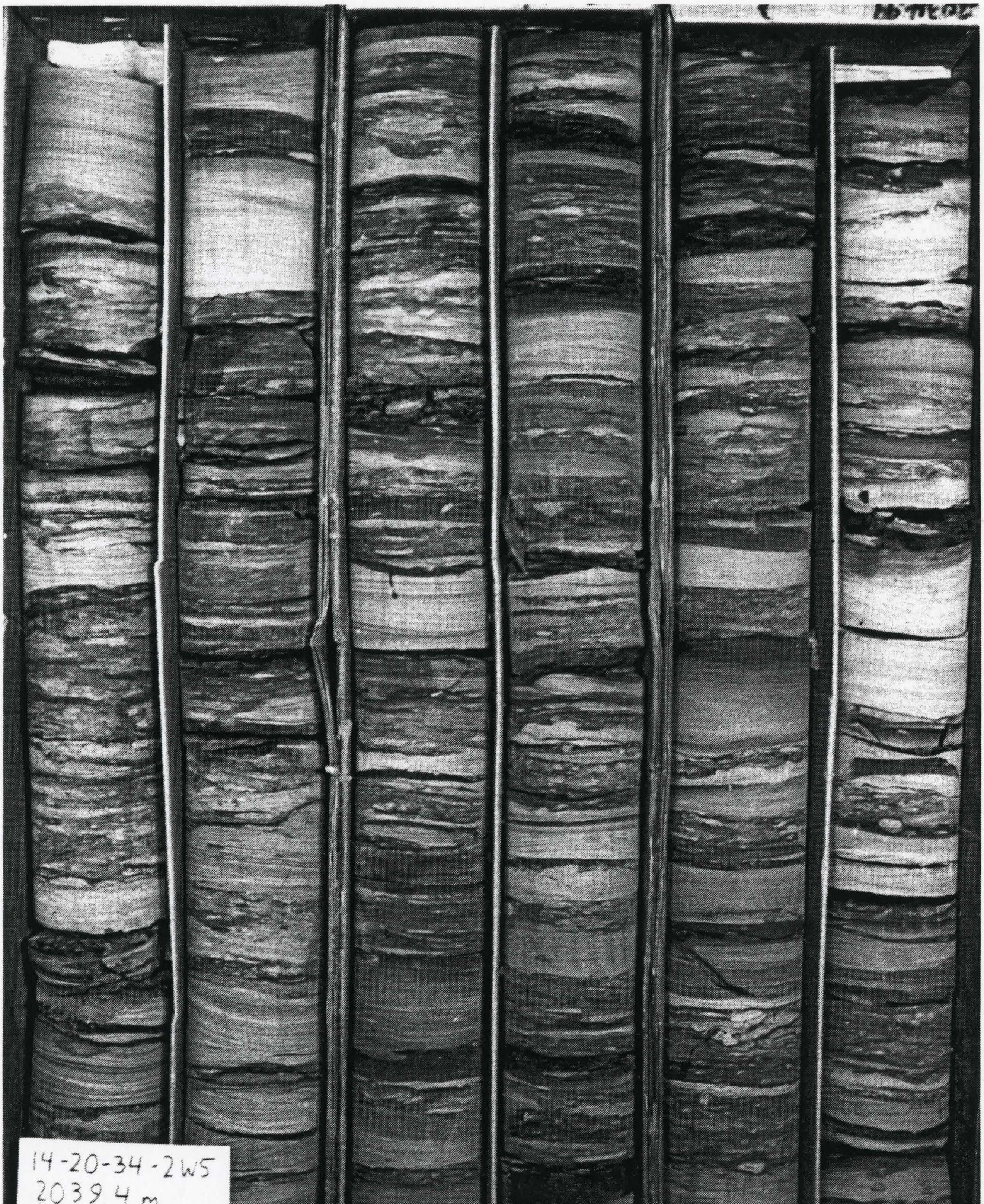

16-12-36-3W5
1991.5 m
BENTONITE

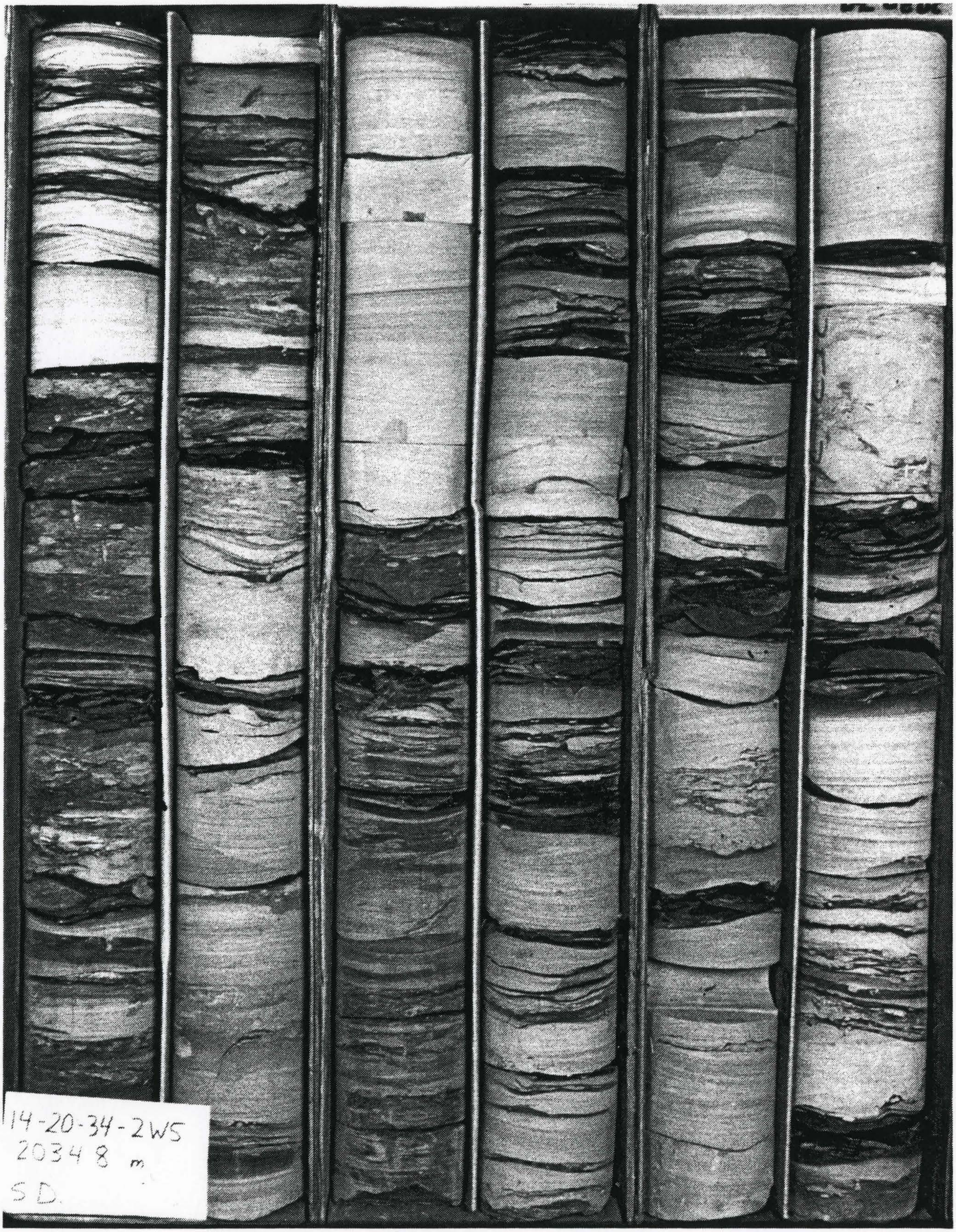
4.4.2 Allomember D

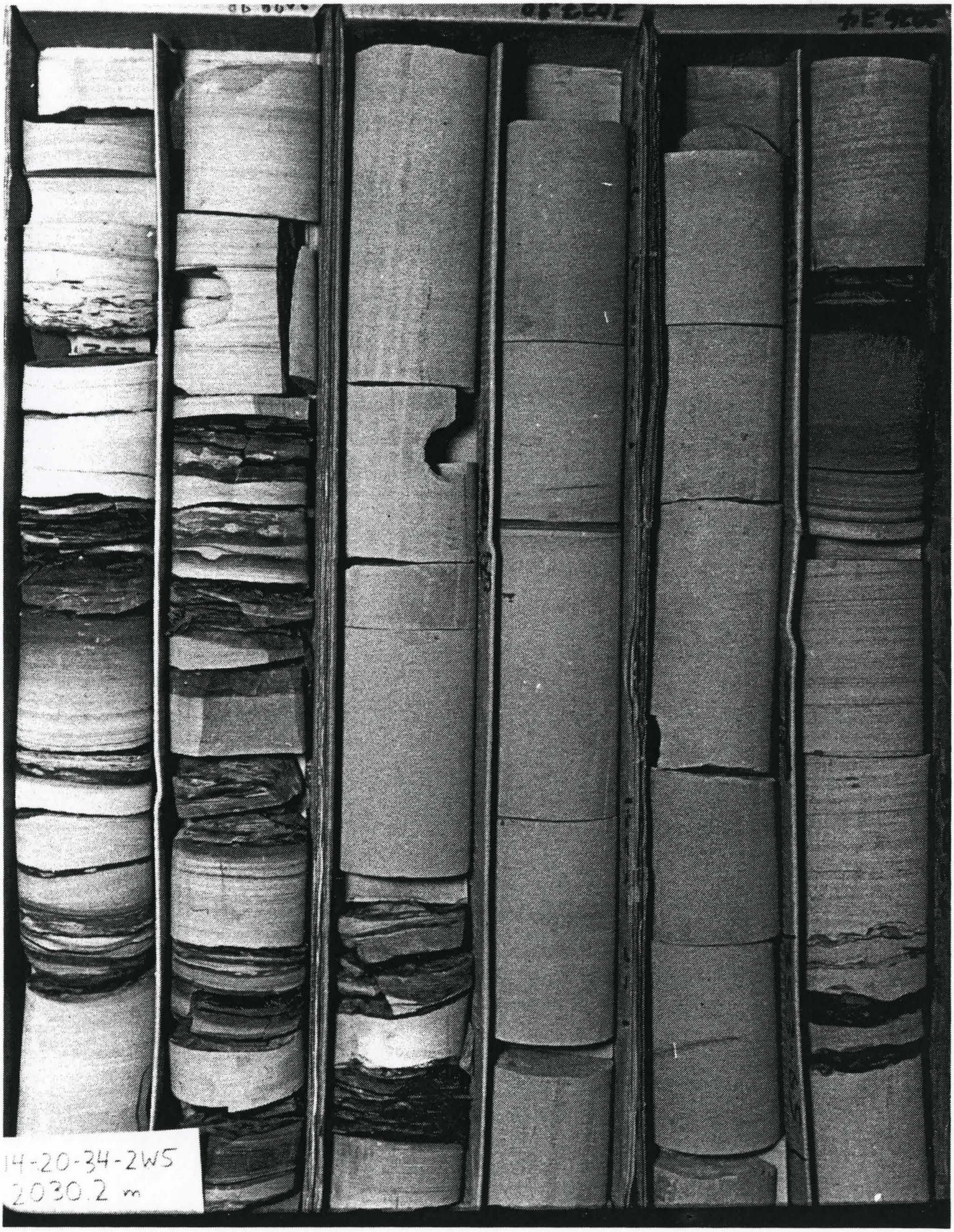
Allomember D is bounded at the base by VE3 and at the top by VE4. It typically consists of Facies 2, burrowed and laminated sandy mudstone overlain gradationally by hummocky cross stratified sandstone (Facies 3) which in turn is gradationaly overlain by swaley cross stratified sandstone (Facies 4). It can therefore be described as a sandier upwards sequence. In addition , there is also a decrease in the degree of burrowing upwards, as well as a decrease in both the number and diversity of trace fossils upwards. The trace fossils changes from a *Cruziana* dominated ichnofacies at the bottom of Allomember D to a *Skolithos* dominated ichnofacies at the top. Facies 5 (cross bedded sandstone with abundant mud rip up clasts) and Facies 10 (paleosol) are also found in Allomember D. Both were observed only once, and both were found immediately beneath VE4. In well 9-22-33-5, Facies 5 sharply overlies Facies 4 (swaley cross stratified sandstone). The relationship of Facies 10 with respect to the rest of the facies which comprise Allomember D is unknown from core, however, it is thought to occur above Facies 4 (SCS sandstone) based on well log correlations.

The other variation of Allomember D is the significant thinning of, and in some cases lack of Facies 4 (swaley cross stratified sandstone) to the north and northeastern portions of the study area.

Figure 4.16 (next 4 pages): Allomember D. Well 14-20-34-2 (base at 2039.4 m) illustrates the sandier upward succession of Allomember D. Facies 2 is gradationally overlain by Facies 3 which is then gradationally overlain by Facies 4. Allomember D is erosively overlain by conglomerate (Facies 6). Core is 3 inches in diameter.


14-20-34-2W5
2039.4 m
SD


14-20-34-2W5
2034 8 m
S D.


14-20-34-2W5
2030.2 m


14-20-34-2W5
2025.8 m.
S.D.

Figure 4.16 shows a typical vertical sequence through Allomember D in core.

4.4.3 Allomember E

Like Allomember B/C, Allomember E is incomplete in the study area because the bounding disconformity which defines its top (BFS) was never observed in core. The BFS, however, was observed in core in the Harmattan East area to the south (S.W.Hadley, pers. com., 1989). The base of Allomember E is the VE4 erosion surface.

Of the three allomembers present in the study area, Allomember E has the most variation and complexity in its vertical succession of facies as well as a great deal of variation laterally across the study area. Generally the facies which make up this allomember are arranged as coarse grained packages (Facies 6,7 and 8) sharply interbedded with Facies 9, black shale. A coarse grained interbed usually consisting of dominantly conglomerate always lies on the VE4 surface. This in turn is overlain by black shale which is then typically overlain by another coarse grained lithology. As many as 6 coarse grained interbeds have been recognized in core, albeit some of them are very thin (< 5 cm). These coarse grained interbeds often overlie a thin, 5 -10 cm layer of sideritized mud and range in thickness from a few centimeters up to 4 meters. The interbed thickness decrease in a non-linear fashion upwards. Higher portions of Allomember E are dominated by black shale. There is a great deal of variation in the vertical superposition of one coarse grained facies (facies 6, 7, or 9) within one interbed across the field. A detailed treatment of this will be given in a later section.

In general, the vertical trends include:

1) the shale encased, coarse grained interbeds are much thicker at Caroline than at Garrington.

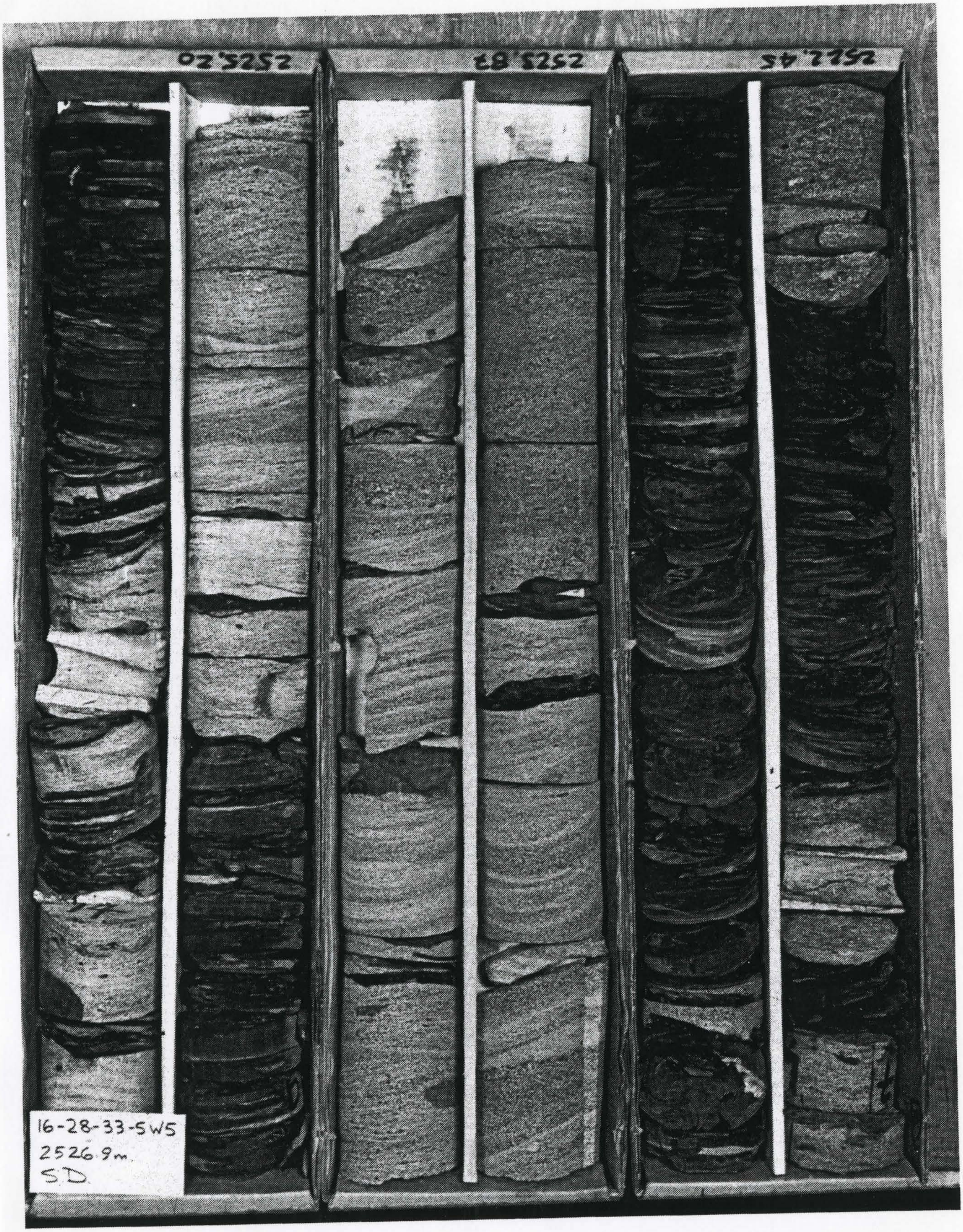
2) there are virtually no shale encased, coarse grained interbeds of substantial thickness in the northeastern portion of the study area.

3) the coarse grained interbeds lying above the VE4-CM2 interval are dominated at Caroline by Facies 7, the pebbly cross stratified sandstone facies whereas those at Garrington are dominated by Facies 8, the pebbly burrowed mudstone facies.

4) compound cross stratification, of possible tidal origin is found exclusively at Caroline although it is not abundant there. Figures 4.17 and 4.18 illustrate typical vertical sequences in core through Caroline and Garrington respectively.

Figure 4.17 (next 3 pages): Allomember E at Caroline. Well 16-28-33-5; Depth of the bottom of the core is 2531.2 m. Allomember E erosively overlies the sandier upward succession of Allomember D. It commences at VE4 (marked by arrow) with an assortment of conglomerate, pebbly cross stratified sandstone and pebbly burrowed mudstone. Note the abundant, unbioturbated mud drapes in the pebbly cross stratified sandstone facies. Facies 9 (black shale) overlies this interval and is sharply overlain by an interbed of pebbly cross stratified sandstone. The interbed contains possible signatures of a tidally influenced origin such as possible compound cross stratification, sharp grain size changes and unbioturbated mud drapes. This interbed is again overlain by black shales. Three more of these coarse grained interbeds occur, all of which are thinner than the first interbed. The last several meters of this well is characterized by predominantly black shale with thin lenses of fine grained sandstones and sideritized mudstone beds.


16-28-33-5W5
2531.2 m
S.D.


16-28-33-5W5
2526.9m.
S.D.

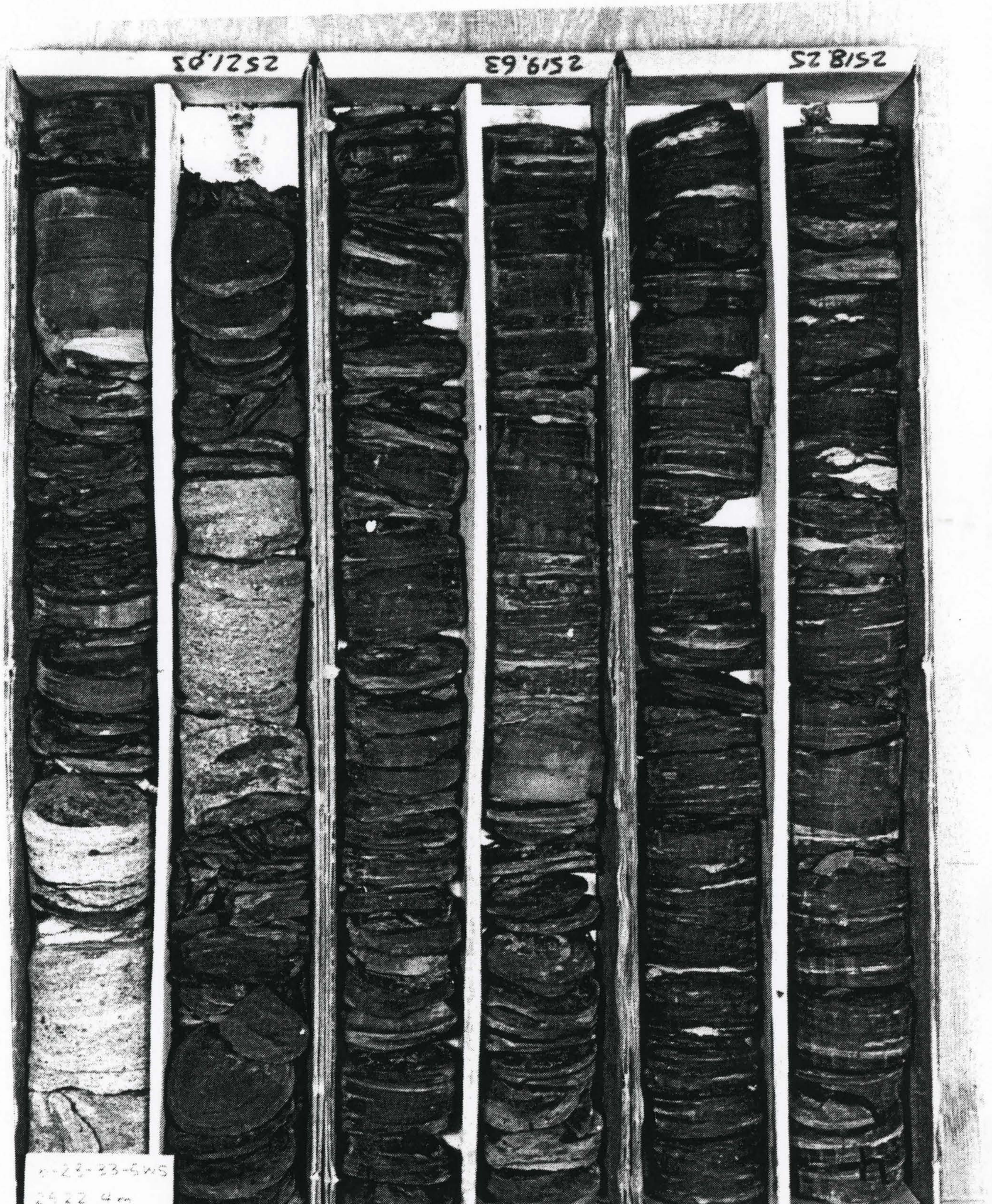
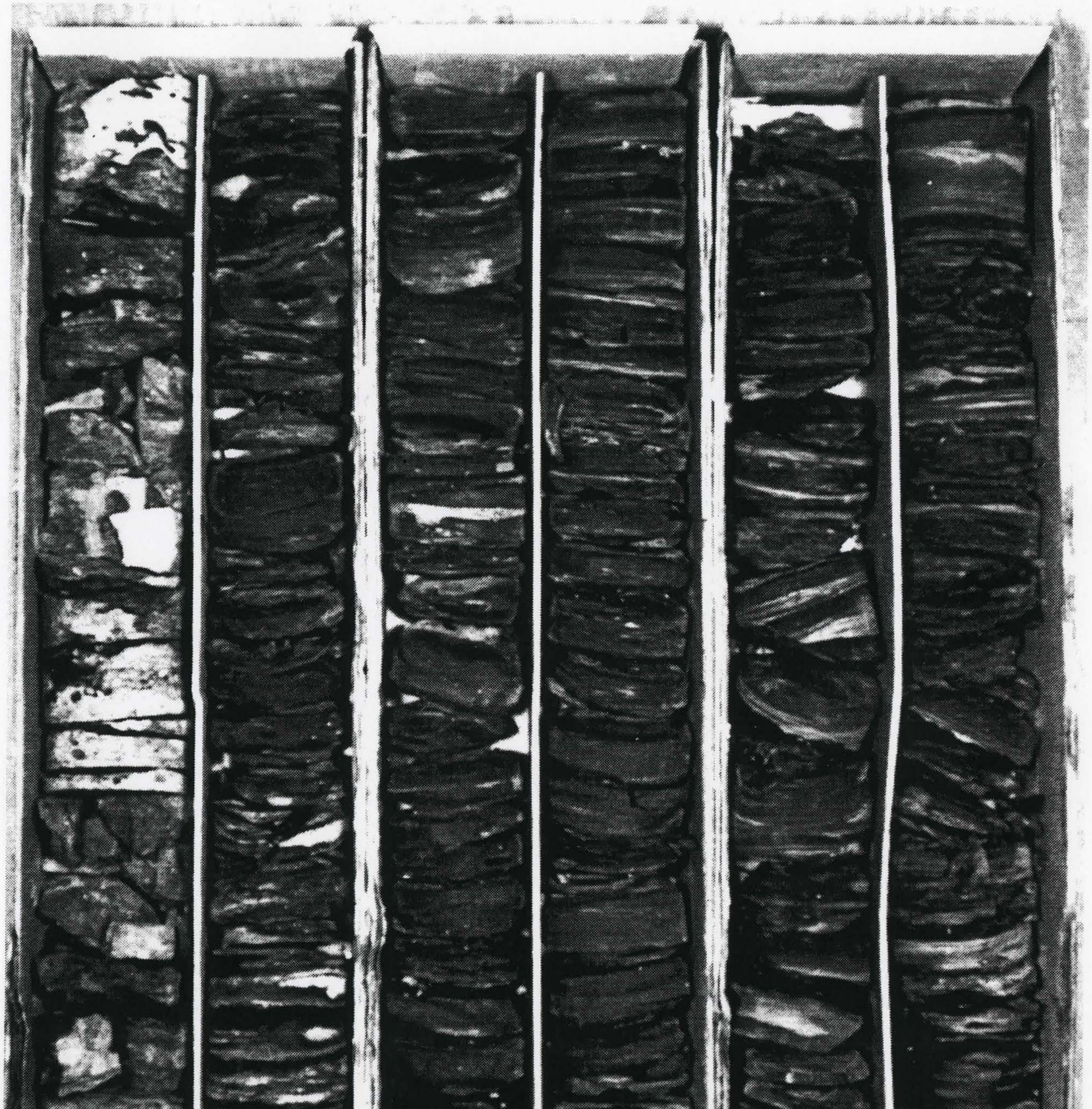
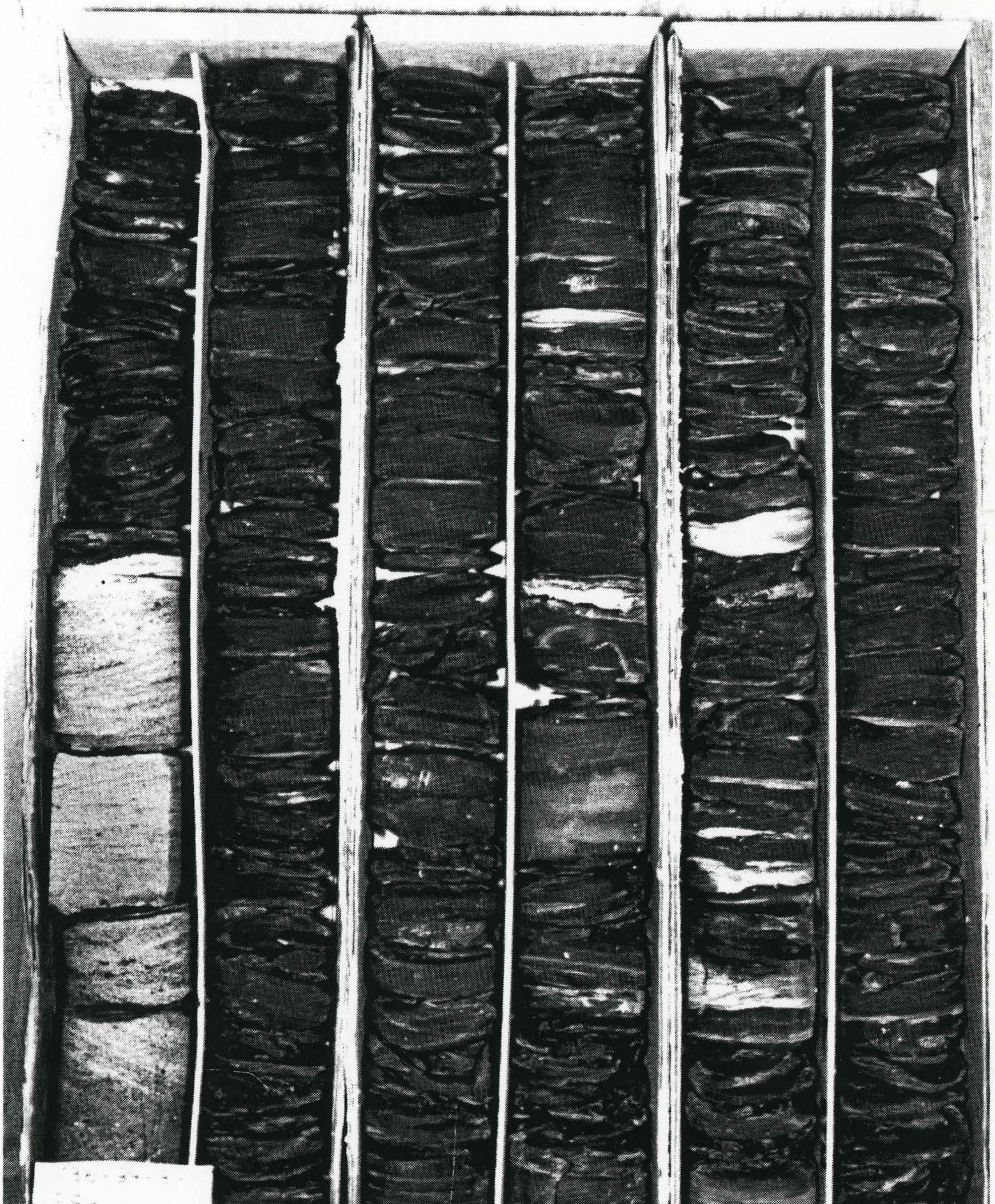


Figure 4.18 (next 3 pages): Allomember E at Garrington. Well 11-36-34-3; Depth of the bottom of the core is 2593.1 m. Overlying the VE4 surface (misidentified here as E3) are a mixture of conglomerate and pebbly burrowed mudstone. This is then overlain by several meters of black shales with thin lenses of fine grained sandstone. A thin interbed of pebbly cross stratified sandstone sharply overlies the shale several meters above. The remainder of the core consists of black shale with thin lenses of sandstone and sideritized mudstone horizons.


E3
11-36-34-3W5
2593.1m.
S.D.


11-36-34-3W5
2588 7m
SD



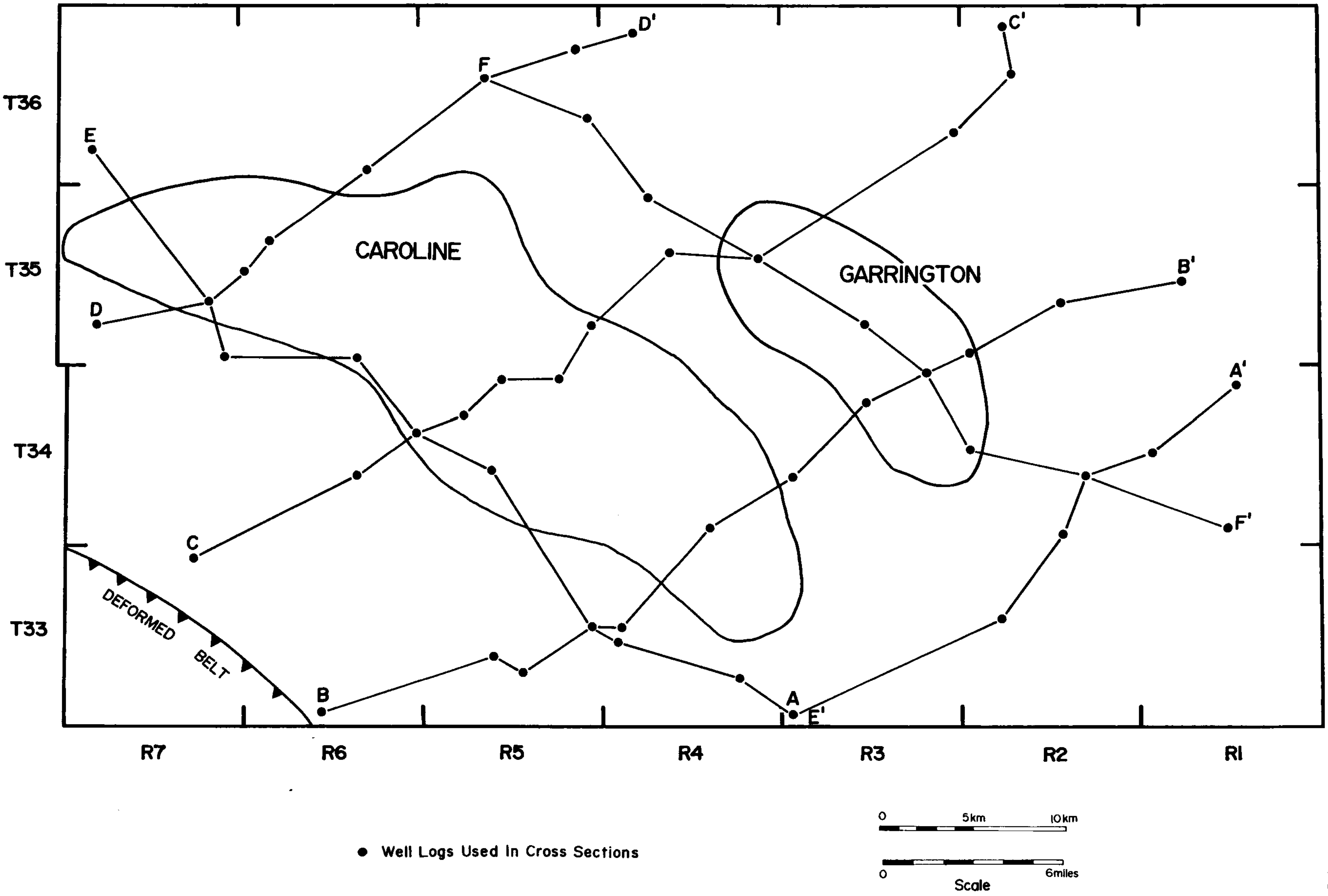
CHAPTER 5: CROSS SECTIONS

5.1 Introduction

In order to fully understand the lateral facies distribution six regional wireline cross sections (Fig. 5.1) have been illustrated in the study area. These have been distilled from 20 working cross sections. Four of these (A-A' to D-D') are dip cross sections, oriented southwest-northeast (they are oriented parallel to the regional dip of the Viking Formation). The other two (E-E' and F-F') are strike cross sections, oriented southeast-northwest (parallel to the regional strike of the Viking Formation). Core cross sections are included only for the four dip sections.

All the cross sections are made up of both resistivity and gamma ray logs when possible. Most of the correlations were derived from the resistivity logs; however, the gamma ray logs were useful in confirming dubious resistivity "picks". There were up to thirteen "picks" made for each well. Of these, the uppermost eight, from VE3 to BFS are the most important for the purposes of this study. The others were included to illustrate the allostratigraphic contexts of the fields. None of these lower markers (Base Viking, LM, VE2) was ever observed in core within the study area. Tying in the strike cross sections to the dip cross sections ensured that the "picks" are consistent across the fields. This density of cross sections allows for reasonably good confidence in

Figure 5.1: Location map of the 6 cross sections used in this study. Cross sections A-A' to D-D' are termed dip sections and include both log cross sections and core cross sections. Cross sections E-E' and F-F' are termed strike sections and are log cross sections only.


T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
RI
CAROLINE
GARRINGTON
DEFORMED
BELT
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
0
5km
10km
0
6miles
Scale
Well Logs Used In Cross Sections

correlations.

The VE3 pick was made by correlation to core where it was observed and is defined on logs as the base of a rightward deflection on the resistivity logs and at the base of the leftward deflection on the gamma ray logs. Core Marker 1 (CM1) is defined in core as the boundary separating HCS sandstone from SCS sandstone and is difficult to pick on well logs because of the gradational sandier upwards sequence characteristic of Allomember D in which it occurs. It is sometimes apparent in logs as the base of a prominent blocky response on both the resistivity and gamma ray logs. VE4 is an easily identified marker in both core and wireline log. In logs, it occurs at the base of a very prominent rightward deflecting resistivity spike and leftward deflecting gamma ray spike. The CM2 "pick" is defined as the top of the first coarse grained interbed immediately overlying the VE4 erosion surface, and beneath the first occurrence of black shale (Facies 9). This is easily identified on logs as the inflection point on the leftward deflecting resistivity spike and a rightward deflecting gamma spike where the response changes rapidly due to the sharp boundary between the coarse grained and shaley interbeds. Above CM2 is the overall shaley response of black shale (Colorado shale). There are up to six coarse grained interbeds in this overall shaley section, and these are detected on logs by sudden rightward deflecting resistivity spikes and leftward deflecting gamma ray spikes.

Five of these interbeds had substantial thickness and could be traced laterally; they are labelled E1 to E5 in the cross section. "Picks" were made at the base of each coarse grained interbed (the inflection point of a rightward deflecting resistivity spike and a leftward deflecting gamma ray spike). The tops of each interbed were not included on cross sections but were recorded for isopach purposes.

The Base of Fish Scales (BFS) is used as a datum for this study and is a relatively easy "pick". It is recognizable by its characteristic very high gamma ray reading and high resistivity response. It is useful as an upper datum for several reason:

1) it is present over thousands of square kilometres in the Alberta Foreland Basin (Cant, 1984).

2) it approximates a time line because it has been paleontologically dated as occurring close to the Upper-Lower Cretaceous boundary (Cant, 1984).

3) it is interpreted to be a condensed horizon, and probably represents as smooth and flat a basin floor as can be reasonably be reconstructed.

A summary of the important characteristics of the cross sections will be included at the end of this chapter if the reader wishes to forego the following descriptions.

5.2 Dip Cross Sections, A-A' to D-D'

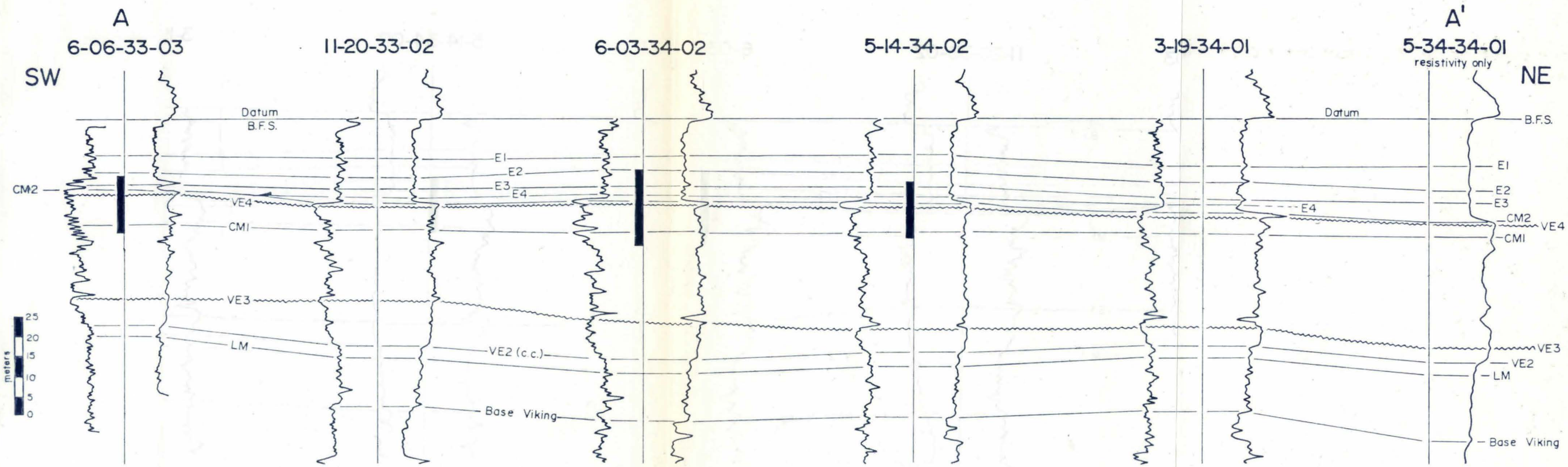
Well log cross sections A-A' to D- D' were constructed normal to the regional strike of the Viking and at an equal spacing across the study area. Well locations were chosen to allow for as much correlation with cores as possible. Each of these cross sections will be described briefly with emphasis on the shape of VE3, VE4, the thickness of the coarse grained deposits between VE4 and CM2, and the nature of the overlying coarse grained interbeds, whose bases are denoted E1 through E5.

5.2.1 Well Log Cross Section A-A'

Cross section A-A' (Fig. 5.2) is approximately 30 km long (Fig. 5.1). Both erosion surfaces VE3 and VE4 have relief with highs relative to the BFS datum occurring in the most south westerly well, 6-6-33-3 and lows at the most northeasterly well 6-34-34-1. VE3 has about 13 m of relief while VE4 has about 7 m of relief. The CM1 marker denoting the HCS-SCS transition remains essentially flat relative to the BFS, but the deposits between CM1 and VE4 thin from 7m in 6-6-33-3 to 3 m in 5-34-34-1.

There are four recognizable coarse grained spikes present in Allomember E and from correlation with other cross section are identified as being E1-E4. E1-E3 are present in all the wells of the cross section, whereas E4 onlaps onto the CM2 surface between wells 6-6-33-3 and 11-20-33-2. These deposits become thinner northeastward, and in many cases are too thin

Figure 5.2: Log cross section A-A'. Location of cross section shown in Figure 5.1.


A
A'
SW
NE
6-06-33-03
11-20-33-02
6-03-34-02
5-14-34-02
3-19-34-01
5-34-34-01
resistivity only
Datum
B.F.S.
E1
E2
E3
E4
CM2
VE4
CM1
VE3
LM
VE2 (c.c.)
VE2
Base Viking
meters
25
20
15
10
5
0

to be accurately measured from the well log and exist as log "picks" only. The E3 marker is the thickest of these markers at well 6-6-33-3. The E4 signature becomes imperceptible by well 3-19-24-1.

5.2.2 Cross Section B-B'

Cross section B-B' (Fig 5.3) is approximately 27 km long (Fig. 5.1). Both VE3 and VE4 have relief and show an undulating topography which drops overall towards the northeast. VE3 has up to 12 m of relative relief and VE4 has 11 m of relative relief. The VE4 surface has two portions of the topography with steeper slopes, one just west of Caroline between wells 7-19-33-4 and 10-3-34-4, where it steps down 3 m, and one just east of Garrington between wells 6-6-35-2 and 3-15-35-2, where it steps down 4.5 m. The term "step" will be hereinafter used to describe a relatively steep topographical slope; the term "tread" will be used to describe a portion of the topography which is generally flat. The VE4 surface also rises slightly (<2 m) between the Caroline and Garrington fields. A paleosol and other non marine deposits are preserved at the extreme southwestern well, 7-4-33-6. The CM1 marker remains virtually flat relative to the BFS but the deposits preserved between the CM1 and VE4 markers have undulatory thicknesses presumably due to topography of the VE4 surface. The coarse grained deposits between the VE4 and CM2 surfaces show an overall northeastward thinning from 7 m (6-16-33-5) to less than 1 m (14-17-35-1). Generally these deposits are

Figure 5.3: Log cross section B-B'. Location of cross section shown in Figure 5.1.

B
B'
SW
NE
7-04-33-06
6-16-33-05
14-10-33-05
7-24-33-05
7-19-33-04
10-03-34-04
6-18-34-03
16-28-34-03
16-35-34-03
6-06-35-02
3-15-35-02
14-17-35-01
Datum
B.F.S.
E1
E2
E3
E4
E5
CM2
VE4
CM1
VE3
VE2 (c.c.)
LM
Base Viking
meters
25
20
15
10
5
0

thickest south west of Caroline and thin noticeably at the first well inside the Caroline field (10-3-34-4).

Within Allomember E there are 5 coarse grained spikes. Only Marker E1 is present in every well in this section; E2 onlaps onto the CM2 surface between wells 7-4-33-6 and 6-16-33-5, E3 onlaps between wells 6-16-33-5 and 14-10-33-5, E4 onlaps between wells 7-19-33-4 and 10-3-34-4 while E5 onlaps between wells 6-6-35-2 and 3-15-35-2. The thicknesses of the deposits between the E markers and the top of each spike seem to generally thin in the northeastern direction. Of the 5 markers, only E2, E3 and E4 show any substantial thickness. The thickest deposits above marker E2 occurs at well 14-10-33-5 where they are about 2 m thick; by well 10-3-34-4 they have become very thin. The thickest deposits above marker E3 are between wells 14-10-33-5 and 6-18-34-3 where thickness reach up to 2 m; after this point E3 thins considerably. Marker E4 has its thickest deposits between wells 10-3-34-4 and 16-28-34-3 after which they thin and eventually lose their signature by well 6-6-35-2. Marker E5 never contains thick deposits and exists as a weak log marker only.

5.2.3 Cross Section C-C'

Cross section C-C' (Fig. 5.4) is approximately 50 km long (Fig. 5.1). The VE3 and VE4 surfaces both have topography and both cut downward northeastward. VE3 cuts down 7 m overall, whereas VE4 cuts down 15 m. The overall drop in the VE4 surface is a result of 2 major "steps", one between 16-24-34-

Figure 5.4: Log cross section C-C'. Location of cross section shown in Figure 5.1.

C
11-35-33-07
8-15-34-06
16-24-34-06
6-29-34-05
resistivity only
10-33-34-05
10-35-34-05
8-12-35-05
14-21-35-04
11-24-35-04
16-12-36-03
resistivity only
16-20-36-02
C'
6-32-36-02
SW
NE
Datum
B.F.S.
E1
CM2
E2
E3
E4
VE4
CM1
VE3
VE2 (c.c)
LM
Base Viking
E5
meters
25
20
15
10
5
0

6 and 6-29-34-5 at the western margin of Caroline where it steps down 3.8 m, and the other between wells 11-24-35-4 and 16-12-36-3 just northeast of Garrington, where it steps down 5 m. The VE4 surface also rises about 2 m between Caroline (8-12-35-5) and Garrington (14-21-35-4). The CM1 surface undulates gently but is generally flat. The SCS deposits found between the CM1 surface and the VE4 surface thin considerably, from 6 m (11-35-33-7) to 3 m (6-32-36-2) northeastward. The thickest coarse grained deposits between the VE4 surface and CM2 marker are found southwest of Caroline. Approximately 7 m of coarse grained deposits between these two markers occur at well 8-15-34-6, but this interval thins to less than two meters by well 6-29-34-5, just inside the Caroline field. The rest of the wells to the northeast, with the exception of 16-12-36-3, have less than 2 m of these deposits. Well 16-12-36-3 which occurs at the base of the major drop of VE3 northeast of Garrington, has approximately 3 m of coarse grained deposits.

All 5 coarse grained markers in Allomember E are present in this cross section, and like cross sections A and B, most of these onlap onto the CM2 surface at various points. Only marker E1 is present in every well in the cross section. Marker E2 onlaps onto the CM2 surface between wells 11-35-33-7 and 8-15-34-6, marker E3 onlaps the CM2 surface between wells 8-15-34-6 and 16-24-34-6, E4 onlaps the CM2 surface between wells 16-24-34-6 and 6-29-34-5, while E5 onlaps the

CM2 surface between wells 11-24-35-4 and 16-12-36-3. Also, the signature of each marker changes towards the northeast, inasmuch as the thickness of the spikes above each marker thins considerably towards the northeast (as in cross section A and B). The thickest deposits recorded by the E markers are those of E3 and E4 at the Caroline field; E3 contains records a coarse grained bed about 2 m thick in wells 16-24-34-6 and 6-29-34-5, but by well 14-21-35-4 the thickness of the spike suggests that the deposit has thinned to much less than a meter.

4.2.4 Cross Section D-D'

Cross section D-D' (Fig. 5.5) is the most northerly of the dip cross sections and is approximately 16 km long. Both VE3 and VE4 cut downward northeastward; VE3 cuts down 8 m while VE4 cuts down 9.5 m. The overall drop in the VE4 surface is accomplished in 2 general "steps". The first step is near the western side of Caroline between wells 4-13-35-7 and 3-19-35-6 where the VE4 surface cuts down 3.7 m, while the second step is at the eastern boundary of Caroline, between 4-29-35-6 and 11-2-36-6 with a step down of 4.5 m. The CM1 marker is present in the southwestern well where the SCS deposits above are up to 7 m thick (6-8-35-7). By well 11-2-35-6 however, this marker has been cut out by the overlying VE4 surface. The deposits between the markers VE4 and CM2 thin progressively northeastward, from 3.5 m (6-8-35-7), to the point where they are cut out by the overlying VE4 surface (11-

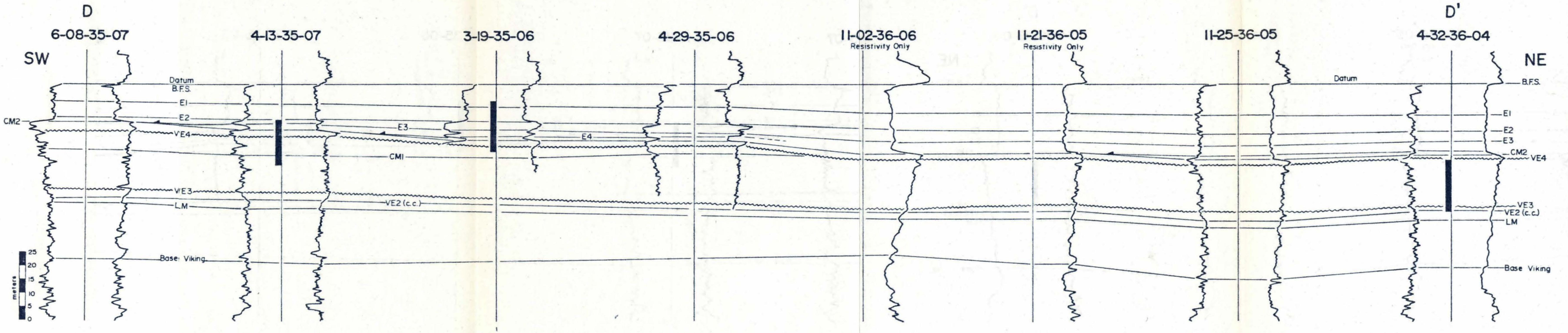
Figure 5.5: Log cross section D-D'. Location of cross section shown in Figure 5.1.

2-36-6).

All 5 of the markers in Allomember E were present in this cross section, E1 through E5. Both E1 and E2 are present in every well in this cross section. Marker E3 onlaps the CM2 surface between wells 6-8-35-7 and 4-13-35-7; E4 onlaps the CM2 surface between wells 4-13-35-7 and 3-19-35-6, and E5 onlaps the CM2 surface between wells 11-21-36-5 and 11-25-36-5. Of these markers, only E3 and E4 are at the base of coarse grained deposits of any substantial thickness. E3 records a deposit about 3.5 m thick at 3-19-35-7 (at Caroline) but is of negligible thickness northeast of Caroline. E4 is overlain by deposits about 1 to 2 m thick in the Caroline wells (3-19-35-6 and 4-29-35-6) but these thin dramatically. By 11-2-36-6 E4 is unrecognizable as a well log signature. At Caroline, E3 and E4 lie close to each other vertically so that in some wells, particularly older wells with poor resolution, they are difficult to separate from each other.

5.3 Core Cross Sections, A-A' to D-D'

The well logs cross section A-A' to D-D' were chosen to allow for maximum coverage in the study area and to permit maximum correlation with cored wells. The core cross sections are included in order to emphasize lateral sedimentological variations. These core cross sections (like the log cross sections) are hung from the BFS.



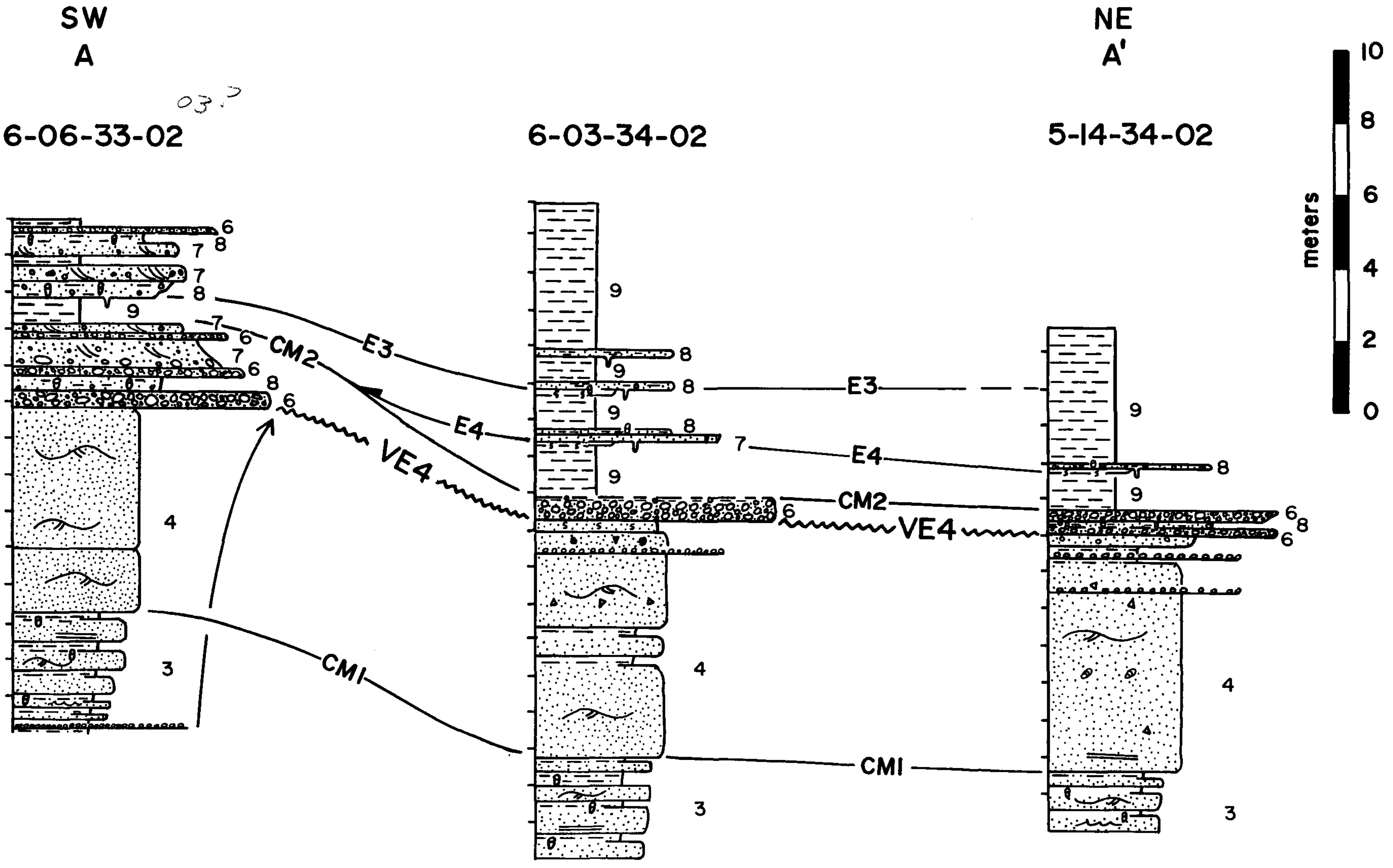
D
D'
SW
NE
6-08-35-07
4-13-35-07
3-19-35-06
4-29-35-06
11-02-36-06
Resistivity Only
11-21-36-05
Resistivity Only
11-25-36-05
4-32-36-04
Datum
B.F.S.
E1
E2
E3
E4
CM2
VE4
CM1
VE3
VE2 (c.c.)
LM
Base Viking
meters
0
5
10
15
20
25

5.3.1 Core Cross Section A-A'

This cross section consists of only three wells (Fig. 5.6). In each of these wells the underlying sandier upwards sequence of Allomember D is present, although incomplete. Allomember D includes the facies below the VE4 surface and above the VE3 surface, where present. Each well showed the transition upward from HCS sandstone (Facies 3) to SCS sandstone (Facies 4). There are local occurrences of scattered pebbles and *Lingula* which are of limited lateral continuity. SCS sandstone, in each well, is overlain sharply by the VE4 surface.

Overlying the VE4 surface are the deposits of Allomember E which, for each well, are incomplete in the sense that the top of Allomember E was not cored. They consist of coarse grained deposits interbedded with black shale before eventually passing into dominantly black shale vertically. The coarse grained deposits between VE4 and CM2 thin to the northeast, as indicated by the log cross section. In addition the facies bounded by these 2 surfaces show lateral variation from southwest to northeast. In the extreme southwest at well 6-6-33-3, the deposits bounded by these 2 surfaces are complex. The deposit commences with conglomerate (Facies 6) which is then overlain by pebbly burrowed mudstone (Facies 8), another conglomerate, pebbly cross stratified sandstone (Facies 7), another conglomerate and then another pebbly cross

Figure 5.6: Core cross section A-A'. Corresponds to the wells in Figure 5.2 which are cored. The numbers included adjacent to the logs in all the following core cross sections are the facies numbers.


SW
A
NE
A'
6-06-33-02
03?
6-03-34-02
5-14-34-02
meters
0
2
4
6
8
10
E3
E4
CM2
VE4
CM1
3
4
6
7
8
9

stratified sandstone before being overlain by black shale. In contrast, the VE4 - CM2 interval in 6-3-34-2 and 5-14-34-2 consists mainly of conglomerate.

Overlying the CM2 marker in all wells is layer of black shale thinner than 1.5 m. In each well the transition from a coarse grained lithology (Facies 6,7 or 8) into black shale is fairly sharp, and occurs in a few cm. In some cases the upper 10 cm of a coarse grained lithology has a burrowed muddy matrix. In each well there is another coarse grained interbed which sharply overlies the shale. These coarse grained interbeds are of dramatically different thicknesses from well to well however. From regional correlation using well logs, the first coarse grained interbed above CM2 in 6-6-33-2 is E3 whereas the first coarse grained interbed above CM2 in 6-3-34-2 and 5-14-34-2 is E4. The E3 interbed in 6-6-33-2 is about 2 m thick and is composed of thin beds of Facies 6,7, and 8. When E3 is traced laterally to 6-3-34-2, it thins to much less than a meter and consists of a thin layer of burrowed pebbly mudstone. The E3 bed cannot be traced in core to the last well (5-14-34-2). The E4 interbed appears to onlap the CM2 surface between 6-6-33-3 and 6-3-34-2. In 6-3-34-2, E4 is a thin bed of pebbly sandstone overlain by burrowed mudstone and in 5-14-34-2 is a thin layer of burrowed pebbly mudstone. The upper portions of both 6-3-34-2 and 4-14-34-2 are dominantly black shale.

5.3.2 Core Cross Section B-B'

Core cross section B-B' (Fig. 5.7) is made up of 11 cores out of the 12 well logs used in the log cross section. All the wells have an incomplete Allomember D, although many of the cores go to deeper stratigraphic levels than core cross section A-A' as Facies 2 is present in many of the cores. Like A-A', Allomember D is characterized by a gradational sandier upward sequence from burrowed laminated sandy mudstones to HCS sandstones and up into HCS sandstones. Within this sequence are isolated occurrences of scattered pebbles and *Lingula* shells. Allomember D at Garrington has a greater preservation of SCS sandstones than off field to the northeast. The paleosol deposit in the southwest well of 7-4-33-6 overlies gravels and coaly mudstones. Unfortunately due to the shortness of the core at this location, its position on top of a complete sandier upwards sequence can only be inferred. All of these deposits are sharply overlain by the VE4 surface.

Deposits of Allomember E found above the VE4 surface are present in every well but all are incomplete. The deposits bounded by the CM2 and VE4 surfaces, which are thickest southwest of Caroline, show a lateral transition from alternating pebbly cross stratified sandstone and conglomerate in 7-4-33-6, to dominantly conglomerate at Caroline (10-3-34-4). The interval remains dominantly conglomeratic northeastward. The coarse grained interbeds which punctuate

Figure 5.7: Core cross section B-B'. Corresponds to the wells in Figure 5.3 which are cored.

SW
B
NE
B'
7-04-33-06
6-16-33-05
14-10-33-05
7-24-33-05
7-19-33-04
10-03-34-04
16-28-34-03
16-35-34-03
6-06-35-02
3-15-35-02
14-17-35-01
E1
E2
E3
E4
CM1
CM2
VE4
meters
0
2
4
6
8
10

the shaley stratigraphy of Allomember E were present in many of the wells; their correlation was established both by correlation of well logs (Fig 5.3) and cores. E1 was only cored in 2 wells (7-19-33-4 and 10-3-34-4) where it is preserved as a sandy sideritized bed in the former and a burrowed mudstone in the later. E2 is present in 3 wells (7-24-33-5, 7-19-33-4 and 10-3-34-4), is made up of burrowed pebbly mudstone, and onlaps the VE4 surface between 7-4-33-6 and 6-16-33-5. E3 is present in 4 cores (7-24-33-5, 7-19-33-4, 10-3-34-4, and 16-35-34-2). It is found in wells southwest of Caroline, and presumably onlaps between 14-10-33-5 and 6-16-33-5. E3 reaches its greatest thickness immediately west of Caroline and in Caroline (7-19-33-4 and 10-3-34-4). It passes laterally from a pebbly cross stratified sandstone, which is the dominant lithology to Caroline, into a mixed burrowed pebbly mudstone at Garrington. E4 is present in only 3 wells in this cross section (10-3-34-4, and 16-35-34-3, 16-28-34-3). The onlapping nature of the coarse grained interbeds is illustrated by E4 in this cross section. The CM2 surface at the well immediately to the southwest of the point of E4 onlap is noticeably higher, stratigraphically, than the E4 marker in the first well where it occurs (10-3-34-4). At 10-3-34-4, E4 is mixed pebbly sandstone, burrowed mudstone and in well 16-35-34-3 where it occurs to the northeast is a burrowed pebbly mudstone.

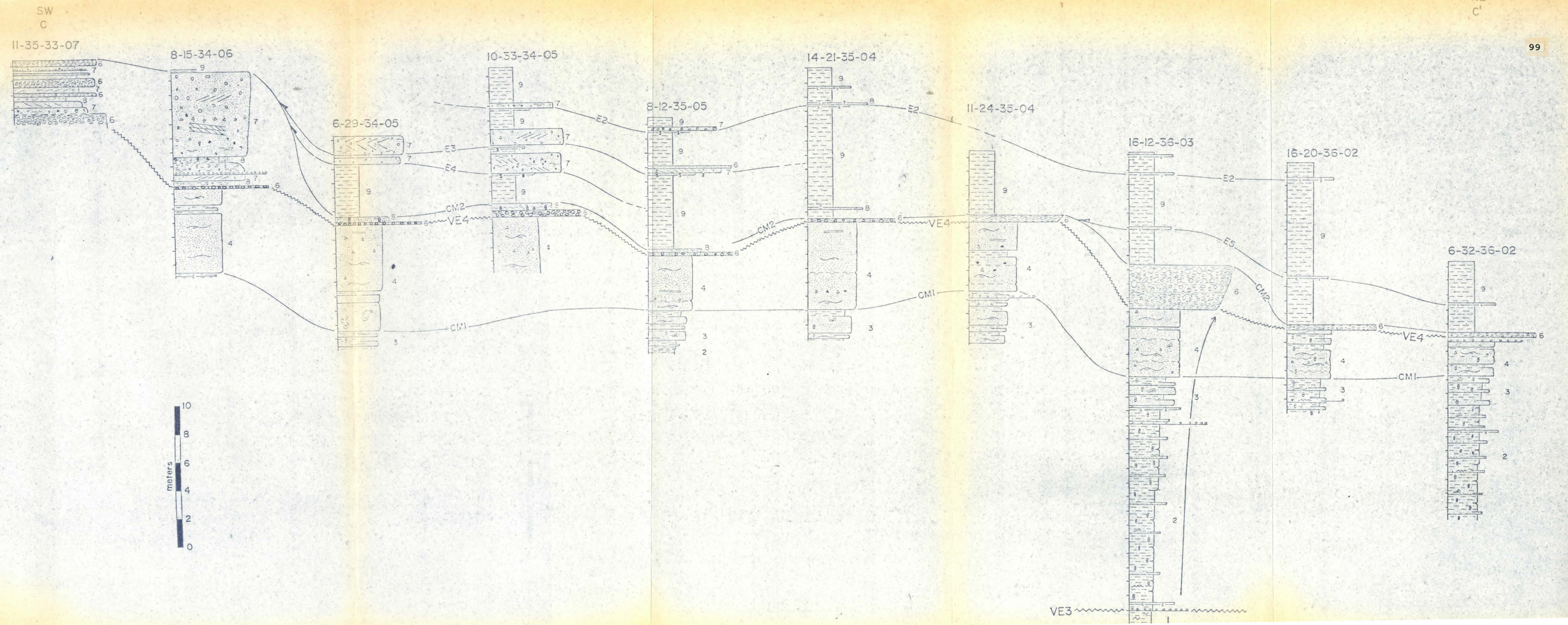
This cross section also shows the presence of minor coarse grained beds (above E2) which could not be correlated regionally. Examination of the well logs reveal many minor positive resistivity spikes which may be due to coarse grained material but were of insignificant thickness to be traced laterally.

5.3.3 Core Cross Section C-C'

Cross section C-C' (Fig. 5.8) contains 10 cores and corresponds to log cross section C-C' (Fig 5.4) made up of 12 logs. Allomember B/C, which consist of facies underlying the VE3 surface, consists of burrowed muddy siltstone (Facies 1: 16-12-36-3). It is capped by a thin pebble veneer (VE3). Overlying VE3 are the deposits of Allomember D, which commence with very muddy Facies 2, burrowed laminated sandy mudstone. The types of mudstone above and below the VE3 surface are clearly distinct from one another. Well 16-12-36-3 has a complete sandier upwards sequence in Allomember D, and the other wells in this cross section also show this pattern. In general, the deposits become muddier towards the northeast, as shown in wells 16-20-36-2 and 6-32-36-2.

The deposits of Allomember E, above the VE4 surface, are similar in their overall trends to the 2 previous core cross sections described. Like these cross sections, the deposits between the VE4 and CM2 markers are considerably thicker southwest of Caroline. They change from a mixture of conglomeratic, pebbly cross stratified sandstone, and minor burrowed pebbly mudstone facies into predominantly

Figure 5.8: Core cross section C-C'. Corresponds to the wells in Figure 5.4 which are cored.


SW
C
NE
C'
11-35-33-07
8-15-34-06
10-33-34-05
6-29-34-05
8-12-35-05
14-21-35-04
11-24-35-04
16-12-36-03
16-20-36-02
6-32-36-02
E2
E3
E4
E5
CM1
CM2
VE3
VE4
meters
0
2
4
6
8
10

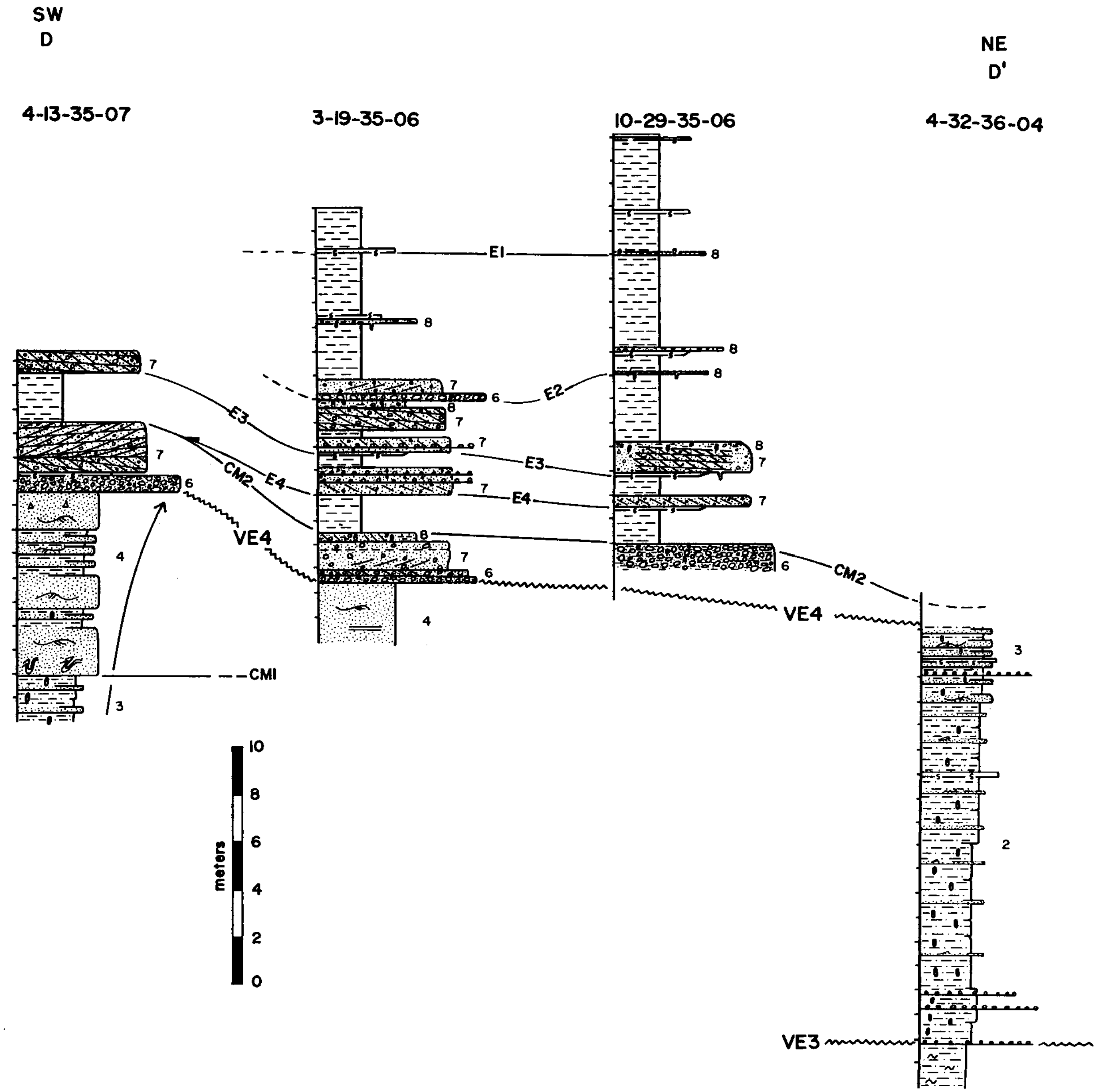
conglomerate by the first well in Caroline (6-29-34-5). They remain mainly conglomeratic for the rest of the wells in the cross section. Well 16-12-36-3 is northeast of Garrington and is unusual in that it has about 3 m of a muddy-matrix conglomerate between the VE4 and CM2 surfaces. Of the coarse grained interbeds which characterize Allomember E, E2 through E5 are represented in core. E2 onlaps to the south west of Caroline; it is quite thin, and changes laterally from a burrowed pebbly mudstone to sideritized mud northeastward. E3 is thickest in the most southwesterly well (6-29-34-5) where it consists of pebbly cross stratified sandstone (high angle bipolar crossbeds). It thins toward 8-12-35-5 where it is a pebbly burrowed mudstone. E4 is present in 2 cores (6-29-34-5 and 10-33-34-5); in 6-29-34-5 it is very close stratigraphically to E3 but is thought to be distinguishable by a thin layer of black shale. In 6-29-34-5, the deposits of E4 consist of pebbly sandstone which grade laterally into pebbly cross stratified sandstone with thin burrowed mudstone layers (10-33-34-5). The thickness of E4 is greater in 10-33-34-5 (1 m) than in 6-29-34-5 (50 cm). E5 is represented by a thin sideritized mud layer in 16-12-36-3, 16-20-36-2 and 6-32-36-2.

5.3.4 Core Cross Section D-D'

This core cross section (Fig. 5.9) consists of four cores from the log cross section D-D'. Allomember C is present in 4-32-36-4, where Facies 1 is about one meter thick at the bottom of the core. Allomember D is very similar in its sandier upwards nature to the other core cross sections. Most striking in this cross section is the northeastward loss of sand; in the most northeasterly core, 4-32-36-4, the VE4 surface directly overlies HCS sandstone (Facies 3) as opposed to SCS sandstone (Facies 4).

The deposits between the VE4 and CM2 surfaces in Allomember E are composed of conglomerate overlain by cross stratified pebbly sandstone in 4-13-35-7 and 3-19-35-6, and conglomerate in 10-29-35-6. Compound cross stratification occurs in 4-13-35-7, whereas in 3-19-35-6 there are faint high angle cross beds. E1 is very thin and composed of only sideritized mud in 3-19-35-6 and burrowed pebbly mudstone in 10-29-35-6. Its point of onlap presumably lies far to the southwest of the cross section. E2 is present in 3-19-35-6 and 10-29-35-6. In 3-19-35-6 E2 appears to have amalgamated with the underlying beds of E3. This interpretation is based on well log correlation. In 3-19-35-6, E2 is composed of a thin layer of conglomerate overlain by pebbly cross stratified sandstone. In 10-29-35-6, E2 is a very thin bed of pebbly burrowed mudstone. E3 consists of predominantly pebbly cross stratified sandstone although it changes laterally towards the northeast from compound cross stratification (4-13-35-7) to compound cross stratified sandstone grading upwards into pebbly burrowed mudstone (10-29-35-6). E4 appears to onlap the CM2 surface between wells 4-13-35-7 and 3-19-35-6. This

Figure 5.9: Core cross section D-D'. Corresponds to the wells in Figure 5.5 which are cored.


SW
D
NE
D'
4-13-35-07
3-19-35-06
10-29-35-06
4-32-36-04
E1
E2
E3
E4
CM2
VE4
CMI
VE3
meters
0
2
4
6
8
10

interbed does not show appreciable variation in lithology laterally in the wells it occurs. It is predominately pebbly cross stratified sandstone in each well. It does thin to the northeast, however, as shown in core.

5.4 Strike Cross Sections, E-E' and F-F'

Two well log cross sections were constructed parallel to regional strike, within the Caroline and Garrington fields; these tie together into the dip cross sections thus establishing correlation of log markers across the entire study area. The same log markers are used in the strike cross section as in the dip cross sections. Emphasis will be given to the markers in Allomember E.

5.4.1 Cross Section E-E'

Cross section E-E' (Fig 4.10) is approximately 26 km long. Neither VE3 or VE4 shows a systematic and regular change in morphology with respect to the BFS datum from one end of the cross section to the other. The VE3 surface drops 6 m overall from E to E' but does so in an undulatory fashion. VE4 rises 3 m overall from E to E' but this is also accomplished in an undulatory, fashion. The CM1 marker, which denotes the HCS sandstone to SCS sandstone transition is generally flat in this cross section although there are minor undulations. The deposits found between VE4 and CM2 show considerable variation in thickness in this cross section, but generally the deposits are thinner in the southeastern portions of this cross section than in the more northwesterly

Figure 5.10: Log cross section E-E'. Location of cross section shown in Figure 5.1.

E
E'
NW
SE
4-08-36-07
4-13-35-07
7-01-35-07
5-02-35-06
16-24-34-06
11-16-34-05
7-24-33-05
15-18-33-04
10-10-33-04
6-06-33-03
Datum
B.F.S.
E1
E2
E3
E4
CM2
VE4
CM1
VE3
LM
VE2 (c.c.)
Base Viking
meters
25
20
15
10
5
0

portions. The greatest thickness of deposits (about 7 m) between these two markers occurs at well 7-1-35-7, whereas the thinnest deposits (< 1 m) are found at 6-6-33-3.

There is considerable complexity with the coarse grained interbeds found in Allomember E. Coarse grained interbeds E1 through E4 are present in this cross section. E1 and E2 are present in every well and remain relatively flat parallel to the BFS. E3 is present in all but one of the wells; it appears to onlap the CM2 surface on either side of well 7-1-35-7. This irregularity is likely due to the orientation of the cross section, which is not always parallel to the strike of onlap. The thickness of the deposits of E3 fluctuate widely in this cross section but generally are thickest at the Caroline wells of 16-24-34-6 and 11-16-34-5. The interbed is quite thin towards the southeast. E4 is only found in 2 of the wells of this cross section, 4-8-36-7 and 11-16-34-5, both of which are slightly east of the general trend of the cross section. The interbeds appears to onlap the CM2 surface on either side of the wells in which they occur.

5.4.2 Cross Section F-F'

Cross section (Fig. 5.11) is approximately 27 km long. The VE3 surface drops 12 m overall from northwest to southeast in an undulatory fashion. At well 10-32-35-4, VE3 drops relative to the surrounding wells and appears to cut out the underlying VE2 marker. The VE4 surface is very undulatory but seems to rise about 2 m from northwest to southeast. It

Figure 5.11: Log cross section F-F'. Location of cross section shown in Figure 5.1.

F
F'
NW
SE
11-21-36-05
7-13-36-05
10-32-35-04
11-24-35-04
8-09-35-03
16-35-34-03
6-19-34-02
5-14-34-02
9-04-34-01
Datum
B.F.S
E1
E2
E3
E4
E5
CM2
VE4
CM1
VE3
VE2 (c.c.)
LM
Base Viking
metres

appears to rise to its greatest height southeastward towards Garrington at well 8-9-35-3 and drops slightly on the southern edge of Garrington at well 5-14-34-2. CM1 remains virtually flat in the cross section but is cut out by the VE4 surface in the extreme northwest (11-21-36-5). Deposits between VE4 and CM2 are always thinner than 2 m.

E1 to E4 are laterally persistent along the cross section, with the exception of E3 which loses its signature in the northwestern wells (11-21-36-5 and 7-13-36-5). These markers tend to drape the underlying topography to a certain extent, with the exception of E1 which remains essentially parallel to the BFS. None of the interbeds in this cross section is of substantial thickness (> 1 m).

5.5 Summary

The cross sections show regional trends of the lateral facies changes and the two dimensional geometry which occur either parallel or perpendicular to strike of the fields.

The following geometrical characteristics are consistently observed in the 4 dip log and core cross sections (oriented perpendicular to the strike of the fields):

1) the VE3 surface drops stratigraphically northeastward relative to the BFS. This drop is generally greatest in the south where up to 13 m of relief was recorded on cross section A-A' and least in the north where 8 m of relief was recorded on cross section D-D'. The overall drop is accomplished in an undulatory, non systematic way.

2) the CM1 surface denoting the HCS sandstone to SCS sandstone transition, was generally sub-parallel to the BFS surface (although minor undulations do exist). The SCS sandstone deposits between CM1 and VE4 generally thins in the northeast direction. In some cases the SCS sandstones and CM1 surface are absent in the more northeasterly wells, presumably because of downcutting by the VE4 surface.

3) the VE4 surface drops with respect to the BFS marker towards the northeast. This drop is accomplished in 2 subtle "steps", one along the western margin of the Caroline field and the other along the eastern margin of the Garrington field. Up to 15 m of relief is present in the cross sections. The VE4 surface rises slightly (<2m) thus defining a "high" along the western margin of the Garrington field.

4) the lowest stratigraphic deposits of Allomember E, found between the VE4 and CM2 surfaces are noticeably thicker west of Caroline where thicknesses are commonly greater than 5 m. They thin quickly inside the western margin of the Caroline field to less than 2 m. The deposits between VE4 and CM2 generally remain at thicknesses of less than 2 m (with minor exceptions) from Caroline throughout the rest of the area to the northeast. There are variations in thicknesses from a few cms to 2 m within this area however. This interval is dominated by alternating conglomerate and pebbly cross stratified sandstone in the southwest portion of the study area (particularly west of the Caroline field) and grades

laterally in the northeastern direction to predominantly conglomerate with some pebbly burrowed mudstones.

5) The coarse grained interbeds in Allomember E are represented in well logs as spikes and can be traced from well to well. Five of these have been identified for this study, E1 to E5. Each of these, with the exception of E1, onlaps the CM2 surface sequentially. E5 occurs at the lowest stratigraphic level and onlaps northeast of Garrington in a line oriented roughly northwest-southeast. E3 and E4 appear to have onlapped the CM2 surface near the western boundary of Caroline in a northwest-southeast direction. E2 onlaps the CM2 surface in only the extreme southwest portions of the study area, whereas E1 is not observed to onlap the CM2 surface within the study area. The markers E2-E4 which onlap the CM2 surface along the west of Caroline are usually pebbly cross stratified sandstone near their point of onlap and change laterally into predominantly pebbly burrowed mudstone and eventually sideritized mud as they thin in a northeastern direction. E5 which onlaps along the eastern edge of Garrington is a very thin, poorly developed bed which is typically composed of sideritized mud.

The two log cross sections which are oriented parallel to the strike of the fields are useful in that they reveal the following characteristics:

1) VE3 drops stratigraphically along strike towards the southeast.

2) VE4 rises slightly along strike towards the southeast.

3) The coarse grained deposits between the VE4 and CM2 surfaces are thicker towards the northern portion of Caroline than in the southern portion.

4) The coarse grained beds in Allomember E, E1-E5 show lateral continuity from well to well in each cross section. Any onlap of markers which occurs can be explained by the slight irregularity of the trend of the cross sections.

CHAPTER 6: MAPS

6.1 Introduction

The cross sections in Chapter 5 documented the presence of 2 regional erosion surfaces within the study area, VE3 and VE4. The cross sections show how enigmatic coarse grained interbeds (E1 to E5) in Allomember E onlap the underlying CM2 surface sequentially in a southwesterly direction. This chapter focuses on the morphology of the VE4 surface within the study area and seeks to determine whether a relationship exists between this surface and the overlying coarse grained beds in Allomember E (VE4-CM2, E1, E2, E3, E4, and E5). This will be accomplished primarily by the construction of isopach maps and augmented with three dimensional mesh diagrams and two dimensional plots. Once the three dimensional geometry of the VE4 surface and the overlying coarse grained intervals in Allomember E has been established, facies distribution maps will be presented to determine if any relationship exists between facies and geometry.

6.2 Construction of Isopach Maps and Three Dimensional Mesh Diagrams

Isopach maps were constructed:

1) to show topography on a particular surface, and,

2) to document the actual thickness between two surfaces.

Isopach maps were made in order to show the topography of the VE3 and VE4 surfaces. The maps show the interval from a lower datum (LD) 110 m below BFS, and VE4. Use of the lower datum, parallel to BFS gives high isopach values for topographic highs and vice versa. If BFS and hence LD are as flat as can be reasonably ~~be~~ reconstructed, the map can then be interpreted as showing the topography on the VE3 or VE4 surfaces.

The second form of isopach map created was made by subtracting the value of an upper horizon from the value of a lower horizon. Because the surfaces are recorded in meters or feet below sea level, this subtraction results in a positive number. Isopach maps of this type were constructed for the VE4-CM2 interval as well as the interbeds in Allomember E with bases denoted E3, E4 and E5.

Many of the isopach maps and mesh diagrams presented here also show asterisks; these represent the wells found within the approximate legal boundaries of the Caroline and Garrington fields. The location of the fields is helpful in determining factors which may have been instrumental in their formation.

As an aid in visualizing these surfaces, three dimensional mesh diagrams and two dimensional plots were also constructed for the VE3 and VE4 surfaces from the same data used to construct the isopach maps.

All data were initially recorded in Lotus 123 (Appendix 2 contains the raw numerical data). The conversion of imperial units to metric, the conversion of CPA numbers for the well locations into arbitrary X,Y coordinates, as well as the necessary subtractions were performed by QuickBasic programs. All isopach maps, 3-D mesh diagrams and 2-D plots were constructed by commercially available software packages, SURFER and GRAPHER, both published by Golden Software Inc. of Golden, Colorado.

6.3 VE3 Morphology; BFS-VE3 Isopach Map and Mesh Diagram

The interval between LD (110 m below BFS) and VE3 has been isopached (Fig. 6.1) to determine the morphology of the VE3 surface. Large numbers indicate topographic "highs", but the actual numerical values are relative only.

The most striking feature on the topographic map is the rise in topography in a southwestward direction. There appears to be a subtle "step" in the topography from the eastern margin of the Caroline field towards the southwest. Garrington appears to be situated in a topographic "low". The dominant trend of the contour lines on the isopach map is northwest-southeast.

A three dimensional mesh diagram of the VE3 surface was also constructed as a visual aid (Fig. 6.2). This 3-D map is viewed from the east northeast (60° east of north) and from an angle of 30° above the horizontal plane. The relief on this mesh diagram is greatly exaggerated because the actual relief from southwest to northeast portions of the study area (78.5 km) is about 22 m.

The 3-D mesh diagram also shows the topography rising in steps towards the southwest. One "step" is apparent the middle

Figure 6.1: Isopach of 110 - (VE3 - BFS). This isopach is intended to show the topography on the VE3 surface. The numerical values are relative only. Note the "low" occurring at Garrington and the "high" which occurs at Caroline.

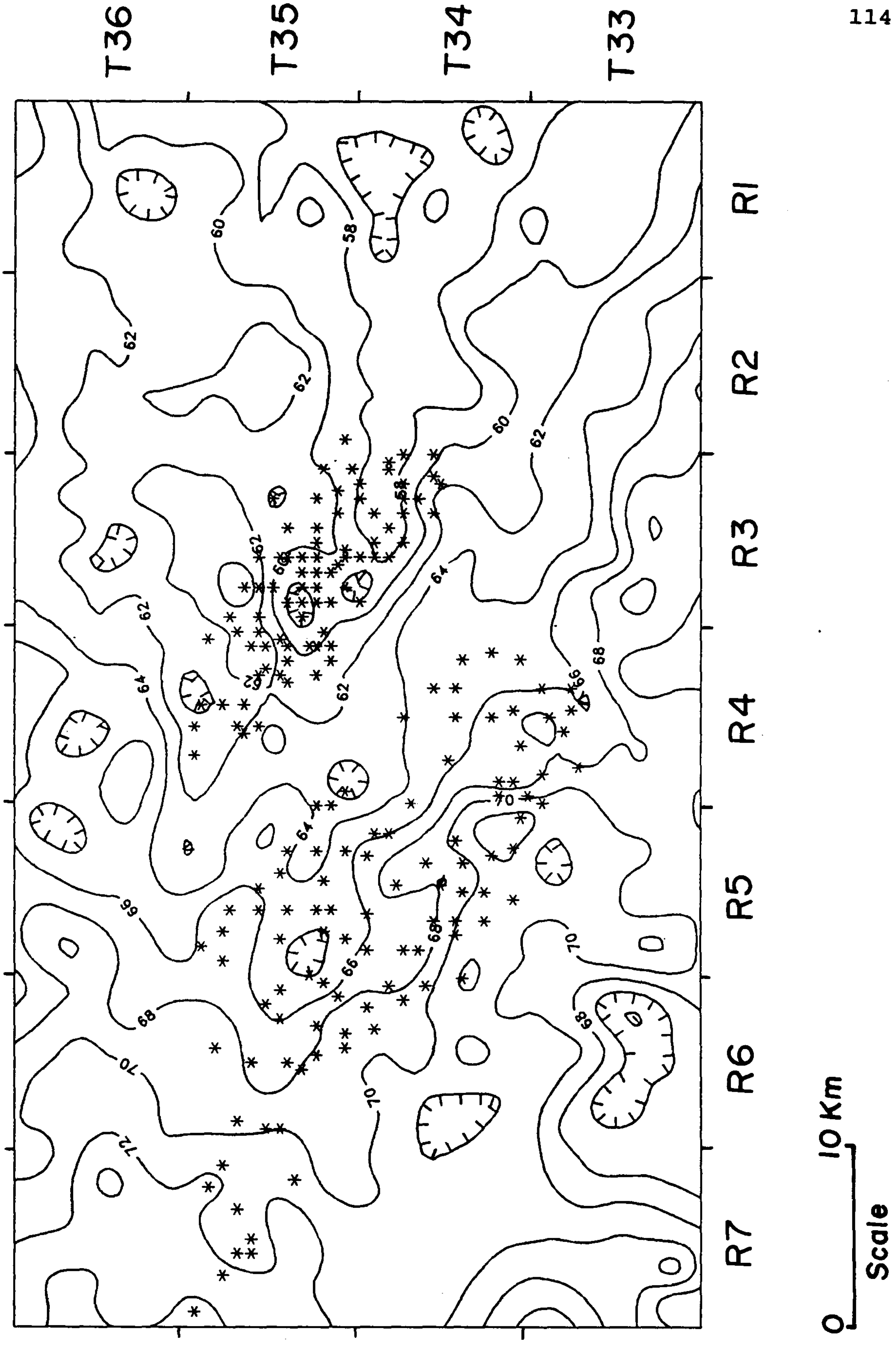
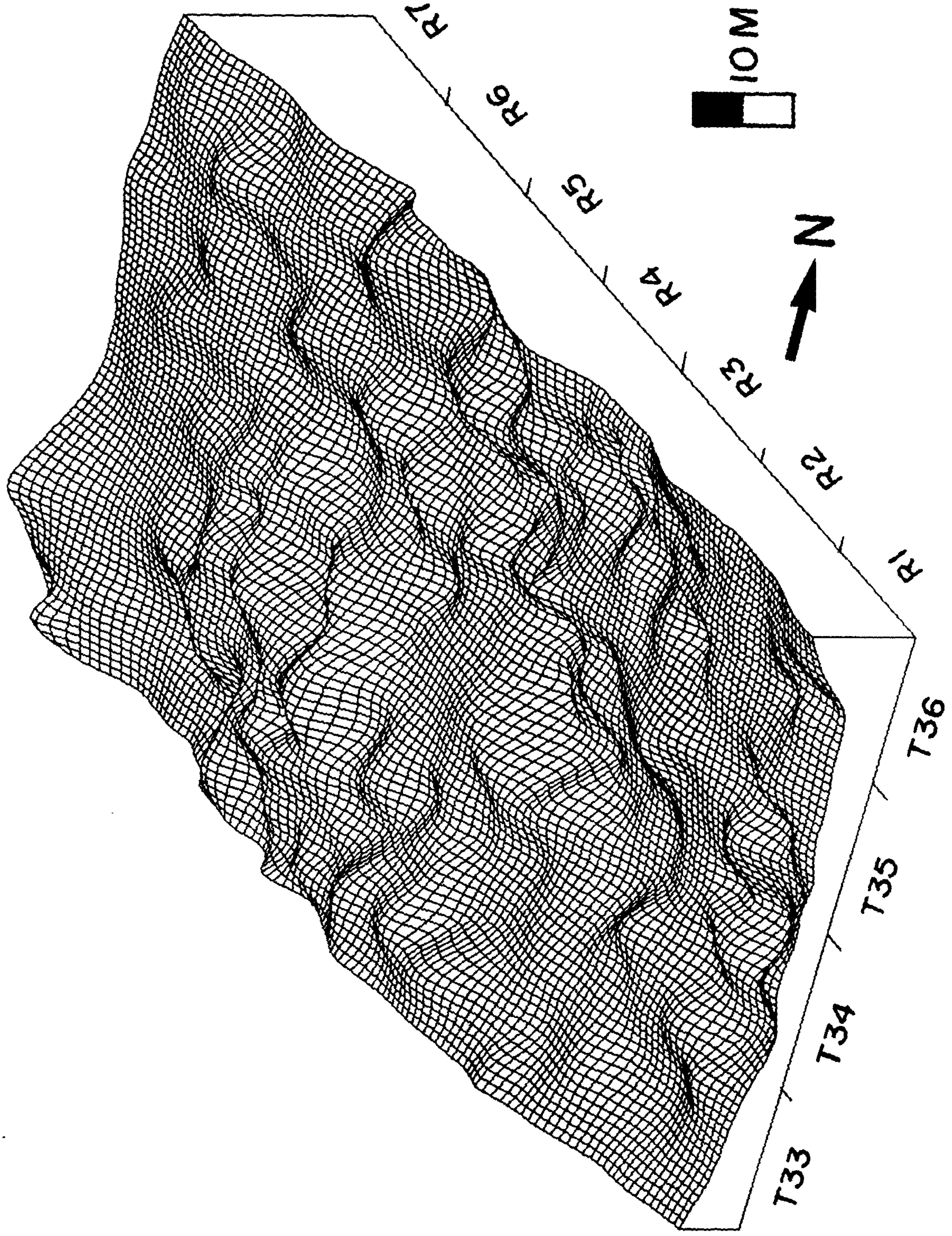

T36
T35
T34
T33
R1
R2
R3
R4
R5
R6
R7
58
60
62
64
66
68
70
72
0
10 Km
Scale

Figure 6.2: 3-D mesh diagram of the VE3 surface. This diagram was constructed from the same data used to construct the isopach map of Figure 6.1. It shows the "low" which occurs at Garrington and the "high" which occurs at Caroline. Note the possible "step" between the Caroline and Garrington fields.


R7
R6
R5
R4
R3
R2
R1
T36
T35
T34
T33
N
IOM

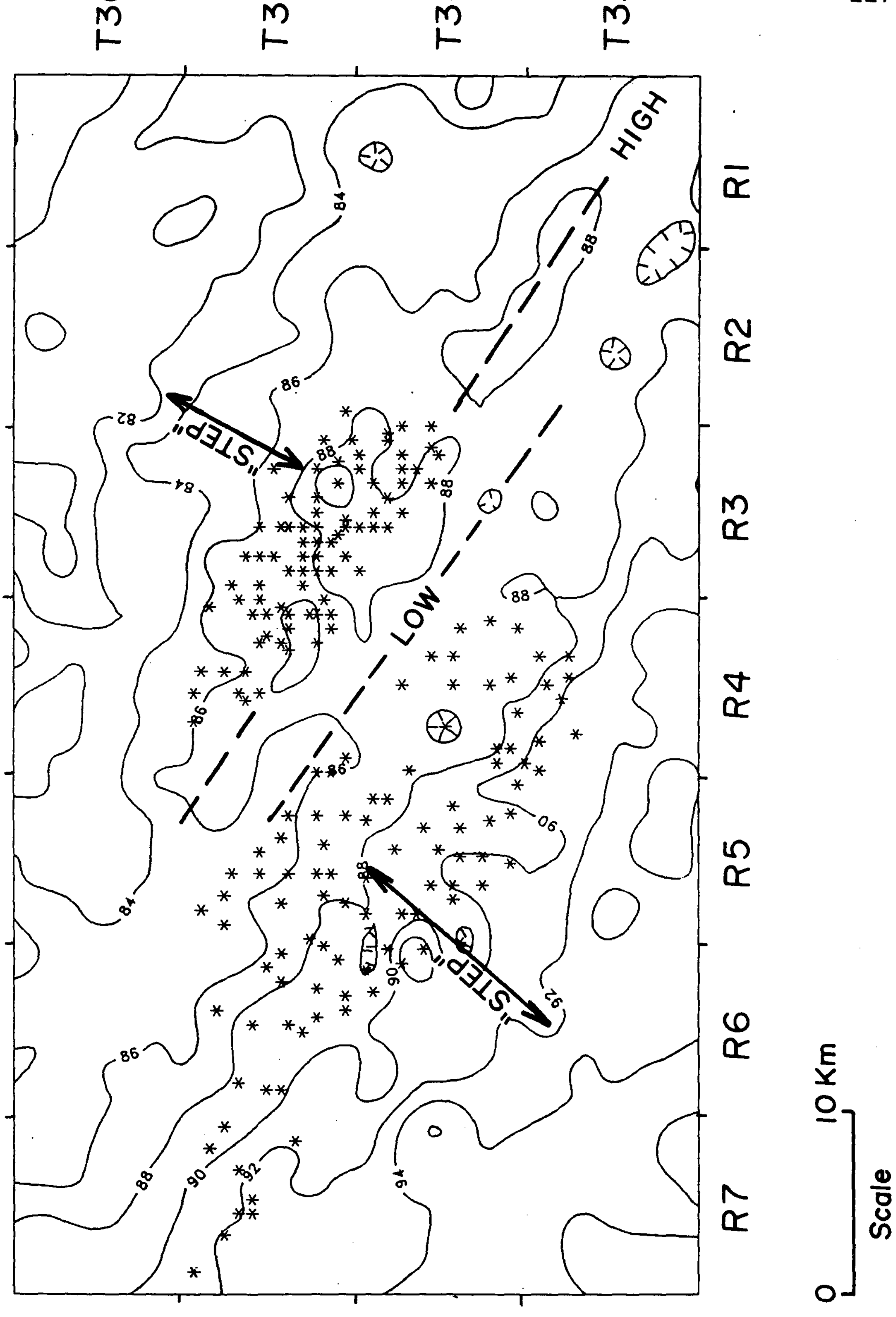
of the map. Another possible "step" is located in the extreme southwest portion of the area. The VE3 surface also seems to rise slightly (about 2 m) towards the north-northeast of Garrington.

6.4 VE4 Morphology; BFS-VE4 Isopach Map and Mesh Diagram

The interval between VE4 and LD has also been isopached to determine the morphology of the VE4 surface (Fig. 6.3). The VE4-LD isopach shows a distinct northeast-southwest trend. Assuming that the LD and BFS are flat, this trend shows the topography on the VE4 surface. There is about 18 m of relief from the southwest portion of the map area to northeast, most of which seems to be due to two subtle southeast-northwest trending "steps" where the contour lines are spaced closely together. One of these is located along the western margin of the Caroline field while the other occurs along the eastern margin of the Garrington field. The Garrington field itself is situated on a slight relative topographic "high" relative to the surrounding areas. The VE4 surface drops noticeably to the northeast and northwest of Garrington; it also drops slightly (about 2 m) southwest of Garrington. The northwestern drop of topography indicates that the "step" on which Garrington is situated is not continuous along strike, but terminates northwest of Garrington. This is in contrast to the "step" west of Caroline which seems to be roughly continuous along strike.

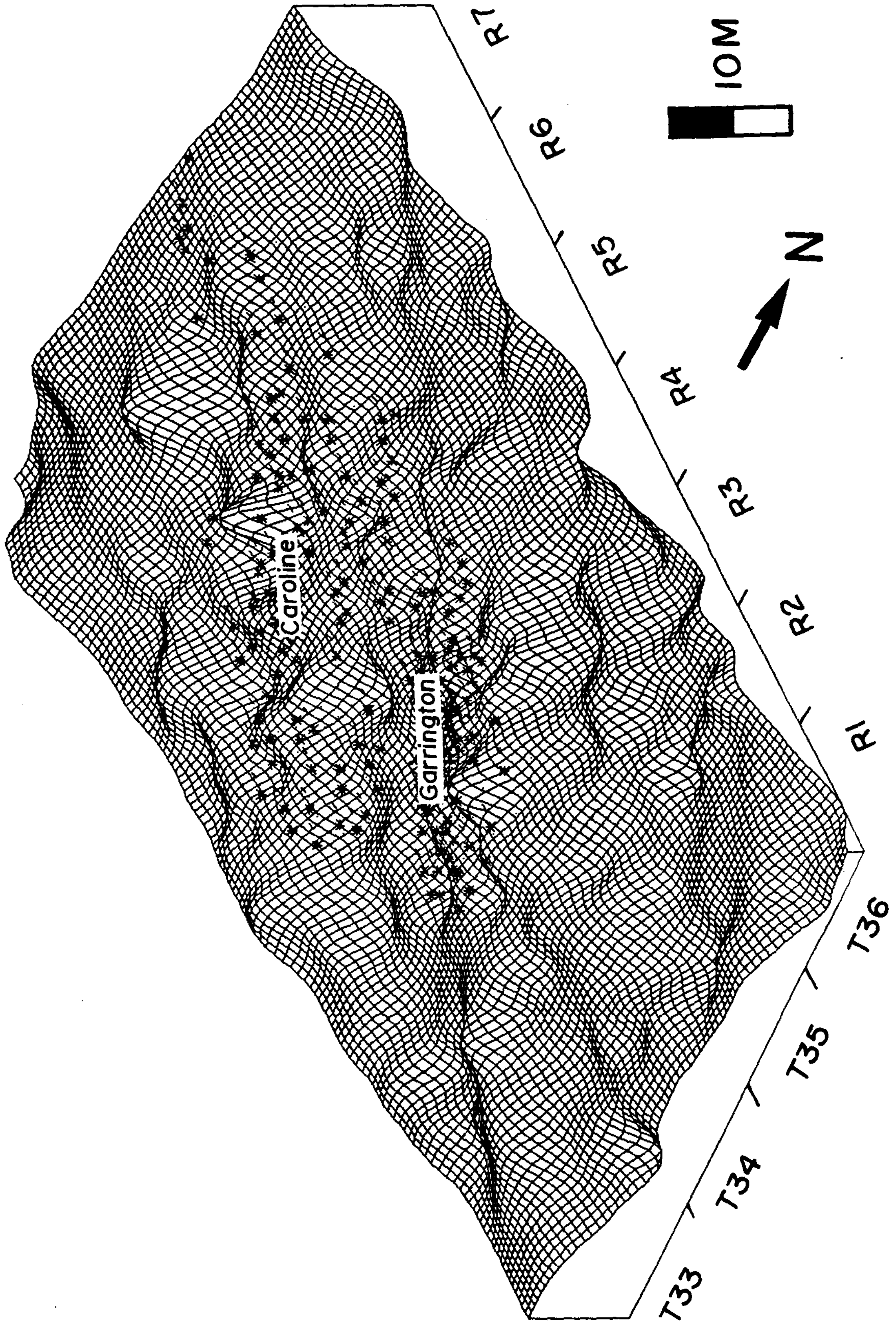
In addition to the two "steps" of the VE4 surface

Figure 6.3: Isopach map of 110 - (VE4 - BFS). This isopach was constructed to show topography on the VE4 surface. Note the closely spaced contour lines slightly east of Garrington and west of Caroline which outline subtle "steps" in the topography. The topography rises towards the southwest.



T36
T35
T34
T33
R1
R2
R3
R4
R5
R6
R7
HIGH
LOW
"STEP"
"STEP"
82
84
86
88
90
92
94
0
10 Km
Scale

Figure 6.4: 3-D mesh diagram of the VE4 surface. This diagram was constructed from the same data used to construct the isopach map of Figure 6.3. Note the two subtle "steps" associated with Caroline and Garrington and the overall rise in topography towards the southwest.


R7
R6
R5
R4
R3
R2
R1
T33
T34
T35
T36
Caroline
Garrington
10M
N

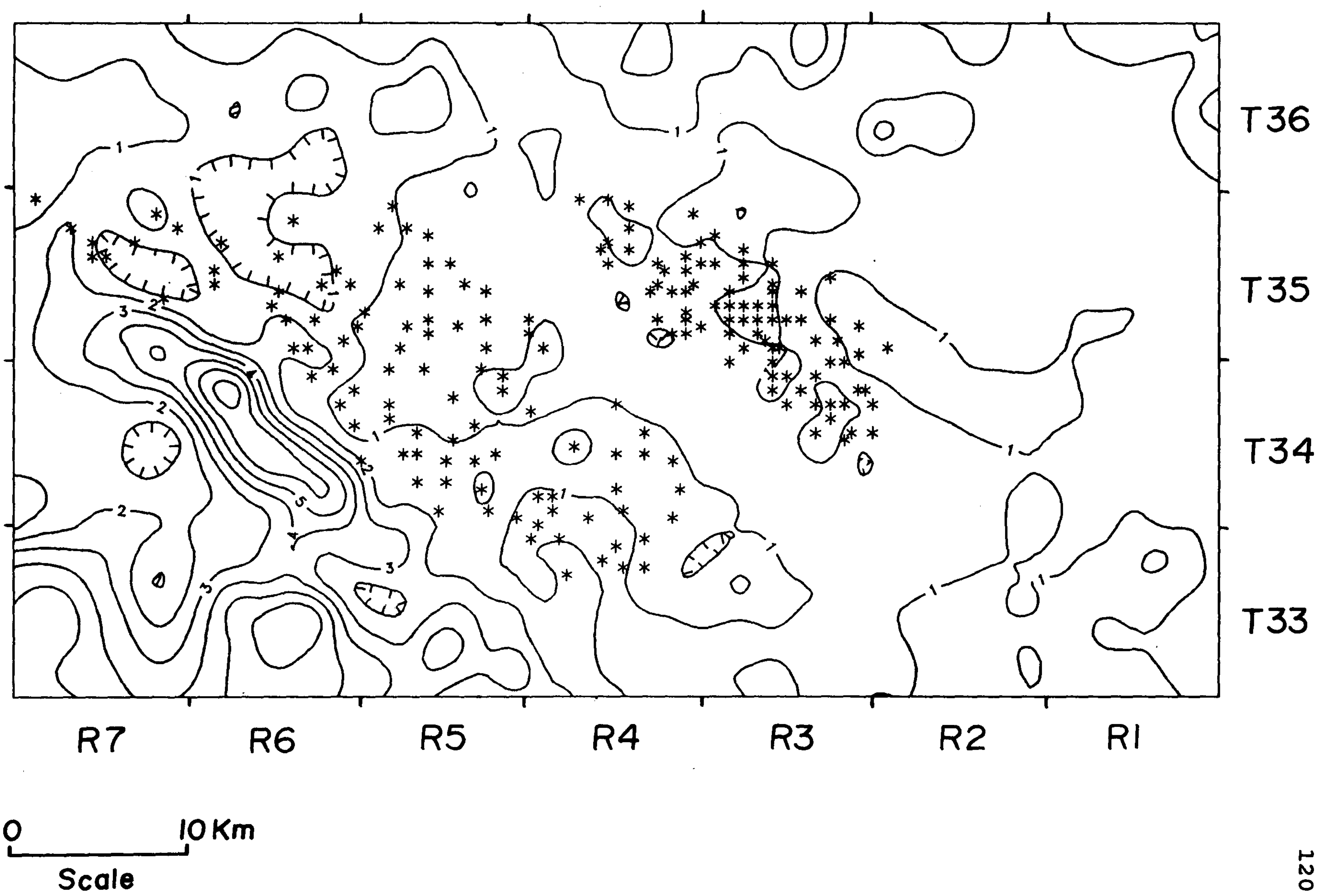
described there is also another topographic "high" in the extreme southwest portion of the study area (T33, R7), but due to the limits of the map area it is impossible to ascertain whether this "high" defines a "step", which would continue along strike, or a topographic "high" which is not continuous along strike (a bump).

A 3-D mesh diagram was also created for the VE4 surface (Fig 6.4). This surface is viewed from the northeast (at 45° from north) at a 30° angle above the horizontal plane and illustrates the "steplike" topography outlined above. For example, there is clearly a "high" of the VE4 surface on which Garrington is situated which subtly drops and fades northwest of Garrington. There is also another "high" along the western margin of the Caroline field which seems to be continuous along strike. An additional "high" is shown in the most southwesterly portions of the map; this may or may not define a third "step".

6.5 CM2-VE4 Isopach Map and Facies Distribution Map

Figure 6.5 is an isopach map showing the thickness of the coarse grained deposits overlying the VE4 surface and bounded on top by the CM2 surface. This interval is always composed of either Facies 6, 7 or 8 and represents the first deposits of Allomember E. The thicknesses used for the construction of an isopach map were measured from resistivity well logs and augmented by core where possible. It should be noted that the measurements made from well log are accurate

Figure 6.5: Isopach map of the VE4 to CM2 interval. This map illustrates the thickness of the coarse grained deposits which overlie the VE4 surface. Note the linear "thick" which occurs immediately west of the Caroline field. The rest of the field towards the northeast is characterized by patchy occurrences of deposits generally thinner than 1 m.

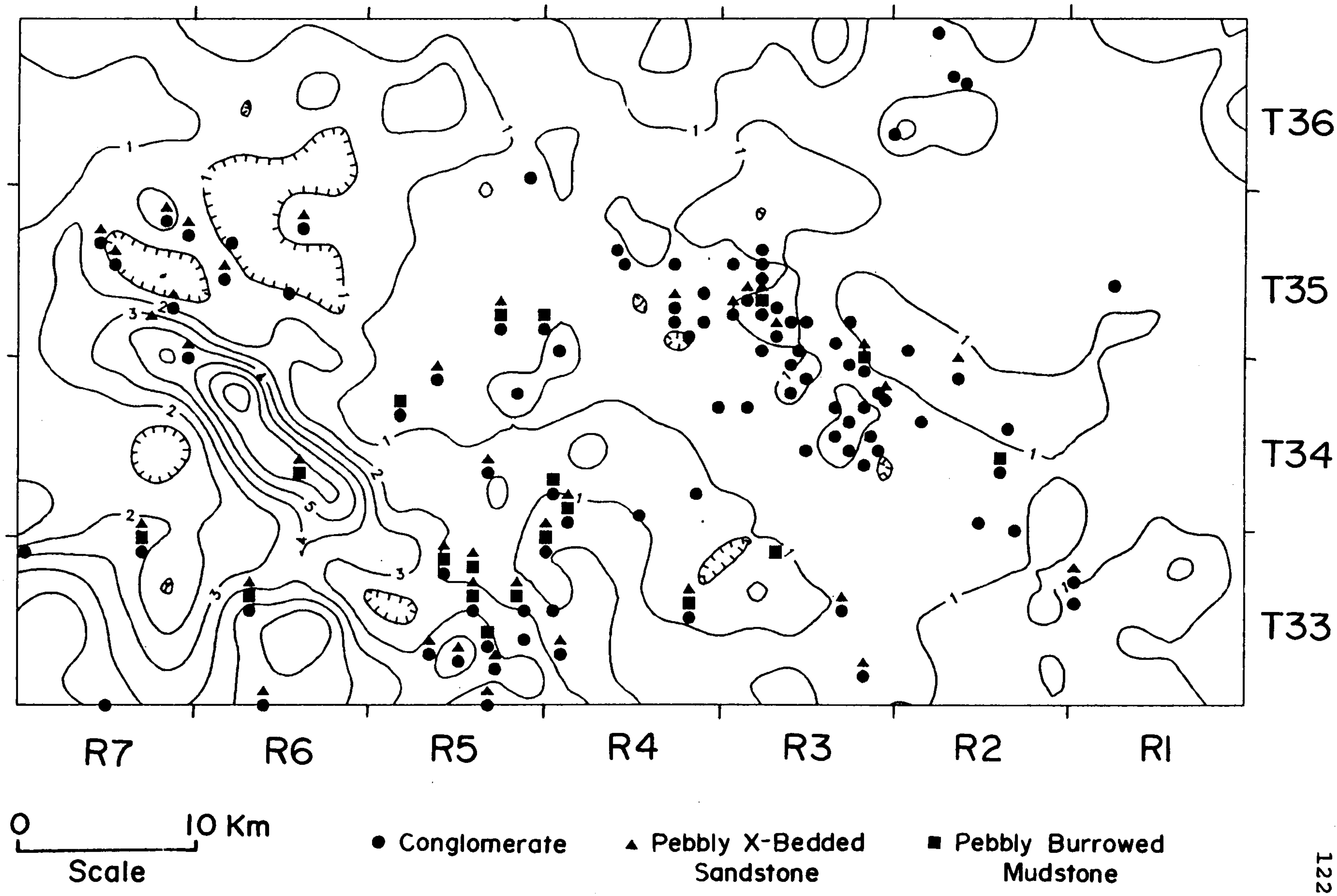

T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
R1
0
10 Km
Scale

to about 1 m; thicknesses less than one meter are difficult to measure. Despite this, the isopach map is still useful for distinguishing the thicknesses of deposits greater than 1 m.

The most obvious feature apparent in Figure 6.5 is the dramatic thickening of this interval west of Caroline and farther to the southwest. The deposits between the VE4 and CM2 surface are up to 2 m thick in the Caroline field, but immediately to the west they thicken to almost 8 m. The "thick" west of Caroline seems to occur in one northwest-southeast linear ridge west of Caroline field in T33 and T34, R6. Additional "thicks" occur in the extreme southwest portion of the map but were not traced along their length due to the restrictions imposed by the limits of the study area.

Facies were superimposed on the VE4-CM2 interval in order to document any lateral facies variation at this interval (Fig. 6.6). The facies at this stratigraphic interval are composed of either conglomerate (Facies 6), pebbly cross stratified sandstone (Facies 7), of pebbly burrowed mudstone (Facies 8). Any of the interbeds in Allomember E, including the VE4-CM2 interval can be composed of more than one of the coarse grained facies (Facies 6, 7, or 8) gradationally or sharply overlying one another. In well locations where this occurs, all of the facies will be symbolically included on the map in a vertical column. The map is somewhat limited in data, as the actual Caroline and Garrington fields have been cored a great deal while many off-field areas have not been extensively

Figure 6.6: Facies distribution map of the VE4 to CM2 interval. This is the same map as figure 6.5 with the facies distribution, measured from core, superimposed. Many of the wells are characterized by more than one facies within the interval in which case each facies is symbolically represented in a vertical column. Pebbly cross stratified sandstones appear to be much more common in the Caroline area than in the Garrington area. Conglomerate is the most common facies within this interval.


T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
R1
0
10 Km
Scale
Conglomerate
Pebbly X-Bedded Sandstone
Pebbly Burrowed Mudstone

cored. Despite this limitation, the map illustrates some interesting trends.

Examination of Figure 6.6 clearly indicates a lateral variation of the facies across the field in a northeasterly direction. Pebbly cross stratified sandstone (Facies 7) is much more frequent within the Caroline field and to the west of the Caroline field than in Garrington and farther to the northeast. Within the Caroline field and to the southwest, this interval is quite complex, typically being composed of more than one facies superimposed on one another. Northeast of a line trending along the eastern margin of the Caroline field, the VE4-CM2 interval is composed almost exclusively of conglomerate (Facies 6). Thus while all three facies occur over the entire area, there is a concentration of pebbly cross stratified and pebbly burrowed mudstone in the Caroline field and to the west of the Caroline field. Conglomerate (Facies 6) is found over the entire map area, but is associated with pebbly cross stratified in Caroline and to the southeast of Caroline. In contrast, conglomerate is the dominant facies in the VE4-CM2 interval at Garrington.

6.6 E1-E5 Location Maps

Well log cross sections A-A' to D-D' (Fig 5.2 to 5.5) show a series of onlapping markers, E1-E4 sequentially onlap the CM2 surface in a southwesterly direction. Therefore, the exact point of onlap is defined here at the point where the base of each interbed merges with the underlying CM2 horizon

Figure 6.7 (next 2 pages): Location maps of the E1 to E5 interbeds.

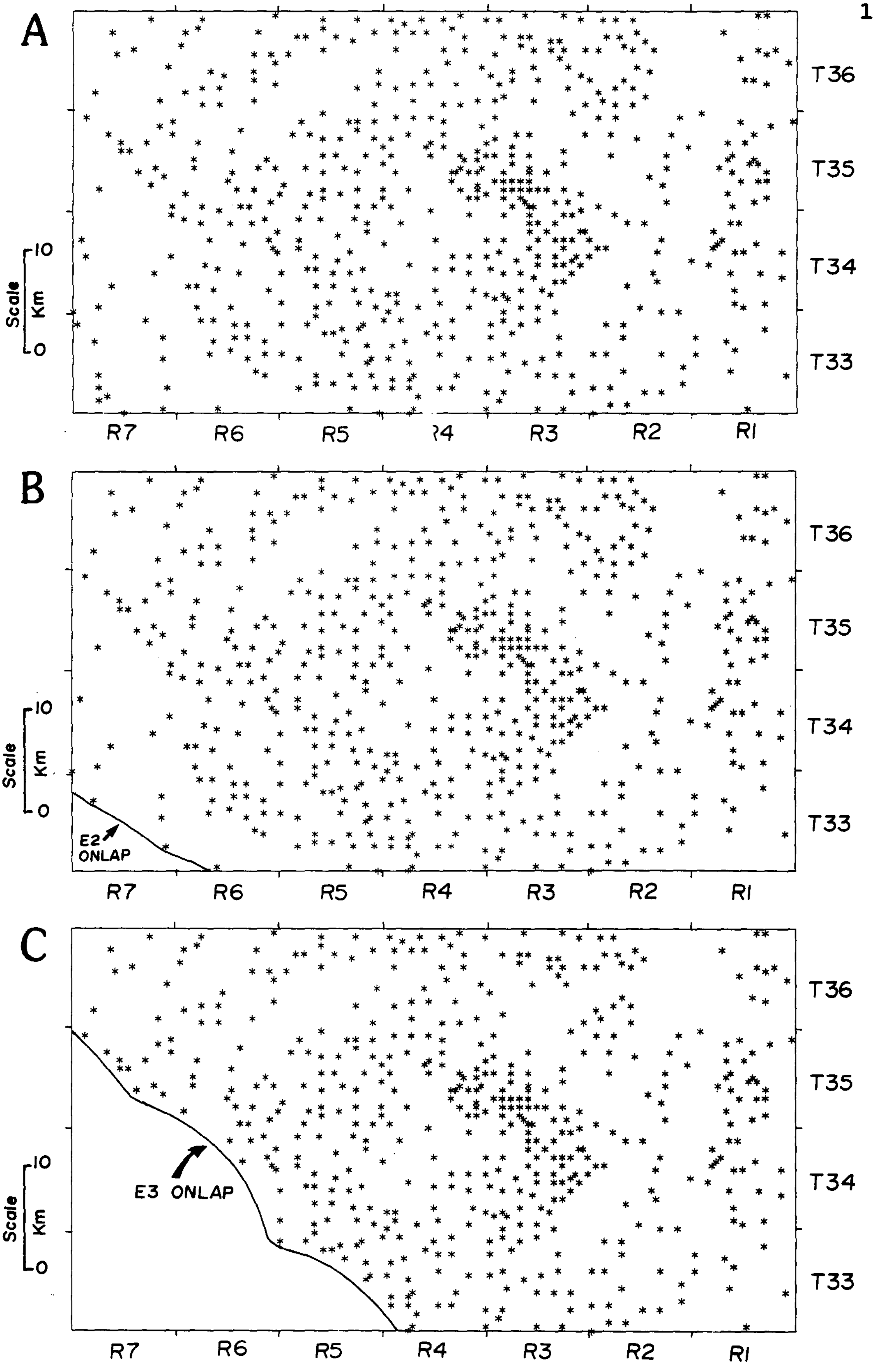
a) well locations (as indicated by asterisks) where the E1 interbed is recognized in well logs. E1 is present over the entire study area and does not onlap the CM2 surface anywhere in the study area.

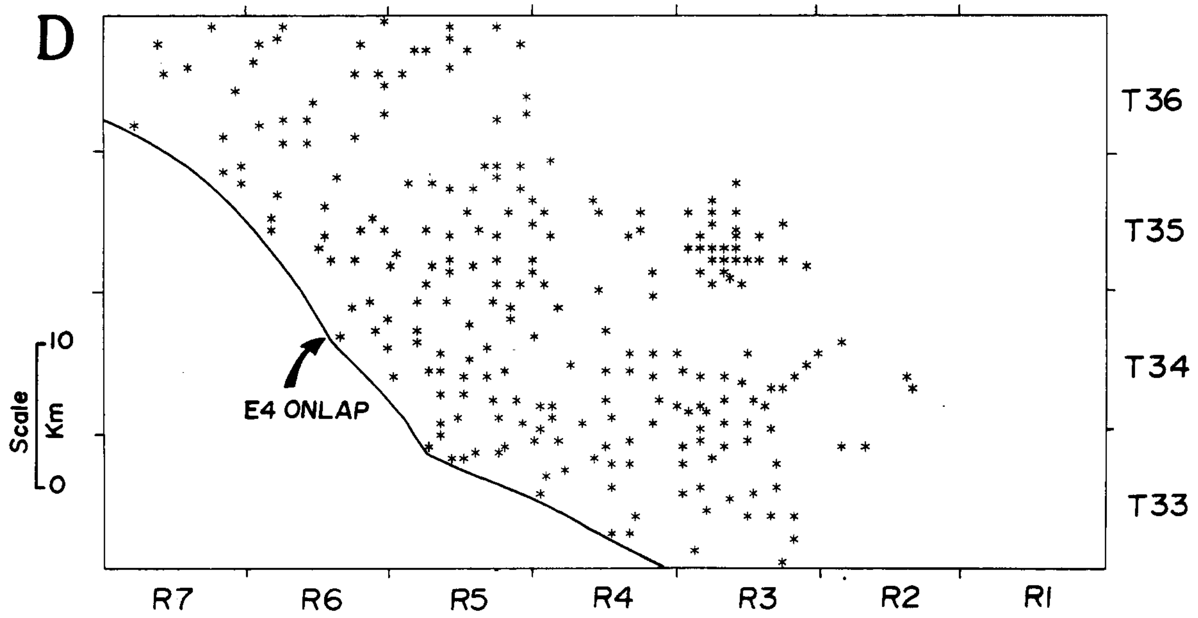
b) well locations where the E2 interbeds occurs. E2 onlaps the CM2 surface in the extreme southwest portion of the study area.

c) well locations where the E3 interbed occurs. E3 onlaps the CM2 surface approximately along a northwest-southeast trend as indicated.

d) well locations where the E4 interbed occurs. E4 onlaps the CM2 surface close to the line of onlap of the E3 interbed.

e) well locations where the E5 interbed occurs. E5 is present over a very limited area in the northeast portion of the study area and onlaps the CM2 surface just east of Garrington.


A
T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
R1
Scale
Km
10
0
B
E2 ONLAP
C
E3 ONLAP


D
T36
T35
T34
T33
Scale Km
10
0
E4 ONLAP
R7
R6
R5
R4
R3
R2
R1

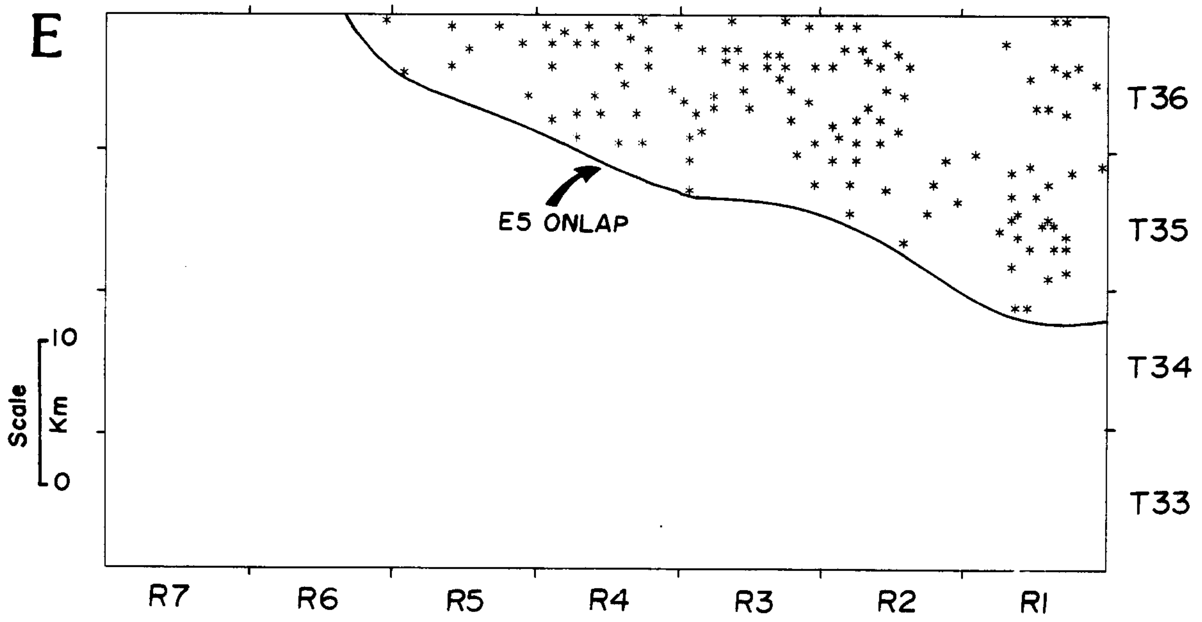
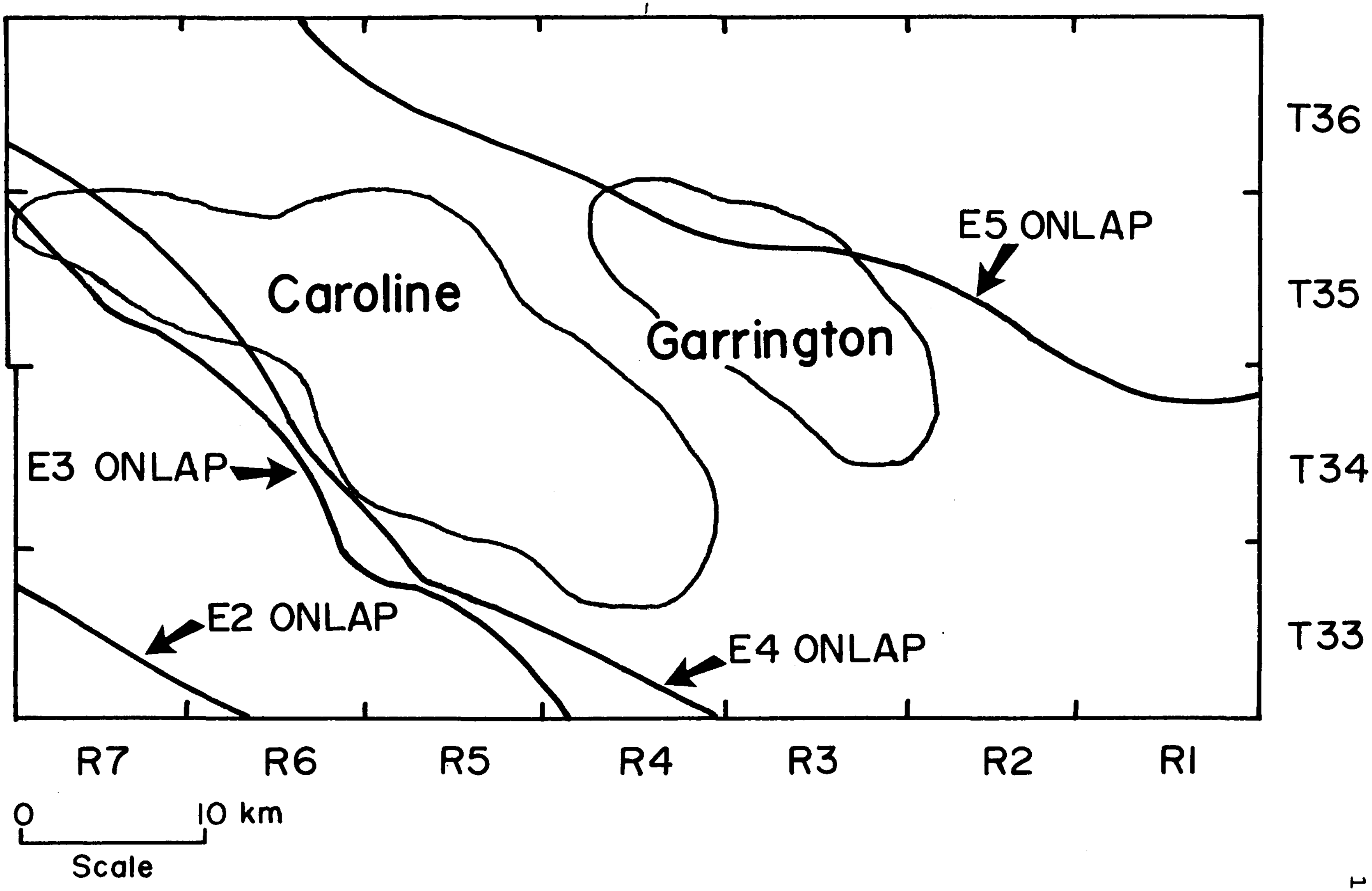

E
T36
T35
T34
T33
Scale Km
10
0
E5 ONLAP
R7
R6
R5
R4
R3
R2
R1

Figure 6.8: Summary diagram of the E1 to E5 interbeds. This diagram shows the line of onlap for each coarse grained interbed. Each interbed exists east of its line of onlap. Note that the trend of each line is approximately northwest-southeast. E1 is thought to onlap the CM2 surface west of the study area.



T36
T35
T34
T33
E5 ONLAP
Caroline
Garrington
E3 ONLAP
E2 ONLAP
E4 ONLAP
R7
R6
R5
R4
R3
R2
R1
0
10 km
Scale

and where the intervening shale would pinch out. In order to determine the regional extent of each of these markers and at which points each marker onlapped the CM2 surface, location maps showing the wells where each marker occurs were created (Fig. 6.7). Thus, the location map for each interbed also has an interpreted southeast-northwest trending line which approximates each respective line of onlap. This is true for each interbed with the exception of E1, the highest stratigraphic interbed, which is present in every well examined and presumably onlaps the CM2 surface somewhere to the southwest of the study area.

Figure 6.7 illustrates that E5 onlaps the CM2 surface just east of the Garrington field while E3 and E4 onlap in close proximity to one another just west of the Caroline field. E2 onlaps the CM2 surface in the extreme southwest portion of the study area. Figure 6.8 is a summary of these findings and shows each line of onlap superimposed on a map showing the locations of the Caroline and Garrington fields.

In order to see if relationships exist between the position where the E markers onlap, the topography of the VE4 surface, and the thickness of the VE4-CM2 interval, two additional maps were constructed. These consisted of the position of onlap for each marker superimposed first on the topographical map of the VE4-CM2 interval (Fig 6.9) and, second on the 3-D surface plot of the VE4 surface (Fig 6.10).

Figure 6.9, showing the position of onlap in relation to

Figure 6.9: Relationship of the onlap markers with respect to the VE4-CM2 interval. This is the VE4-CM2 isopach map with the lines of onlap superimposed on it. Note that the E3 and E4 interbeds onlap along the eastern margin of the "thick" occurring west of Caroline. E2 similarly onlaps the CM2 east of another "thick" in the extreme southwest portion of the study area. E5 onlaps east of the Garrington field.

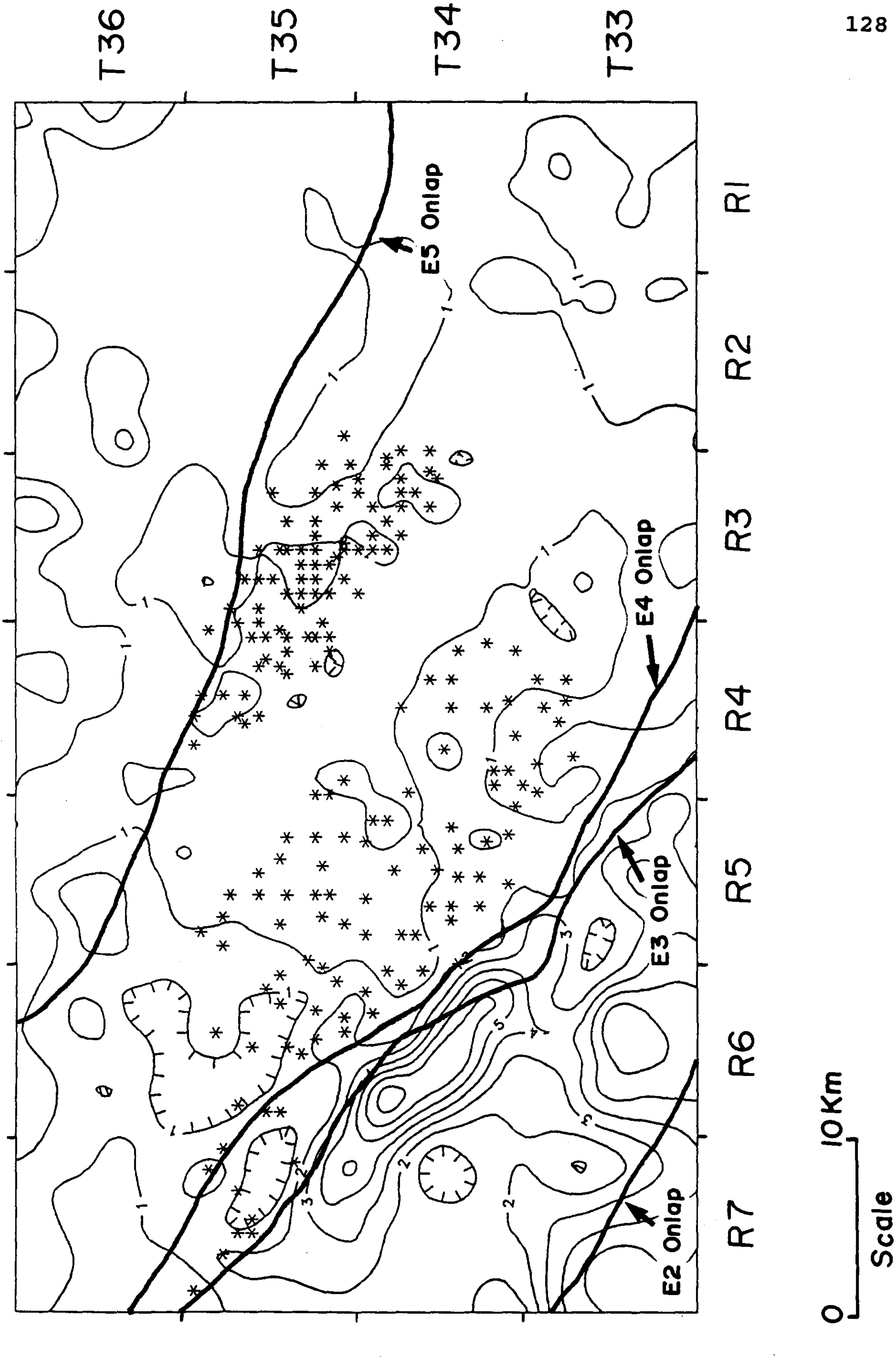
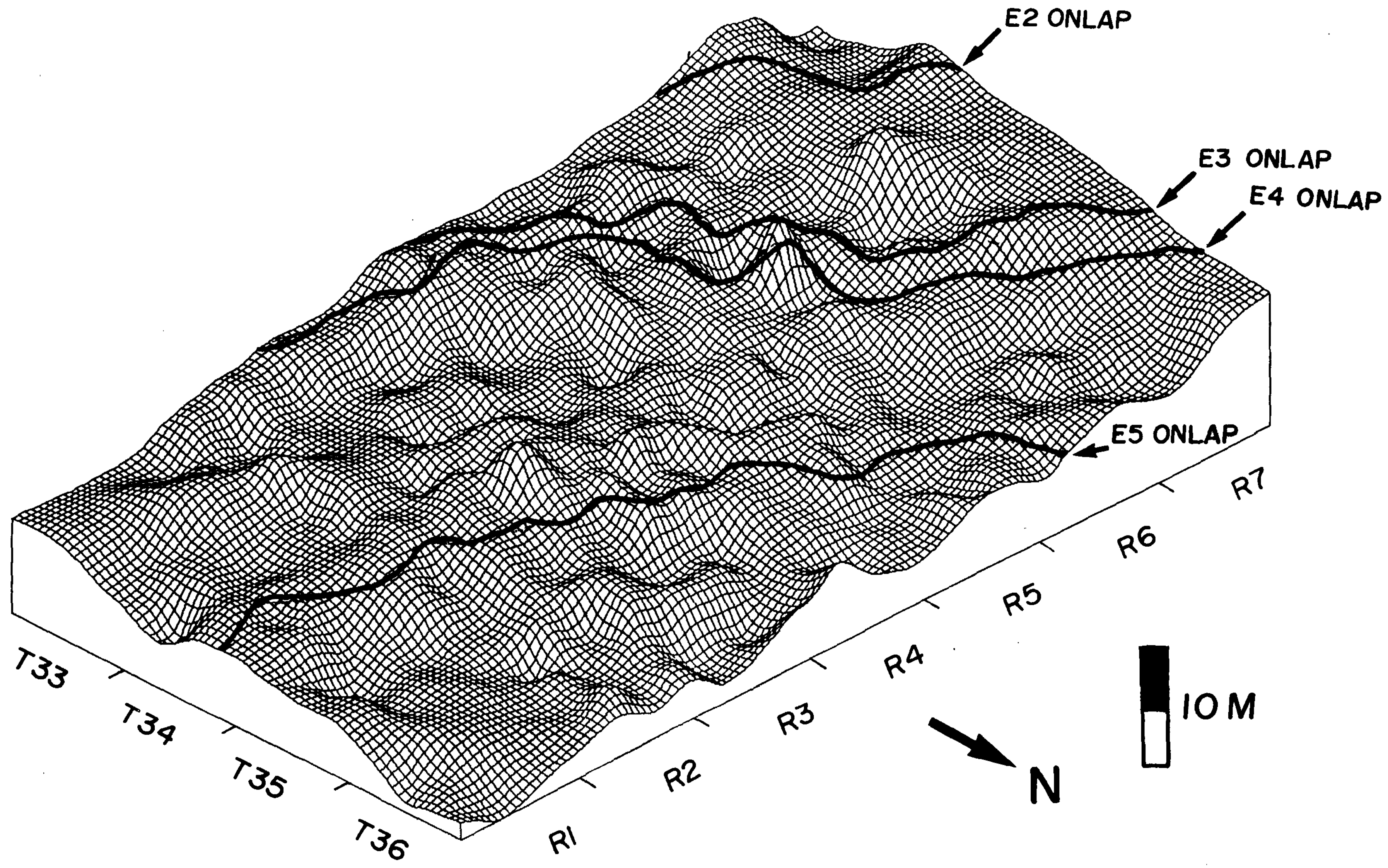

T36
T35
T34
T33
R1
R2
R3
R4
R5
R6
R7
E5 Onlap
E4 Onlap
E3 Onlap
E2 Onlap
0
10Km
Scale

Figure 6.10: Relationship of the onlap markers with respect to the VE4 surface. This 3-D mesh diagram of the VE4 surface, with lines of onlap for the E2-E5 interbeds superimposed, indicates that the interbeds seem to onlap along the basinward flanks of the "steps" described in the text.


E2 ONLAP
E3 ONLAP
E4 ONLAP
E5 ONLAP
R1
R2
R3
R4
R5
R6
R7
T33
T34
T35
T36
N
10 M

the VE4-CM2 interval and indicates that the position of onlap for each E marker is always immediately to the east of a topographic "thick" of the underlying VE4-CM2 interval. This is most convincingly indicted by the markers, E3 and E4 which onlap the CM2 surface along the eastern margin of the thick, linear, northwest-southeast trending VE4-CM2 deposits west of Caroline. E5 onlaps the CM2 surface just east of the slight thick which occurs at Garrington while E2 onlaps east of the thick which occurs in the extreme southwest.

Figure 6.10, showing the position of onlap for each E marker with respect to the underlying VE4 surface indicate that the location of onlap is associated with the position of the "steps" previously described in the VE4 surface. All of the markers which onlap the underlying deposits within the study area (E2-E5) do so along the northeastern flank of one of the steps in the VE4 surface.

E5 onlaps the underlying deposits along the "step" which occurs northeast of Garrington. E3 and E4 onlap along the flank of the "step" which occurs southwest of Caroline while E5 onlaps along the flank of the "high" which occurs in the extreme southwest.

6.7 E3, E4, and E5 Isopach Maps and Facies Distribution Maps

Isopach maps were created for the coarse grained interbeds E3, E4, and E5 to examine the variation of thickness of each interbed from its point of onlap onto the underlying CM2 surface out into the basin. The tops and bases of each

Figure 6.11: Isopach map of the E3 interbed. This isopach map was produced by subtracting the value of the top of the interbed from the value of its base. The map shows that the E3 interval thins towards the northeast. The thickest deposits (up to 3.3 m) occur within 15 km of the line of onlap.

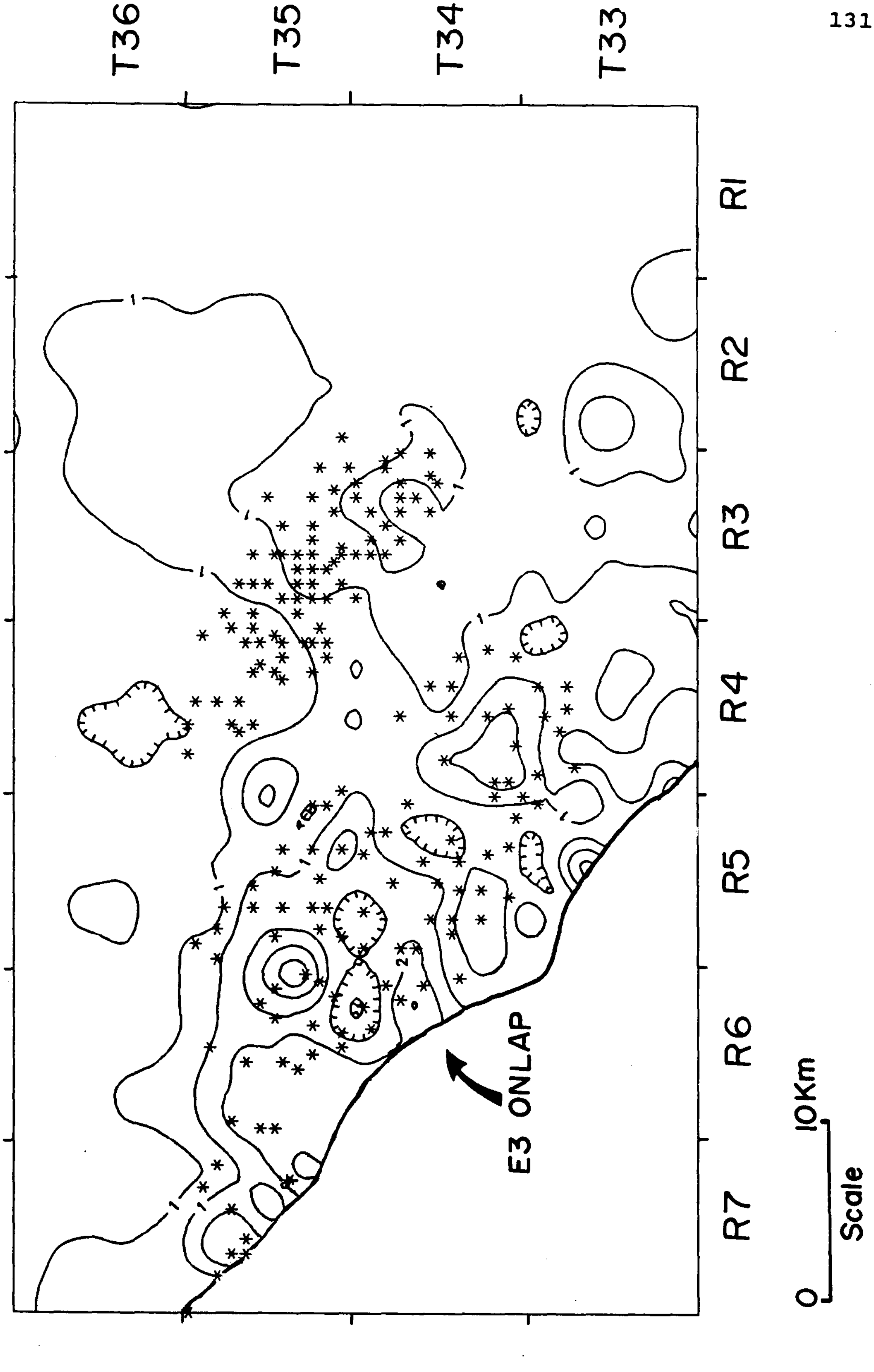
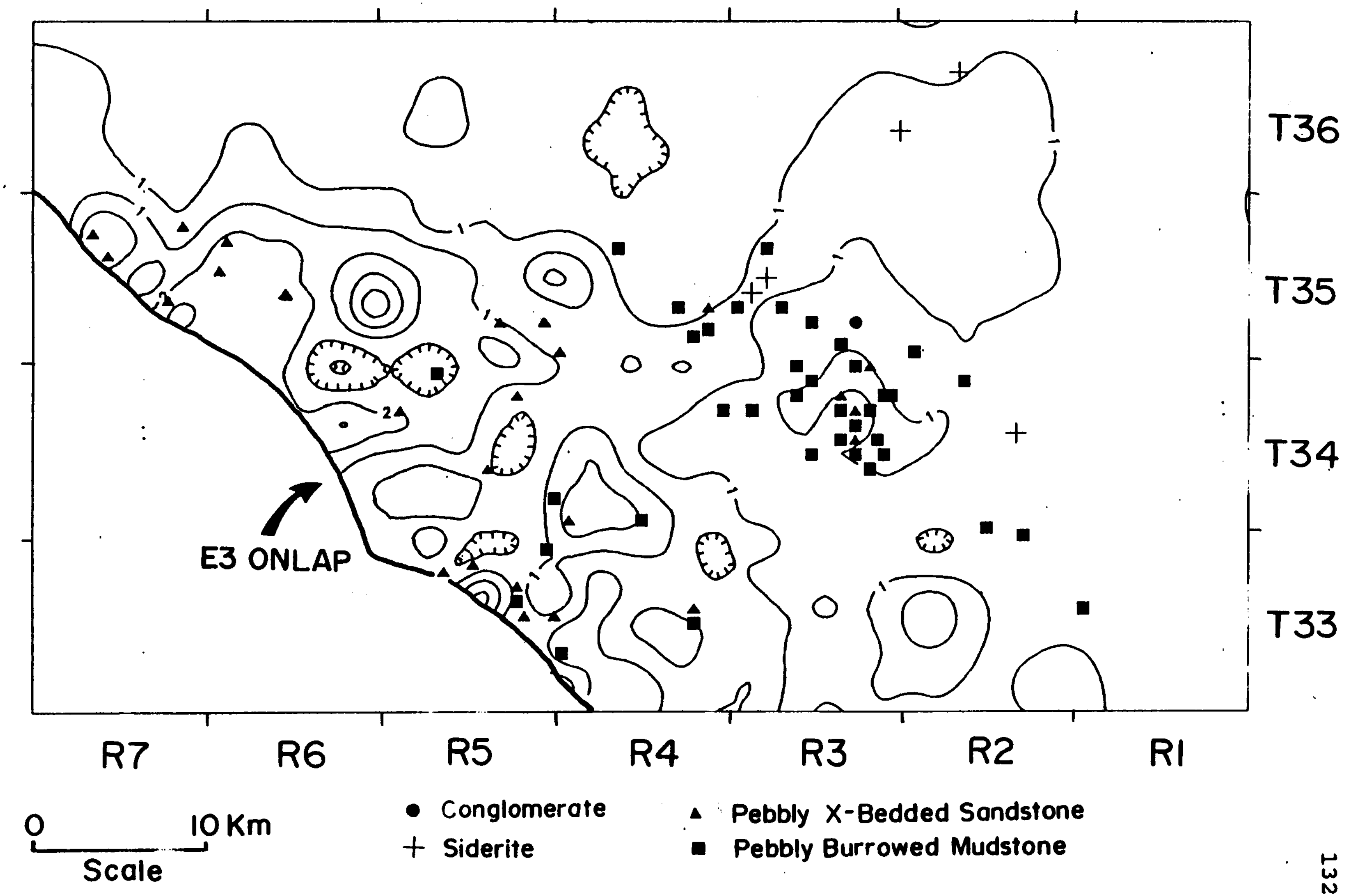

T36
T35
T34
T33
R1
R2
R3
R4
R5
R6
R7
E3 ONLAP
0
10Km
Scale

Figure 6.12: Facies distribution map of the E3 interbed. This map shows that pebbly cross stratified sandstone is the most predominant facies close to the line of onlap whereas pebbly burrowed mudstone is the dominant facies farther towards the east (at Garrington). In several cores where this interval is very thin, only sideritized mud occurs.



T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
R1
E3 ONLAP
2
2
0
10 Km
Scale
Conglomerate
Siderite
Pebbly X-Bedded Sandstone
Pebbly Burrowed Mudstone

interbed were measured off resistivity logs because this measurement was found to be reasonably close to the actual thickness measured in core. Although these interbeds could often be recognized across the study area from their point of onlap, they generally thinned to a point where thicknesses could no longer accurately be determined. It was at this point that the interbed was assigned a value of zero. Once each isopach map was constructed, an additional map was made with the facies distribution, measured from core, superimposed on to the isopach map. Facies distribution maps were created for E3 and E4 only; core data from E5 is too sparse to show on a map.

The E3 isopach map (Fig 6.11) illustrates the general thinning of this interbed basinward, towards the northeast. The greatest accumulation of sediment occurs in the southern half of T35, R5-R6, and the northern half of T34, R5-R6 where up to 3.3 m of deposits are present. The thickest deposits are not immediately adjacent to the line of onlap but occur about 6 km away to the northeast. This is consistent with the overall non-uniform, somewhat patchy thinning of the interbed basinward. Isolated pods of deposit (1-2 m thick) seem to occur up to 15 km away from the line of onlap. Farther than approximately 15 km from the line of onlap, the deposits are generally very thin, and patchy.

The facies distribution map (Fig. 6.12), showing the distribution of facies measured from core superimposed on to

Figure 6.13: Isopach map of the E4 interbed. This map was produced in the same way as Figure 6.11. It shows a thinning of the interval from the line of onlap towards the northeast. Note that this interbed is much thinner and of a lesser regional extent than E3. The interbed never exceeds 2 m in thickness.

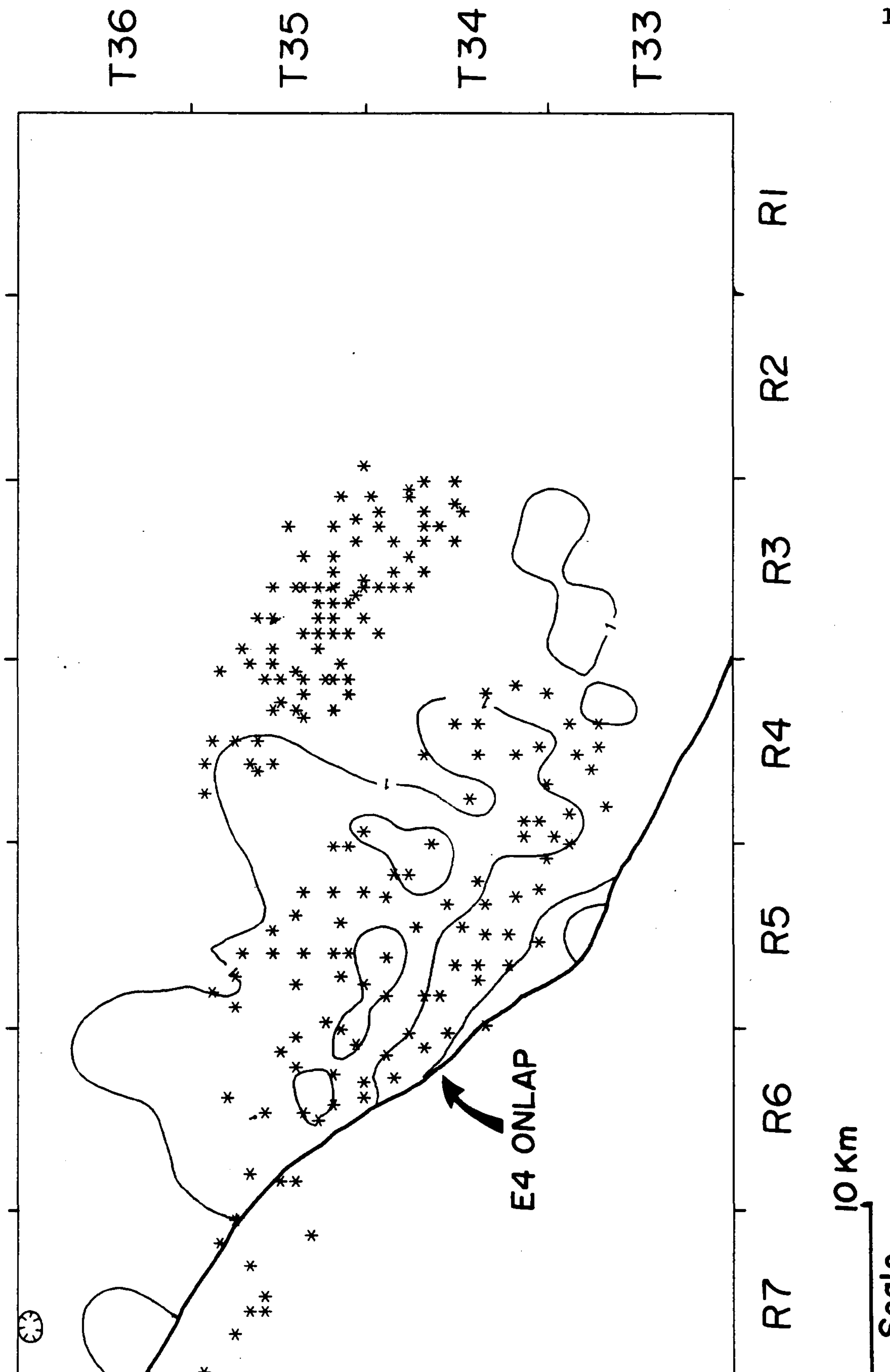
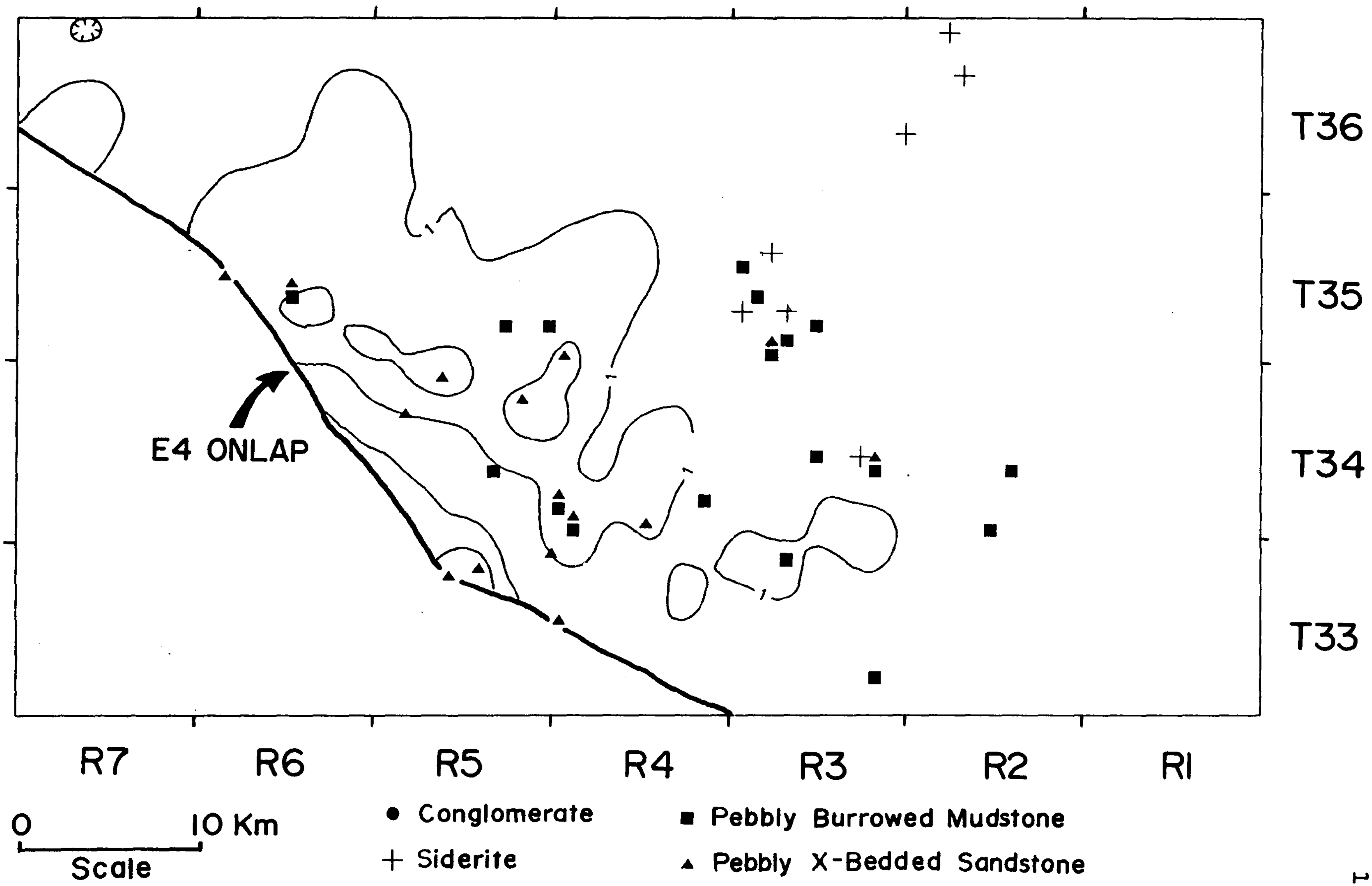

T36
T35
T34
T33
R1
R2
R3
R4
R5
R6
R7
E4 ONLAP
0
10 Km
Scale

Figure 6.14: Facies distribution map of the E4 interbed. This map shows the same general trend as Figure 6.12 in that pebbly cross stratified sandstone dominates close to the line of onlap whereas the burrowed mudstone and siderite are the most common towards the northeast.


T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
RI
E4 ONLAP
0
10 Km
Scale
Conglomerate
Siderite
Pebbly Burrowed Mudstone
Pebbly X-Bedded Sandstone

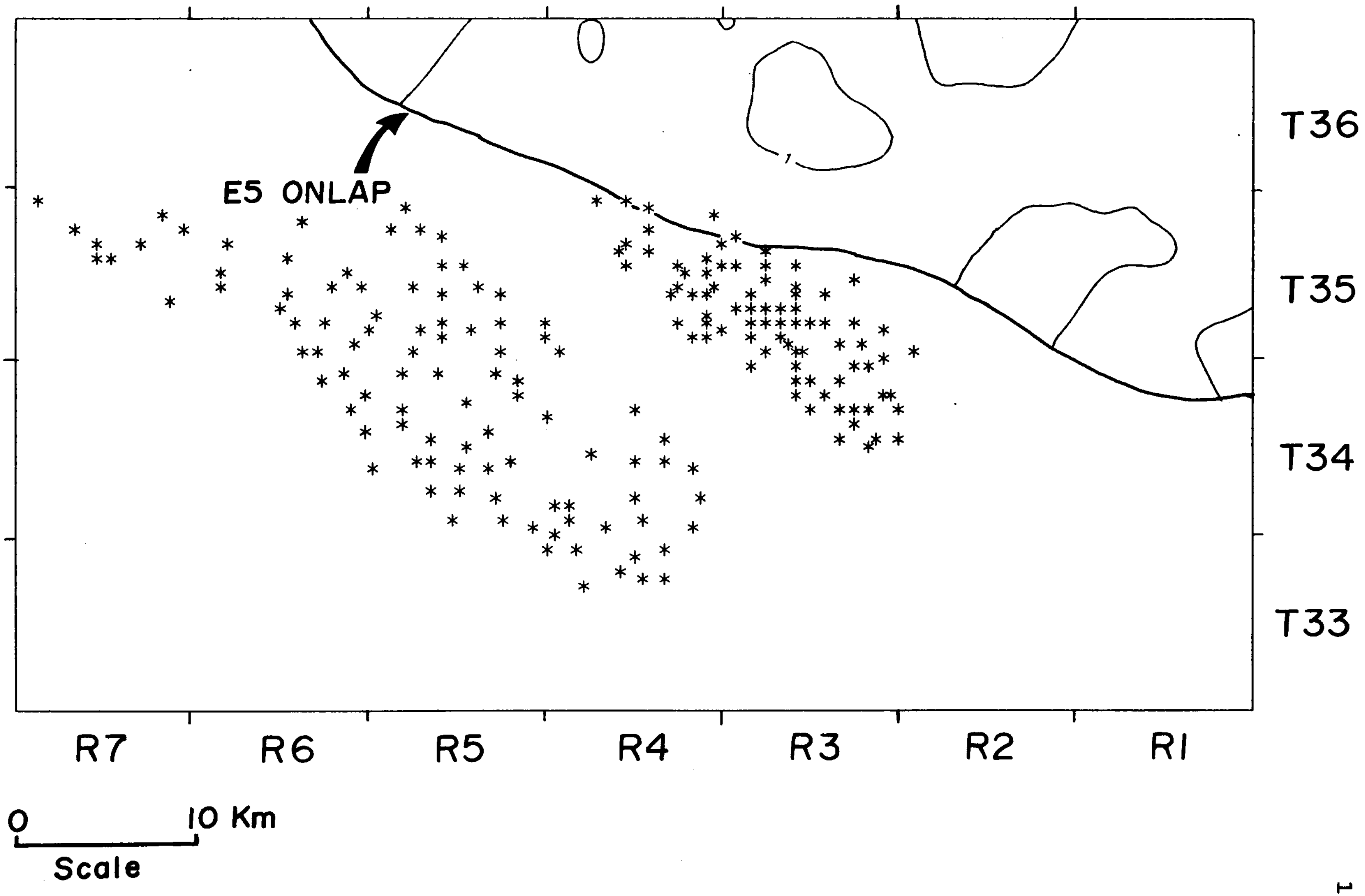
the isopach map, reveals a distinct northeastern trend from pebbly cross stratified sandstone common close to the line of onlap and in the interbeds of greater thickness, to pebbly burrowed mudstones. Conglomerate (Facies 6) is not common at this stratigraphic level.

The E4 isopach map (Fig. 6.13) illustrates many of the same trends characteristic of the E3 isopach map. Like the E3 isopach map, the greatest deposit thicknesses are located close to the E4 onlap line and these thin northeastward. The greatest thicknesses are located in T35, R5-R6 and T34, R4-R5 where thicknesses up to 1.6 m occur. By Garrington, the E4 interbed has become very thin (< 0.5 m); farther to the northeast the interval has thinned and faded out.

The facies distribution map for the E4 interval (Fig. 6.14) is also very similar to that of the E3 interval. The E4 interbed is thickest in areas close to the line of onlap (Caroline) and thins away from the point of onlap. Areas close to the line of onlap are characterized by pebbly cross stratified sandstone whereas the interval is generally made up of pebbly burrowed mudstone in more distal areas. Conglomerate is very rare in this interbed.

The isopach map produced for the E5 interbed is illustrated in Fig. 6.15 and indicates a very limited development of E5. As previously noted, this interval is generally quite thin and is therefore difficult to measure accurately from resistivity logs. This, coupled with the lack

Figure 6.15: Isopach map of the E5 interbed. Note the patchy, limited distribution of this interbed. The thickest deposits, measured from well logs, is 1 m although this thickness was never observed in core.


E5 ONLAP
T36
T35
T34
T33
R7
R6
R5
R4
R3
R2
R1
0
10 Km
Scale

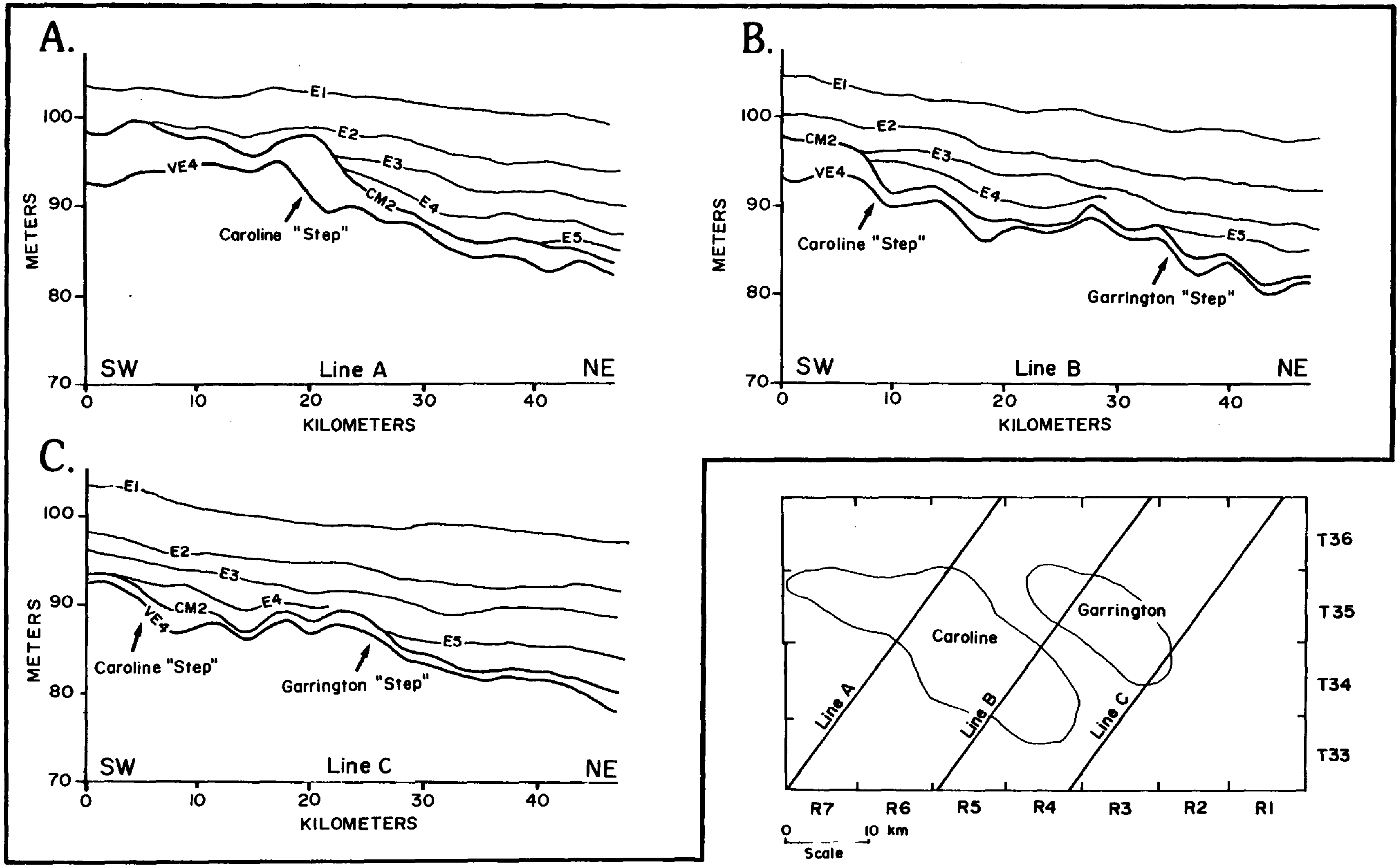
of core data for this interval, makes the results of this isopach map dubious. However, the isopach map for E5 is still useful in that it illustrates the general thinness of the E5 interbed basinward. The greatest thickness of the E5 interbed measured off well logs is 1 m and areas where these thicknesses occur are generally few and of limited areal extent. They also occur relatively close to the line of onlap for E5. It should be noted that thicknesses of 1 m for the E5 interval were never noted in core.

6.8 Two Dimensional Plots

All observations so far have pointed towards a subtle "step-like" ~~like~~ topography in the VE4 surface, and the sequential onlapping of the overlying, shale-encased interbeds onto the CM2 surface. However, cross sections are constructed from limited data and often may miss large areas and important features. Isopach maps and 3-D mesh diagrams can only portray one surface at a time. A useful way to tie down the subsurface morphology and document conclusively the important features already discussed is to construct two dimensional plots through the surfaces along several profile lines using the data from which the isopach maps were constructed. Three of these plots are presented in Figure 6.16. The plots were constructed in GRAPHER and contain lines for the VE4, CM2, and E1-E5 surfaces. All the horizons were hung on the BFS.

The three plots shown in Figure 6.16 back up many of the observations made previously. These include:

Figure 6.16: 2-D Plots. These plots were constructed using the isopach data of the VE4, CM3, and E1-E5 surfaces. All surfaces are hung from the BFS and therefore these surfaces show the topography of all the surfaces and their relationship to one another. Each plot was constructed approximately parallel to the general trend of the contour lines in the VE4 isopach map (Fig. 6.3). The locations of Line A (6.16a), B (6.16b) and C (6.16c) are shown on the map.


A.
METERS
100
90
80
70
E1
E2
E3
VE4
CM2
E4
E5
Caroline "Step"
SW
Line A
NE
0
10
20
30
40
KILOMETERS
B.
METERS
100
90
80
70
E1
E2
CM2
E3
VE4
E4
E5
Caroline "Step"
Garrington "Step"
SW
Line B
NE
0
10
20
30
40
KILOMETERS
C.
METERS
100
90
80
70
E1
E2
E3
CM2
E4
VE4
E5
Caroline "Step"
Garrington "Step"
SW
Line C
NE
0
10
20
30
40
KILOMETERS
T36
T35
T34
T33
Caroline
Garrington
Line A
Line B
Line C
R7
R6
R5
R4
R3
R2
R1
0
10 km
Scale

1) 2 general "steps" in the VE4 topography in Line B and Line C, and one general "step" in the VE4 topography in Line A. These "steps" seem to account for most of the topographical relief; Line A has about 12 m of relief on the VE4 surface, Line B has about 13 m of relief while Line C has about 14.8 m of relief. The two steps are termed the Caroline "step", to represent that which occurs along the western margin of Caroline, and the Garrington "step" for that which occurs along the eastern margin of Garrington. These two "steps" refer to the larger scaled rises in topography as shown in Figure 6.16, however, they are both undulatory in nature. Slope values for the two "steps", averaged from all three 2-D plots are 0.027° for the Caroline "step" and 0.028° for the Garrington "step".

2) the thickest deposits overlying the VE4 surface tend to occur on the northeastern sides of the "steps" and along the top of the "steps". This is most apparent in Line A along the northeastern flank of the Caroline "step". The thinnest deposits are found in areas between the Caroline "step" and the Garrington "step", and at the bottom of the Garrington "step".

3) the onlap markers onlap at, or near the top of a "step" in the VE4 morphology. They also tend to dip slightly into the basin (at approximately 0.01°) and are more or less planar. They do show a slight tendency, however, to mimic the underlying topography but this becomes less prominent for each

interbed with distance away from its point of onlap.

The plots are also useful in that they illustrate a very undulatory VE4 topography. The Caroline "step" and the Garrington "step" both appear to made up of a series of rising smaller "steps". Between the "steps", on the "treads", there are also minor undulations in the VE4 surface. This is particularly noticeable in Line B between the Caroline and Garrington "steps". Previous isopach maps have shown Garrington to be located on a slight topographic high with respect to the area immediately to the southwest. It should be noted that the vertical relief on these 2-D plots is extreme and in reality these "bumps" are of very small proportions, seldom reaching heights of 2 m over many kilometres. The slopes of several of these northeast of Garrington and northeast of Caroline were measured and are very small, about 0.01°.

6.9 Summary of Observations

This chapter has conclusively documented a VE4 erosion surface with 2 subtle "steps", one southwest of Caroline and the other along the northeast edge of Garrington. These "steps" are linear features which trend northwest-southeast and have northeast dips in the 0.026° to 0.03° range. The Garrington step seems to "die out" in a northwestern direction. The "steps" account for most of the relief on the VE4 surface, which drops towards the northeast. Another "step" is hinted at by the presence of a prominent high in the extreme southwest corner of the study area.

The greatest thickness of coarse grained deposits between the VE4 and CM2 surfaces has been shown to occur immediately to the west of the Caroline field. With respect to the VE4 surface, this thickness is found along the northeastern flank of the Caroline "step" and on top of the Caroline "step". Conglomerate thicknesses over the remainder of the study area are thin in comparison and patchy, but greater thicknesses do seem to occur along the flank, and on top of, the Garrington "step". The area between Caroline and Garrington is characterized by a very thin VE4 to CM2 interval. Conglomerate is, overall, the predominant lithology comprising this interval but is generally superseded by pebbly cross stratified sandstones in the Caroline field and farther to the southwest.

The shale-encased coarse grained interbeds, E1-E5, have been shown to onlap the CM2 surface sequentially in a southwesterly direction. E1 onlaps in the lowest stratigraphic interval and farthest to the northeast while E2 onlaps at the highest stratigraphic interval and farthest to the southwest. E1, the highest stratigraphic interbed documented in this study, is presumed to onlap the CM2 surface southwest of the study area. Numerous lines of evidence have shown that these interbeds onlap the CM2 surface near, or at, the top of one of the "steps" in the underlying VE4 topography. Thus, E2 onlaps at the "high" in the extreme southwest corner of the map, E3 and E4 onlap in close proximity to one another at the Caroline "step", while E5 onlaps at the Garrington "step". The greatest thickness of coarse grained deposits overlying the VE4 erosion surface also tends to occur immediately west of the point of onlap of any of these markers. This is especially true west of the position of onlap of the E3 and E4 interbeds.

These interbeds have also been shown to generally thin away from the point of onlap, although the greatest thicknesses of any one interbed do not always occur immediately adjacent to the point of onlap. While many of these interbeds can be traced across the study area, they only contain deposits of measurable thickness (>1 m) up to approximately 15 to 20 km away from their point of onlap. These interbeds, particularly E3 and E4 for which core data is good, are characterized by pebbly cross stratified sandstone near their point of onlap (at Caroline) and pebbly burrowed mudstone at greater distances from their point of onlap (at Garrington).

CHAPTER 7: INTERPRETATIONS

7.1 Introduction

The aim of this chapter is to interpret the facies, their vertical and lateral distribution; the nature, extent and geometry of the bounding disconformities; and the relationships of the facies distribution to the bounding disconformities.

The interpretations will provide answers to the original questions of the thesis, namely:

1) are there bounding disconformities present in the study area and, if so, what are their nature, extent and geometry.
2) how were the facies deposited and under what sorts of sea level controls,
3) what is the origin of the coarse grained interbeds in Allomember E.
4) are the boundaries of the Caroline and Garrington fields depositional or erosional.

7.2 Allomember B/C

Due to the uncertainty of the existence of the VE2 erosion surface (or its correlative conformity) in this study, it is difficult to place Facies 1 (burrowed muddy siltstone) within the allostratigraphic framework. To resolve this problem, more correlation is required with the Willesden Green area to the north, which would involve examination of the cores in Townships 37, 38, and 39.

Boreen (1989) reported that a major erosion surface occurs at the base of major incised valleys at Willesden Green, Sundance, Cyn-Pem, Edson, and Crystal. He named this erosion surface VE2. By his reasoning all areas south of Willesden Green would have been subaerially exposed; the record of that exposure would have been removed by the subsequent transgression responsible for the VE3 surface. If this is true, then the marker presented as VE2 (correlative conformity) in all cross sections in this study is not correlatable with the VE2 of Boreen (1989) and is probably just a regionally extensive log marker. This being the case, then Facies 1, which directly underlies the VE3 surface would, by definition, make up part of Allomember B. This scenario is reasonable due to the striking similarity of this facies with the pale siltstone assemblage of Allomember B of Boreen (1989).

The other possibility which exists is that the base of the incised valleys (that Boreen (1989) had termed VE2) is actually an additional erosion surface, and has been given the name VE3c (where c refers to channelling) and the VE2 (correlative conformity) marker correlated in this thesis represents a regional ravinement surface (A.D. Reynolds, pers. comm., 1989). If this is the case, then Facies 1 would make up part of Allomember C, and an additional name would have to be to given the channel deposits bounded by VE3c and VE3. The allostratigraphic nomenclature of Boreen (1989) is favoured, but until the uncertainty is resolved, the allomember underlying the VE3 surface in the study are will be couched in the term B/C.

Additional mapping of the areas between this study and that of Boreen (1989) to the north might resolve this question. Although rocks in the underlying Allomembers are of little commercial value in the study area and are infrequently cored, a resolution of this problem would be useful in the creation of an accurate Viking allostratigraphy. This, in turn, would aid in understanding the effects of relative sea level changes on regional stratigraphy.

Despite this allostratigraphic uncertainty, an interpretation of the environment of deposition of Facies 1 is possible. Due to the abundance of clay and silt and the high degree of burrowing, this facies is interpreted to have been deposited in an offshore setting below fair-weather wave base. Similar deposits found in the Willesden Green (Boreen, 1989) and Joffre (Downing and Walker, 1988) areas have been described and attributed to an offshore setting.

7.3 <u>VE3 Contact</u>

The sedimentological expression of VE3 within the study area is a thin, cm thick, gravel veneer with pebbles up to several cm's in diameter. It mantles the underlying Facies 1, and is overlain by the offshore-shoreface transitional Facies 2 which make up the lower portions of the prograding shoreface deposits of Allomember D. This surface has been correlated as far north as Crystal (S.A.J. Pattison, pers. comm., 1989), and as far south as Harmattan East (S.W. Hadley, pers. comm., 1989). The VE3 surface separates 2 facies of distinctly different sedimentological styles (Facies 1 from Facies 2). In cross sections, the marker was shown to be erosive by Boreen (1989) in the Willesden Green area where it cuts underlying log markers.

An interpretation of the VE3 surface needs to account for the following observations made in this study:

1) there is up to 22 m of relief, much of which is accomplished in a subtle southeast-northwest trending "step" (refer to section 5.2.2. for the definition of a "step"), between the western margin of Caroline and the western margin of Garrington,

2) marine offshore to offshore-lower shoreface transitional facies are present above and below the surface (Facies 1 and Facies 2),

3) a thin burrowed gravel veneer occurs immediately above the contact.

4) at Willesden Green, VE3 erosively overlies the transgressively filled estuarine deposits of Allomember C (Boreen, 1989),

5) also at Willesden Green, the VE3 surface is penetrated by sand-filled *Arenicolites* and *Skolithos* burrows and is overlain by a thin gravel veneer (Boreen, 1989).

The VE3 surface can only form in one of three environments; fully subaerial, fully submarine or, subaerial modified by subsequent marine transgression. Arguments for each of these scenarios has been made for similar surfaces in the Cardium Formation (Bergman and Walker, 1987, 1988; Leggitt, 1987; McLean, 1987 and Pattison, 1988), for the VE3 surface at Joffre (the E2 surface of Downing and Walker, 1988), and for the VE4 surface of this study (section 7.6) to which the reader is referred for an in-depth discussion. The possibility that the VE3 surface was formed subaerially and not subsequently modified is rejected because there is no evidence for either subaerial exposure (roots, paleosol, coaly horizons, desiccation cracks) or incised channelling anywhere along the surface (chapter 4). The alternative possibility, that the VE3 surface was formed under fully marine conditions, is also not favoured. It is difficult to envisage local marine scour being capable of creating up to 22 m of relief, or the subtle "step" like topography on this surface. It is equally difficult to envisage local marine scour removing more sediment farthest away from the proposed paleoshoreline southwest of the study area than closest to it, as wave energy would logically decrease with increasing depth.

The third possibility, that the VE3 surface was initially created subaerially, but modified during transgression, seems the most likely. The scenario invokes erosional shoreface retreat during transgression as the mechanism responsible for the creation of the erosion surface and has been invoked by other authors to explain similar surfaces. The erosion surface produced by such a process is termed a ravinement surface (Nummedal and Swift, 1987). It suggests that the VE3 surface was created by transgression towards the southwest.

Swift et al (1984), suggested such a mechanism to explain the erosion surface that underlies much of the stratigraphy created during the Holocene transgression at the New Jersey shelf, while erosional shoreface retreat has been called upon to explain many of the erosion surfaces in the Cardium Formation (Bergman and Walker, 1987, 1988; Leggitt, 1987; McLean 1987; Pattison, 1988). This interpretation most easily explains the VE3 erosion surface in the Willesden Green area which separates transgressively filled estuarine deposits of Allomember C from the overlying offshore deposits of Allomember D. It also explains the fact that in the present study area, VE3 separates two marine mudstones of distinctly different sedimentological styles. The pebbles associated with this surface are interpreted to be a lag deposit created by the winnowing of the sediment at the toe of the shoreface as the shoreface retreats landward.

The presence of sand filled *Arenicolites* and *Skolithos* burrows along the VE3 contact in the Willesden Green area indicates that a pause in deposition may have occurred at this time, allowing both partial compaction and colonization of the sediment. This idea is compatible with the incised shoreface model because during a transgression, as the shoreline translates landward, the loci of terrigenous deposition would also move landwards, effectively starving pre-existing shelf areas of terrigenous material which would result in partial lithification of the beds (Loutit et al., 1988).

The incised shoreface model is also most compatible with the topography of the VE3 surface. The subtle "step" which seems to occur in the Caroline area can be explained by an increase in the rate of transgression, which would enable the shoreface to translate more rapidly vertically.

7.4 Allomember D

The most common vertical facies succession of Allomember D in most of the cores examined consists of a sandier-upwards succession where Facies 2 (burrowed laminated sandy mudstone) is gradationally overlain by Facies 3 (hummocky cross stratified sandstone) which, in turn, is overlain by Facies 4 (swaley cross stratified sandstone). A similar succession has been reported south of the study area in the Harmattan East field (S.W. Hadley, pers. comm., 1989), as far north as the Crystal field (S.A.J. Pattison, pers. comm., 1989), and as far east as the Joffre field (Downing and Walker, 1988). The thickest accumulations of Allomember D have been reported in the Harmattan East area. These accumulations differ from those in this study area, in that swaley cross stratified sandstone is overlain by coarse grained cross bedded sandstone (interpreted as upper shoreface), coaly horizons, paleosols, and possible lacustrine deposits (S.W. Hadley, pers. comm., 1989). The thinnest accumulations of Allomember D occurs north of T39 and north to the Crystal area, where only isolated patches of about 1 m in thickness are preserved (Boreen, 1989).

Earlier preliminary interpretations (Chapter 4) have established that the facies which comprise Allomember D were deposited in a marine, storm-dominated setting as indicated by the presence of such trace fossils as *Skolithos, Ophiomorpha*, and *Teichichnus*, and HCS sandstone beds interbedded with burrowed mudstones. The SCS which overlies HCS has been previously interpreted to be a storm-dominated structure formed above fair-weather wave base (Leckie and Walker, 1982) and is considered to be a variant of HCS (Rosenthal and Walker, 1987). Although more commonly observed in the ancient geological record, a possible modern example of HCS occurs along the barred coast of Kouchibouguac Bay, New Brunswick (Davidson-Arnott and Greenwood, 1976).

The vertical facies sequence suggest deposition in progressively shallower water depths, ranging from offshore to transitional lower shoreface (Facies 2) up to the middle of the shoreface (Facies 4) as part of a wave dominated progradational shoreface sequence. Similar progradational sequences are widely reported in the literature, and examples include the Upper Cretaceous Mesaverde Group in Utah (Swift et al., 1987), the Lower Cretaceous Moosebar and Gates Formation in British Columbia (Leckie and Walker, 1982), the Upper Cretaceous Milk River Formation in Alberta (McCrory and Walker, 1986), the Upper Cretaceous Chungo Member of the Wapiabi Formation in Alberta (Rosenthal and Walker, 1987), the Lower Cretaceous Cadotte Member in Alberta (Rahmani and Smith, 1988) and the Raven River Member of the Cardium Formation in Alberta (Eyles and Walker, 1988).

The progradation of Allomember D is interpreted to have been from a southwesterly source. This is based on the presence of interpreted beach deposits, coaly horizons and plaeosols which cap SCS southwest of the study area (S.W. Hadley, pers. comm., 1989) as well as the overall thinning and muddying of Allomember D to the north of the study area (Boreen, 1989). Although some of the northerly thinning may be attributed to erosion by the overlying VE4 surface, the evidence of beach and subaerial deposits to the southwest favours a sedimentary thinning towards the northeast.

The erosively based coarse grained cross bedded deposits of an interpreted channel origin found at 9-22-33-5 and the paleosol deposit at 7-4-33-6 are consistent with the interpretation of shoreface progradation during a relative lowering of sea level. It is reasoned that during the progradation, the shoreline had advanced to some point northeast of 9-22-33-5, allowing for both fluvial incision and subaerial exposure. Deposits resulting from both fluvial incision and subaerial exposure were probably more widespread than now observed but most have been removed by the subsequent transgression associated with the VE4 surface. Other channel fill deposits, paleosols, coaly horizons and lacustrine deposits are quite common south of the study area (S.W. Hadley, 1989). Gravel stringers found most commonly within the upper SCS deposits indicate that gravel was being supplied to the basin during this lowstand, probably as storm deposits. Similar gravel stringers have been reported in the upper to middle portions of other storm-dominated prograding shorefaces (Arnott, 1988; Howard and Reineck, 1981; Rosenthal and Walker, 1987).

7.5 VE4 Contact

The prograding shoreface deposits of Allomember D are truncated by the regionally extensive VE4 erosion surface, and are overlain by the interbedded conglomeratic and shale succession of Allomember E. The following observations have been made about the VE4 surface:

1) there is an overall rise in this surface towards the southwest resulting in approximately 18 m of relief,

2) 2 subtle "steps" are present in the VE4 surface topography, each of which is less than 10 m in overall relief,

3) minor undulations (about 1 m in vertical relief) are superimposed on both the "steps" and the "treads",

4) VE4 rests on top of the dominantly middle shoreface to

offshore deposits of Allomember D, and there is occasional superposition on top of shallow fluvial channel deposits and a paleosol; and

5) the overlying Allomember E deposits, despite their enigmatic nature, show signs of deepening upwards. ?

The VE4 surface is regionally extensive and has been documented south of the study area in the Harmattan East field (S.W. Hadley, pers. comm, 1989) and as far north as the Crystal field (S.A.J. Pattison, pers. comm., 1989). In the Willesden Green area, it has been shown to cut out the underlying VE3 surface (Boreen, 1989). The VE4 surface in the study area is overlain by the interbedded conglomeratic and shale succession of Allomember E.

Interpretation of the VE4 surface will first focus on the mechanisms responsible for its formation. As was discussed for the VE3 surface, there are three possible ways in which the VE4 surface could have been formed; fully subaerially, fully submarine or by transgressive shoreface incision. Once a mechanism of formation has been determined, the relationship of the VE4 surface to the overlying deposits in Allomember E will be examined.

Subaerial Erosion:

To document erosion subaerially, signs of exposure such as desiccation cracks, paleosols, and coaly horizons must be documented, as well as signs of shallow fluvial incision (Weimer, 1983). It is reasoned that exposing former shelf deposits (i.e. Allomember D) to subaerial processes will strip off the upper portions of the shelf deposits, thereby creating an erosion surface on which terrigenous deposits may accumulate. Similarly, exposing the former shelf areas and incising fluvial systems will also create erosion surfaces over which fluvial deposits can accumulate. An additional consideration is that rivers run, as a rule, parallel to the paleodip of the surface, which in the case the Viking is towards the northeast.

Within the study area evidence for both subaerial exposure and fluvial incision are present in the form of paleosols, and shallow channel fill deposits. However, in contrast to the model presented above, the VE4 surface, as seen in core and as correlated in well logs, lies above both the paleosol and the channel deposits. This is corroborated to the south of the study area where the VE4 surface overlies abundant paleosols, coaly horizons, possible lacustrine deposits and fluvial channel fill deposits (S.W. Hadley, pers. comm., 1989). In addition, the topography that is reported in the VE4 surface is not that which would be expected from fluvial incision. The northwest-southeast trending, one-sided "steps" documented in the VE4 surface are not in agreement with a fluvial origin. Therefore, a fully subaerial origin for the VE4 surface can be ruled out. While features indicative of subaerial exposure do exist (paleosols and fluvial channel deposits), they were clearly formed prior to the erosion by

VE4.

Submarine Erosion:

Submarine erosion can occur by either meteorological currents, tidal currents, or turbidity currents. Submarine erosion by meteorological (storm) currents can be rejected because it is incompatible with the amount of relief present within the study area and the fact the greatest amount of relief occurs farthest away from the presumed paleoshoreline. Eighteen meters is probably too great to have been produced by wave scouring of a bed totally subaqueously (Downing and Walker, 1988). However, recent research has suggested that tides may have been operating in the W.I.S. at the time of VE4 erosion, and deposition of Allomember E (Ryer and Kauffman, 1981; Leckie, 1986; Boreen, 1989) and therefore a tidal origin for the VE4 surface cannot be dismissed outright. Tidal scours are associated with powerful near-surface tidal currents, and are elongate in the directions of peak tidal currents (Stride et al., 1982). These scours can cut up to 260 m below surrounding ground (Mogi, 1979 in Stride et al., 1982), and have been reported to be up to 5 km wide (Hamilton and Smith, 1972 in Stride et al., 1982). These characteristics of tidal scours are not consistent with the documented morphology of the VE4 surface within the study area. While the possible dimensions of tidal scours are great, the VE4 surface is much more regionally extensive than any known tidal scour. The fact that tidal scours are elongate hollows is also not consistent with the overall "step-like" rise in the VE4 topography towards the southwest. Tidal currents may have had an influence on the VE4 surface (such as the carving of the small scale undulations), but, some other mechanism appears to be responsible for the overall VE4 topography.

Erosive Transgression:

It is reasoned that the overall VE4 morphology can be best explained by wave-scour processes operating during erosional shoreface retreat, and VE4 is therefore a ravinememt surface. Wave scour processes at any one storm-dominated shoreface profile can be expected to operate to depths of up 5-15 m (fair-weather wave base) (D.J.P. Swift, in Walker, 1985) and sediments eroded from the shoreface by storm currents will be redeposited above the ravinement surface farther seaward. The model of erosional shoreface retreat assumes that as sea level rises, the shoreface profile translates upward and landward, and the ravinement surface cut by this process will physically rise landwards (Nummedal and Swift, 1987). The irregular "step-like" topography present on the VE4 surface can be explained by variations in the rate of sea level rise. The "steps" present are thought to mark the end of a period of stillstand or slow transgression. Rapid transgression would then result in a increased vertical component of the sea-level rise resulting in the preservation of the steps. This model has been used to explain the stepped surface of the Cardium E4 and E5 erosion surfaces (Bergman and

Walker, 1987, 1988; McLean, 1987; Leggitt, 1987; Pattison, 1988) and variations of it have been discussed for many basal Holocene erosion surfaces (Kraft, 1971; Swift et al., 1973; Swift et al., 1984; Sanders and Kumar, 1975; Rampino and Sanders, 1980). If this model is applied to the VE4 surface within the study area, it necessitates a rapid drop in relative sea level after the northeastward progradation of Allomember D. At the end of the relative sea level drop, sea level would stabilize and incise the first shoreface profile. At the end of this episode of relative sea level lowering, the whole study area would have been subaerially exposed, producing the observed paleosol and fluvial channel deposit. Relative sea level is then interpreted to have risen, preserving the first "step" somewhere to the northeast of the study area. It then continued to transgress southwestward but was punctuated with slower rates of sea level rise or stillstands, thus forming the Caroline and Garrington "steps".

The details of the Garrington and Caroline "steps" seem to be consistent with general characteristics of modern shoreface environments. Modern shorefaces occur between the surf zone and fair-weather wave base (5-15 m) (D.J.P. Swift in Walker, 1985; Reinson, 1984; Walker, 1984). They typically have a one sided scour, concave upwards geometry with slopes on the order of 1:40 (1.43°), 1:200 (0.286°), and 1:2000 (0.0286°) for the upper shoreface, lower shoreface and inner shelf respectively (Niedoroda et al., 1978).

The relief displayed by both the Caroline "step" and Garrington "step" is less than 10 m. These figures are within the range acceptable for shorefaces, and it is possible that the upper portions of each postulated shoreface were removed by the subsequent transgression. Similarly, the slopes displayed by the steeper portions of both "steps" (0.027° to 0.028°) are consistent with those of lower shoreface to inner shelf environments. Also, both the Caroline and Garrington "steps" are one sided scours, as would be expected.

The only problem which arises for the shoreface model is the presence of low relief, gently dipping undulations which exist on both the "steps" and the "treads" of the VE4 surface. These may have arisen in one of three ways: 1) minor tidal scours, 2) small scale northeastward tilting of the sea floor during transgression such that the southwest dipping (0.01°) portions of these undulations were essentially horizontal or 3) imprecision in hanging the VE4 surface from the BFS datum and errors associated with computations of the best fit. Unfortunately, there is no evidence to suggest which of these is more likely.

7.6 Allomember E

The sedimentological and stratigraphic style of Allomember E is markedly different from that of the prograding shoreface deposits of Allomember D. In contrast to the orderly shallowing upward succession of predominantly fine grained sands and muds which comprise Allomember D, Allomember E is made up of a complicated succession of poorly sorted conglomerates, pebbly cross stratified sandstones, and pebbly burrowed mudstones, interbedded with black shale. HCS and SCS, which are ubiquitous in Allomember D, are absent in Allomember E.

The most interesting and problematic aspect of Allomember E is the presence of black shales interbedded with very coarse grained deposits. One would expect to find, in a vertical succession, facies overlying each other which normally can be found adjacent to one another areally. The enigmatic way in which the CM2-VE4, and E1-E5 interbeds are sharply interbedded with marine shales is problematic and difficult to reconcile with known modern environments.

An explanation for this succession may lie within the context of relative sea level fluctuations.

7.6.1 Geometry of the Onlap Markers

The cross sections presented in Chapter 5 have shown that each shale-encased coarse grained interbed (E1-E5) onlaps the underlying CM2 surface sequentially in a southwesterly direction. The maps presented in Chapter 6 showed that these interbeds exist as sheets, which, as a generalization thin in a northeasterly direction; 15-20 km away from their lines of onlap, they are of negligible thickness. These lines of onlap trend approximately northwest-southeast, or parallel to the "steps" in the VE4 surface. The interbeds onlap the underlying CM2 surface near the upper portions of the "steps" in the topography rather than at the "treads". The E3 and E4 interbeds also onlap the CM2 surface immediately northeast of a substantial "thick" in the VE4-CM2 interval. While the VE4-CM2 interval is dominantly conglomeratic, with some cross stratified sandstone occurring in the southwesterly portions of the study area, the overlying E3 and E4 interbeds show a distinct transition from cross stratified sandstone close to the line of onlap, to pebbly burrowed mudstones further basinward (Figures 6.12 and 6.14).

These features can be explained by a model which incorporates the role of the relative sea level changes responsible for the creation of the VE4 surface. During the creation of the "steps" by wave scouring in periods of stillstand, streams were able to transport coarse sand and gravel to the newly created shoreline. Some sort of transport mechanism was then able to transport this material basinward over older, deeper shoreface profiles, which had, by that time, been blanketed by mud. This basinward transport would account for the thinning and general fining of each interbed basinward. Each onlap marker would, therefore, be contiguous with the VE4-CM2 interval landward of its line of onlap onto that surface. This would explain the substantial thick in the VE4-CM2 interval which occurs immediately southwest of the E3 and E4 lines of onlap; the sediments found in the E3 and E4 interbeds are actually an extension of the VE4-CM2 interval. The VE4 ravinement surface is time transgressive and each coarse grained interval would be, in effect, a timeline formed during one period of stillstand during the overall transgression.

Within the Cretaceous in the W.I.S., other stepped shorefaces have also been documented. However, neither the E5 Cardium erosion surface (Bergman and Walker, 1987, 1988; Leggitt, 1987), nor the Cardium E4 surface (Pattison, 1987), nor the Bad Heart Formation (Plint and Walker, 1987) is associated with extensive coarse grained onlap markers as is suggested here for VE4. The coarse grained deposits overlying the erosion surfaces in the examples cited above are quite narrow and lie directly on the erosion surface. The Viking Formation at Caroline and Garrington, by contrast, is characterized by sheets of coarse grained sediments which overlie the VE4 surface and continue out into the basin over previously deposited marine shales. The difference in extent of the coarse deposits may be due to the duration of the stillstand events; the Cardium stillstands may have been comparatively short, with insufficient time to allow the progradation of coarse sediment. In the Viking study area, I suggest longer periods of stillstand, allowing for both deposition of mud below fair-weather wavebase and the transport of coarse clastic material basinward.

7.6.2 Transport Mechanisms for Coarse, Clastic Deposition

The mechanism responsible for the transport of coarse, clastic material basinward may involve tidal currents, storm currents, ocean currents, or some combination of these. However, the facies succession found in the VE4-CM2 interval and the E1-E5 interbeds are complex and difficult to interpret. Within any one of these intervals, there is commonly a seemingly random superposition of the different coarse grained facies. In addition, the individual beds within any one interval are often of limited lateral continuity.

There is a growing body of evidence that tides operated periodically during the Cretaceous in the W.I.S (Ryer and Kauffman, 1981; Leckie, 1986; Boreen, 1989). Most modern tidal shelves, or shelves of a mixed tide-storm influence, do not show simple patterns of sedimentation (Anderton, 1976). There can be an extensive range in the types of bedforms generated and therefore the stratification types (Johnson and Baldwin, 1986). These bedforms also occur in a patchy distribution on the sea floor (Levell, 1980). Tides would also be very effective at reworking sediment both brought in at the shoreline and left in place as a winnowed lag, because tides are capable of moving coarse sediment in several tens of meters water depth.

Although there are no unequivocal diagnostic criteria to indicate tides in an open shelf setting (Johnson and Baldwin, 1986), many features associated with the coarse grained deposits found in Allomember E are indicative of rapidly changing flow regimes which might be attributed to tides.

The pebbly cross stratified sandstones were deposited by strong traction currents capable of eroding the underlying substrate and transporting pebbles. High angle cross stratification in coarse sediment in a marine setting is either a product of waves or tides (Leckie, 1986). Within the cross stratified sandstones, the presence of several orders of reactivation surfaces, mud drapes, hierarchal bedform development (compound cross stratification), bipolar opposed cross stratification and interbedding with conglomeratic horizons and burrowed horizons suggest a regularly fluctuating flow regime.

The compound cross stratification documented in several cores within the study area and to the north of study area in the Willesden Green area (Boreen, 1989), is probably the strongest indicator of tidal conditions. This form of stratification is thought to be the result of sandwave migration under conditions of time velocity asymmetry of tidal currents (Allen, 1980), resulting in the migration of small scale bedforms such as megaripples down the lee-face of a larger sandwave. This would produce low angle master bedding surfaces down which higher angle forms of cross stratification could migrate. This form of stratification has been interpreted for modern sand waves in the North Sea (Reineck, 1963; Houbolt 1968; Terwindt, 1971) and has been documented in several ancient deposits such as the Gog quartzite outcrop in Yoho National Park (Hein, 1982), and the Lower Cretaceous

Folkestone Beds in England (Allen, 1982).

The presence of planar tabular and tangential bedforms indicate the migration of 2-dimensional straight crested and 3-dimensional sinuous crested bedforms. These may correspond to sandwaves and megaripples respectively. While not diagnostic of tidal conditions, the rare occurrence of bipolar opposed cross stratification is supportive of fluctuating flow regimes.

The abundant shale partings which drape individual beds in the sandstones indicate dramatic changes in flow velocity, when settling out of suspension during periods of quiescence could occur. These mud drapes, although common, are not systematic in their occurrence. This occurrence is thought to be the result of the less pronounced time-velocity asymmetry characteristic of tides on an open shelf setting (Boersma and Terwindt, 1981) where longer period fluctuations in flow velocities related to waning flow events (McCave, 1970), or seasonal variations in the suspended sediment concentration (Leckie, 1986) allow the periodic settling of mud out of suspension.

It should be noted that the more diagnostic characteristics of tidal conditions are relatively rare in the study area and are generally restricted to the E3 and E4 interbeds within cross stratified sandstones, as well as the VE4-CM2 interval southwest of the E3 and E4 line of onlap. Since the E3 and E4 interbeds are interpreted to have formed at the same time as the VE4-CM2 interval during the same stillstand event, it is possible that due to a change in basin configuration, tides were operating only during this time.

The conglomeratic facies has a more enigmatic origin. The predominant mode of occurrence is a structureless clast or matrix supported conglomerate with either a poorly sorted sandy or gritty mud matrix. Much of the conglomerate which lies within the VE4-CM2 interval is probably derived from winnowing of the underlying substrate during transgression. Fluvial input at each successive position of the shoreline is reasoned to be the source of additional pebbles.

Several features associated with the conglomerates indicate that they were subsequently overprinted by marine processes. The rare occurrence of imbrication and cross bedding in the conglomerates indicates that strong traction currents must have been capable of moving the pebbles. Many of the conglomerates also contain unbioturbated mud drapes on the cross beds and therefore indicate short term periodic interruption of bedform migration. In addition, many of the predominantly conglomeratic horizons are composed of erosively-based bands of gravel superimposed on one another, indicating that the interval was not a single event bedform. These features are not diagnostic of any single shelf hydraulic regime. The conglomerates towards the southwest of the study area and in the E3 and E4 interbeds are associated with pebbly cross stratified sandstones of a possible tidal origin and may therefore be tidally generated gravel waves. Gravel waves are observed on modern tidal shelves and can be up to 1 m high and 10 m long (Belderson et al., 1972). The more massive conglomeratic horizons may have been part of a reworked gravel sheet, or may have been part of gravel waves with indistinct cross bedding. Strong storm currents are also capable of moving pebbles and forming bedforms (Johnson and Baldwin, 1986) and may be responsible for some of the conglomerate seen.

Conglomerate horizons are often found as sharp based bands with bioturbated tops interbedded with other coarse grained facies. This occasional association with pebbly burrowed mudstones is thought to be the result of storm deposition of gravel layers out into the basin followed by periods of quiescence when burrowing could occur.

The pebbly burrowed mudstone facies is a structureless burrowed mixture of sand, silt, mud and pebbles. This facies grades shoreward into conglomerate and pebbly cross stratified sandstones. Its interpreted origin is similar to that of Facies 2, in that it probably represents an offshore environment periodically affected by storms. Thus the coarse grained material would be brought in by storms, and a lot of this material would be reworked by burrowers during fair-weather periods. The mixed *Skolithos-Cruziana* trace fossil assemblage associated with this facies is compatible with an lower shoreface to offshore environment of deposition.

Underlying many of the shale-encased, coarse grained interbeds are decimetre-thick sideritized mud horizons penetrated by sand-filled *Arenicolites* and *Skolithos* burrows. These horizons are interpreted to be condensed sections, where extremely slow sedimentation rates related to maximum transgression result in authigenic mineral formation (glauconite, phosphorite, and siderite) and a burrowed, slightly lithified bed (Loutit et al., 1988). The fact that they occur underlying coarse grained interbeds implies that following each episode of maximum transgression, a reduced rate of transgression or stillstand occurred allowing for the input of coarse clastic material.

The lack of burrowers in Facies 9 (black shale) attests to a stressed environment, whereas the presence of burrowers in the pebbly burrowed mudstone facies suggests that the conditions which existed in periods of stillstand were quite different. This further suggests dramatic changes in the environments of deposition between the black shale and coarse grained interbeds.

The black shales must have accumulated in an offshore setting where storm or tidal currents could not deliver coarse sediment. This is thought to have occurred after a period of stillstand when sea level rose, and areas that had previously been at shallower depths were now in a deeper environment.

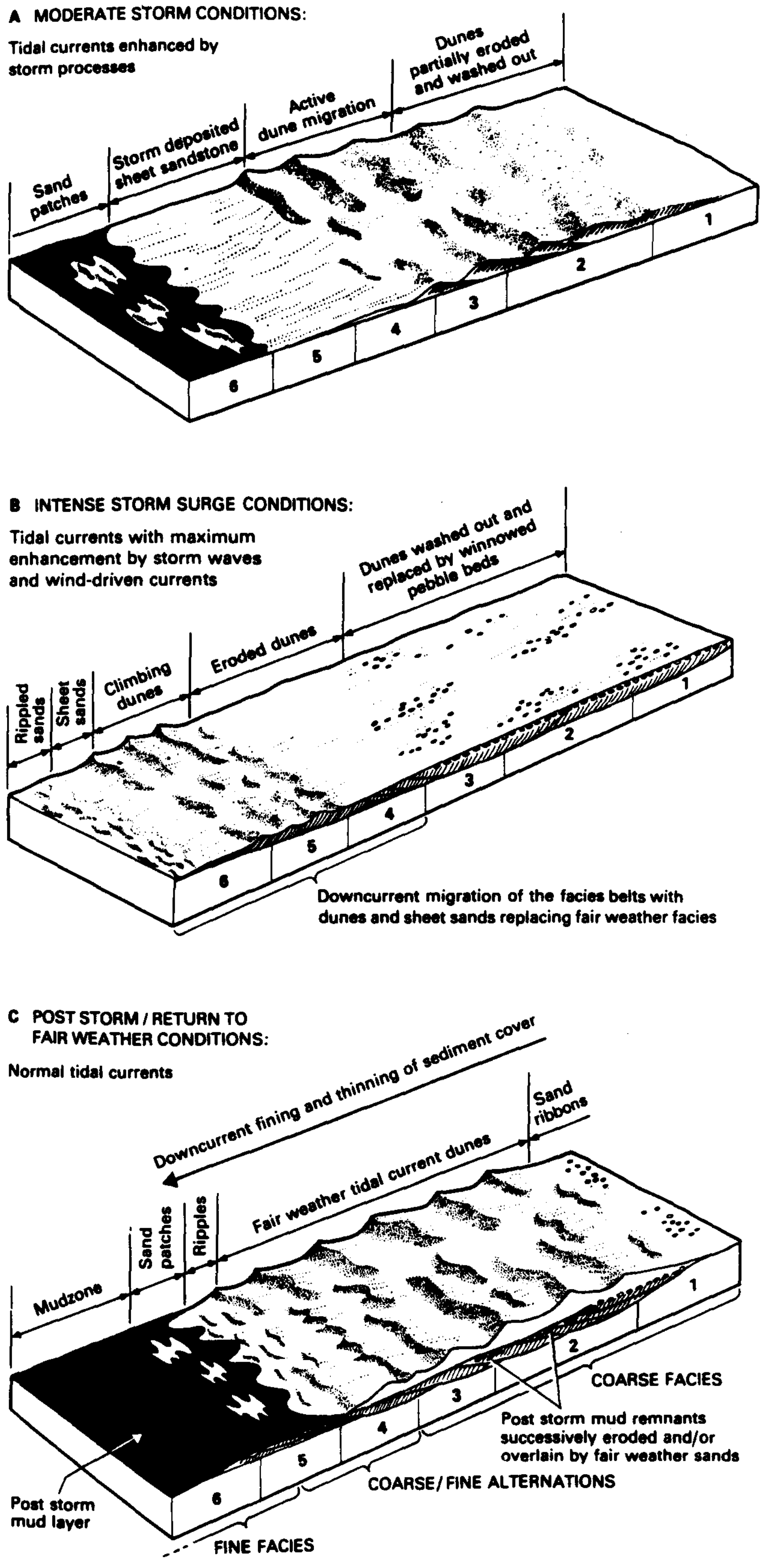
During the transgression, sediment supply would have been dramatically reduced, thus explaining the lack of appreciable coarser grained beds and structures in the shale rich environment.

The presence of these black shales, however, is difficult to reconcile with a tidal regime, because tides are a day by day occurrence and can move sediment in depths of tens of meters. While mud zones are common within tidal systems, they are generally restricted to the end of tidal current transport paths and at moderate depths (Stride, 1963). As was shown in the German Bight, mud can accumulate in depths of 20-40 m at rates of 15.5 cm/100 year despite maximum near surface tidal current velocities of 60 cm/sec (McCave, 1970). It is therefore possible that some of the mud may have been deposited in a tidal system. The evidence of tides occurs predominantly in the E3 and E4 interbeds and the correlative portions of the VE4-CM2 interval to the southwest. An alternative explanation is that, due to some change in basin configuration, tides were more dominant at time intervals during which the E3 and E4 interbeds were formed. Relatively rapid changes in the shelf hydraulic regime (tides or storms) have occurred during the Holocene in the German Bight, the Washington coastline, and Calades Island, Florida, as a result of changes in the rate of sea level change, sediment availability and gradient and configuration of their coastlines (Davis and Clifton, 1987). Another possibility is that the tidal regime was relatively mild and effective to only shallow depths and that deeper offshore areas were unaffected by the tidal currents. Storm enhanced tidal deposits similar to those found in some of the coarse grained interbeds have been documented in several ancient examples such as the Late Precambrian Jura Quartzite (Anderton, 1976) and the Late Precambrian Upper Quartzitic Sandstone in Norway (Johnson, 1977). A modern analogy for the coarse grained sediments is the Middle Atlantic Bight (Swift, et al., 1973). Anderton's model of storm enhanced tidal deposits is shown in Figure 7.1 and is helpful in the interpretation of the complex sedimentological facies associations of Allomember E.

7.6.3 Summary of Allomember E

The geometric association of the coarse grained interbeds with the underlying VE4 surface is fairly clearly associated with the tops of the "steps" present. The interbeds are thought to represent progradation of coarse grained sediment out into the basin during stillstand. Tidal currents and storms are interpreted to have been able to transport this material 10's of kilometres basinward over older shoreface profiles, which had by that time been blanketed by mud. Storm enhanced tidal currents may have been responsible for the complex patterns of bedform development documented in these coarse grained intervals, especially in areas close to the inferred paleoshorelines. This would account for the wide variety of cross stratified sandstones and conglomerates

Figure 7.1: Hypothetical reconstruction of the Jura Quartzite shelf sea as developed under tidal and storm conditions. This reconstruction is used as a possible analogy to depositional conditions of the coarse grained interbeds, E1-E5 in the study area. Numbers refer to hypothetical depositional zones along a tidal current transport path. From Johnson and Baldwin, 1986 modified from Anderton, 1976.


A MODERATE STORM CONDITIONS:
Tidal currents enhanced by storm processes
Sand patches
Storm deposited sheet sandstone
Active dune migration
Dunes partially eroded and washed out
1
2
3
4
5
6
B INTENSE STORM SURGE CONDITIONS:
Tidal currents with maximum enhancement by storm waves and wind-driven currents
Rippled sands
Sheet sands
Climbing dunes
Eroded dunes
Dunes washed out and replaced by winnowed pebble beds
1
2
3
4
5
6
Downcurrent migration of the facies belts with dunes and sheet sands replacing fair weather facies
C POST STORM / RETURN TO FAIR WEATHER CONDITIONS:
Normal tidal currents
Downcurrent fining and thinning of sediment cover
Sand ribbons
Fair weather tidal current dunes
Ripples
Sand patches
Mudzone
1
2
3
4
5
6
COARSE FACIES
Post storm mud remnants successively eroded and/or overlain by fair weather sands
COARSE/FINE ALTERNATIONS
Post storm mud layer
FINE FACIES

amalgamated within one interval present. The deposits were generally storm-dominated in more distal areas of the basin as shown by the predominance of thin intervals of pebbly burrowed mudstone with increased distance from the line of onlap. Successive stillstands, therefore, are responsible for the series of coarse grained interbeds in a vertical section. The intervening black shales are interpreted to have been deposited in an offshore setting when sea level had risen during transgression.

The deposits of Allomember E comprise a transgressive sequence as opposed to the progradational sequence of Allomember D. In Allomember E, sediments deposited in a relatively shallow, nearshore environment are overlain by sediments of a relatively deeper, offshore environment. The overall transgression is punctuated by reduced rates of transgression or stillstands during which times coarse sediment was deposited. However, in any one vertical sequence, there will be a general thinning and fining of the coarse grained intervals upwards as a function of the overall rise of relative sea level and transgression of the shoreline towards the southwest.

An additional difference between Allomember D and Allomember E is that Allomember D contains features such as SCS, HCS, and sharp based sandstone beds, indicative of a storm-dominated hydraulic regime, whereas Allomember E contains features thought to result from a mixed storm-tide influence. This change in hydraulic 'style' may be a result of a change in relative sea level and basin configuration during transgression.

7.7 General Order of Events

In chronological order, the events can be summarized as:

1) deposition of offshore to shoreface-transitional open-marine sediments of Allomember B/C. The source of these sediments cannot be deduced in the study area (Fig. 7.2a).

2) a major drop in relative sea level, incising valleys in the Willesden Green area and subaerially exposing the deposits in the study area. The sea retreated northeastward. This sea level drop may be related to the world wide eustatic drop (97 Ma) of Hancock (1975), Vail et al., (1977), and Weimer (1983). This is illustrated in Figure 7.2b.

3) Evidence of subaerial exposure (e.g. roots, plaeosols) was subsequently planed off by the ensuing transgression responsible for the VE3 ravinement surface. The expression of this transgression within the study area is a thin pebble veneer. During this overall transgression, evidence exists for a minor stillstand or reduced rate of transgression resulting in the formation of the "step" present in the VE3 within the study area (Fig. 7.2c).

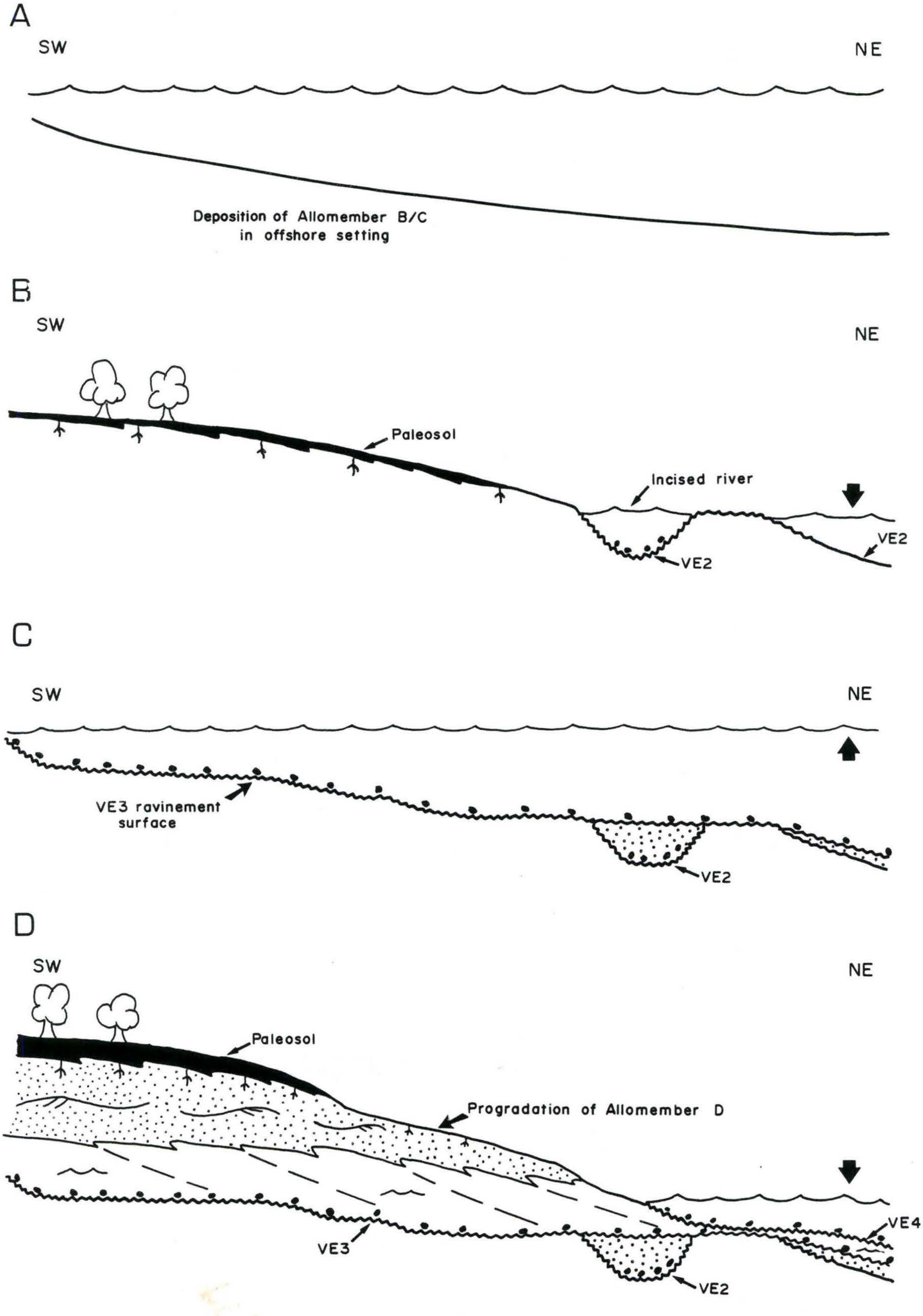
4) an increase in sediment supply or a relative lowering of sea level resulted in the progradation of the shoreface deposits of Allomember D towards the northeast (Fig. 7.2d). The basin at this time was storm dominated, as indicated by

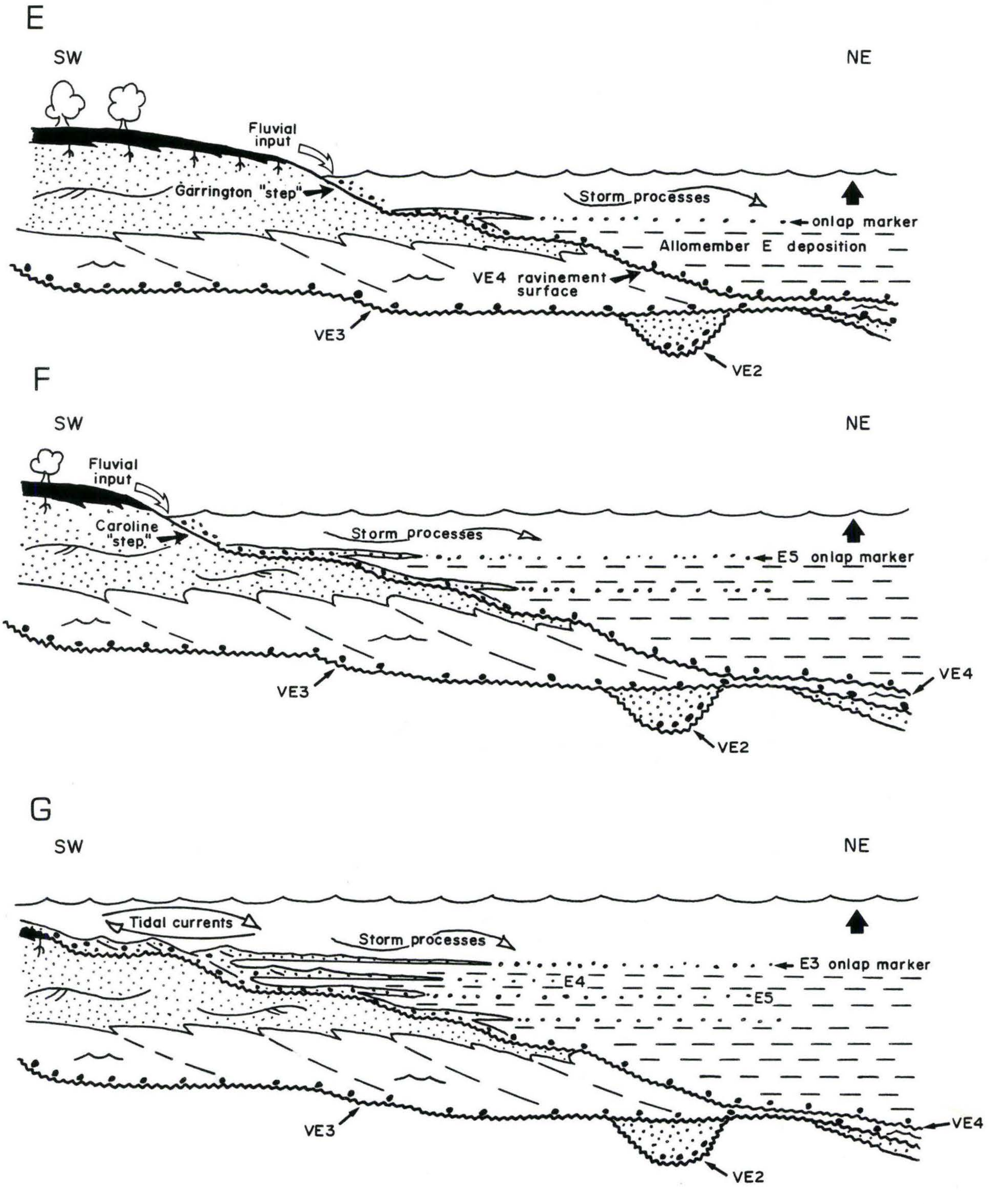
the predominance of HCS and SCS within the shoreface deposits. During progradation, former shelf areas became exposed subaerially allowing for the development of terrestrial deposits (paleosols) and the incision by shallow fluvial systems. These fluvial systems are interpreted to have supplied coarse sediment and pebbles to the subsequent shorelines.

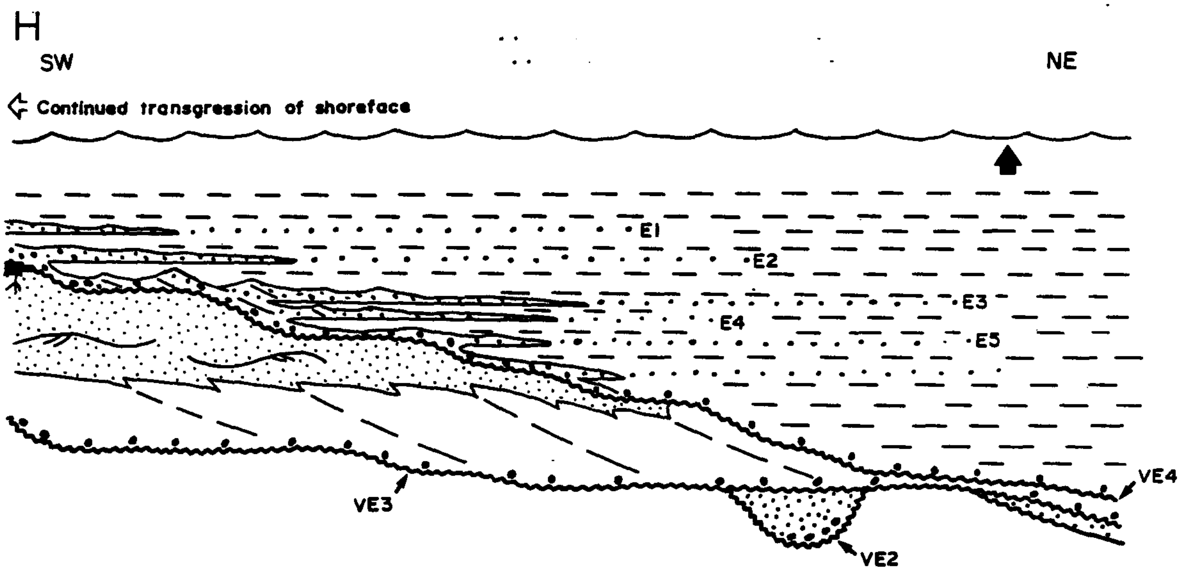
5) the ensuing basinwide rise of sea level resulted in the stepwise retreat of the shoreline towards the southwest. This gave rise to the VE4 surface. Within the overall rise were a series of stillstands, during which "steps" were cut into the underlying deposits, and coarse grained sediment was delivered to these shorelines by rejuvenated fluvial systems. Tidal currents, not prominent during the deposition of Allomember D, were able to rework sediment and move sediment out into the basin over pre-existing stepped shorefaces to form the present onlapping markers. Thus the E5 interbed was derived from the stillstand responsible for cutting the Caroline "step", while the E3 and E4 interbeds were derived from a stillstand responsible for cutting a presumed "step" in the extreme southwest portion of the map area and beyond. By the same logic, E2 and E1 can be thought of as even later stillstand deposits derived from some inferred paleoshorelines southwest of the study area (Fig. ~~6~~7.2e,f and g).

6) continued transgression led to the deposition of predominantly shaly, offshore deposits in the upper portions

Figure 7.2: Summary diagram of deposition of the Viking Formation within, and slightly to the north of the study area. Detailed explanations of each of the figures are given in section 7.7. No vertical or horizontal scale is implied.


A
SW
NE
Deposition of Allomember B/C
in offshore setting
B
SW
NE
Paleosol
Incised river
VE2
VE2
C
SW
NE
VE3 ravinement
surface
VE2
D
SW
NE
Paleosol
Progradation of Allomember D
VE4
VE3
VE2


E
SW
NE
Fluvial input
Garrington "step"
Storm processes
onlap marker
Allomember E deposition
VE4 ravinement surface
VE3
VE2
F
SW
NE
Fluvial input
Caroline "step."
Storm processes
E5 onlap marker
VE4
VE3
VE2
G
SW
NE
Tidal currents
Storm processes
E3 onlap marker
E4
E5
VE4
VE3
VE2


H
SW
NE
Continued transgression of shoreface
E1
E2
E3
E4
E5
VE3
VE4
VE2

of Allomember E (Fig. 6.2h). This sea level rise is thought to represent the final flooding of the Boreal sea in late Albian times (Weimer, 1983).

7.8 Location and Boundaries of the Fields

One of the original objectives of this study was to determine the boundaries of the Caroline and Garrington fields. The two field are in close proximity to one another and are elongate in a northwest-southeast trend, however, definition of the geological boundaries of each has not been adequately discussed in the literature.

In contrast to some of the fields in the Cardium Formation, which are quite long and linear, the Viking Caroline and Garrington fields are quite broad, although they do display a linearity. In addition, the coarse grained deposits in Allomember E (the fine grained shoreface deposits in Allomember D have very minimal permeabilities and are not economic Robb, 1985) occur at several stratigraphic horizons and generally as sheets of sediments. They have been interpreted here as originating at the shoreface, as in the Cardium Formation, but tidal processes were able to effectively rework and move sediment farther out into the basin resulting in the onlapping coarse grained markers. Another complicating factor is that the coarse grained interval VE4-CM2 does thicken substantially, but it does so southwest of the western legal boundary of the Caroline field. Elsewhere this interval is about 1-2 m but rarely thins to a cm thick pebble lag as in the Cardium Formation.

The legally defined Caroline field is producing from the Viking "A pool" of industry (ERCB, 1983). The Viking A pool is, in fact, the E3 coarse grained interbed of this study. Examination of the type well log of the Caroline field (4-20-34-4) prepared by Fulton (1967) shows that the main producing horizon is what he termed conglomerate and occurs within the E3 interbed. There are, however, small local pools producing in the VE4-CM2 interval immediately west of Caroline in the sediment thick, which, as shown in this study is continuous with the E3 interbed basinward. Preliminary work by the author has shown that the oil-water contact is in the vicinity of, and trends parallel to the western boundary of the Caroline fields. This explains why the sediment thick in the CM2-VE4 interval west of the Caroline field is not a major producer. Thus Caroline is producing from the E3 interval which, as shown, thins and becomes muddier basinward (or by Garrington).

By contrast, Garrington is producing from the coarse grained deposits in the VE4-CM2 interval. Preliminary work has shown that its western boundary is defined, in part, by the oil-water contact whereas its eastern boundary is defined by a thinning and muddying of the VE4-CM2 interval.

Therefore, the Caroline and Garrington fields are where they are due to a number of factors. The Caroline field is producing from the upper E3 and possibly E4 coarse grained intervals while the Garrington field is producing from the

VE4-CM2 interval. The locations of these coarse grained intervals are a result of sea level fluctuations. However, oil is localized by the various oil-water contacts, related to post-depositional factors. The producing intervals are in fact better defined as sheets than they are as long and linear.

CHAPTER 8: CONCLUSIONS

1) Two bounding disconformities, VE3 and VE4, are present within the study area. These are regionally extensive, subtly "stepped" ravinement surfaces and are correlatable within the study area, and as far south as Harmattan East, as far north as Crystal and as far east as Joffre. Both VE3 and VE4 were created by erosive shoreface retreat during 2 relative rises of sea level. The "steps" present represent different position of the shoreline during the relative rises of sea level.

2) The sediments of Allomember D, which underlie the VE4 surface, were deposited as part of a shallowing upward, storm-dominated, prograding shoreface. Progradation of Allomember D is interpreted to be the result of a relative lowering of sea level. Facies of Allomember E were deposited in a storm-enhanced tidal system during an overall rise in sea level. In any one vertical section the coarse grained interbeds in Allomember E get thinner and finer upwards thereby indicating a transgressively created, retrogradational sequence.

3) The shale-encased coarse grained interbeds which make up part of Allomember E were deposited during periods of stillstand during the overall transgression responsible for the formation of the VE4 surface. The deposits originated at the "steps" (marking the positions of old paleoshorelines) during periodic stillstands in the overall transgression, from both transgressive winnowing of the underlying substrate and

from fluvial input. They were subsequently swept basinwards in a storm-enhanced tidal system over older, stratigraphically lower "steps" which were, by that time, below wave base, and had been blanketed by mud. Thus, each interbed is essentially a timeline created during one time period in the overall transgression. Each is continuous with the transgressive deposits directly overlying the VE4 surface from the point of onlap of that interbed to the top of the next "step" landward.

4) Caroline is producing largely from the shale-encased E3 interbed (the Viking A sand of industry) whereas Garrington is producing from the stratigraphically lower VE4-CM2 interval, which directly overlies the VE4 erosion surface. Post-depositional localizing of the oil-water contacts is also responsible for the boundaries of the fields.

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APPENDIX I - CORED WELL LOCATIONS

Well Location	Interval Measured
10-19-33-1	6555.0-6607.0 ft.
10-30-33-1	1991.6-2005.4 m
10-23-33-2	2008.6-2022.3 m
6-33-33-2	2070.0-2086.0 m
6-6-33-3	2271.5-2284.8 m
6-12-33-3	2178.0-2196.0 m
6-33-33-3	2215.0-2233.0 m
1-18-33-4	7946.0-7971.3 ft.
7-19-33-4	7938.0-7979.0 ft.
6-24-33-4	7632.0-7689.0 ft.
11-31-33-4	2387.1-2406.8 m
6-2-33-5	2491.8-2508.5 m
14-9-33-5	2586.0-2602.4 m
14-10-33-5	2483.2-2491.4 m
10-11-33-5	2492.0-2499.7 m
15-13-33-5	2453.0-2471.5 m
2-14-33-5	8122.0-8222.0 ft.
6-16-33-5	2564.0-2573.6 m
9-22-33-5	2429.7-2443.8 m
7-24-33-5	2453.0-2464.7 m
3-25-33-5	8015.0-8067.0 ft.
16-28-33-5	2514.0-2532.0 m
6-34-33-5	2460.0-2478.8 m
7-4-33-6	2725.0-2736.0 m
11-21-33-6	2751.0-2769.0 m
16-4-33-7	6905.2-6910.1 m
6-24-33-7	2782.0-2788.0 m
6-29-33-7	2957.5-2960.0 m
6-31-33-7	9074.0-9109.2 ft.
11-35-33-7	2790.2-2794.7 m
2-2-34-2	2021.0-2029.8 m
6-3-34-2	1989.0-2006.5 m
5-14-34-2	2022.0-2037.8 m
6-19-34-2	2055.8-2073.8 m
14-20-34-2	2022.0-2040.0 m
11-23-34-2	6477.0-6548.0 ft.
6-30-34-2	2047.6-2064.2 m
13-30-34-2	2040.0-2056.3 m
7-33-34-2	6467.0-6517.0 m
14-11-34-3	2122.0-2122.0 m
16-11-34-3	2100.0-2108.6 m
6-13-34-3	2062.2-2084.0 m
16-13-34-3	2057.0-2082.3 m
16-14-34-3	2097.0-2113.0 m
14-15-34-3	2138.0-2156.6 m
16-21-34-3	2143.0-2152.3 m
6-23-34-3	2108.4-2111.4 m
16-23-34-3	2092.0-2110.0 m
7-24-34-3	2069.0-2087.2 m

6-25-34-3	2077.0-2095.0 m
16-25-34-3	2064.0-2078.3 m
6-26-34-3	2097.5-2112.6 m
6-27-34-3	2120.0-2130.0 m
16-27-34-3	2106.0-2124.0 m
16-28-34-3	2127.8-2138.5 m
6-29-34-3	2177.8-2194.0 m
6-30-34-3	2185.0-2202.0 m
8-33-34-3	2118.0-2122.2 m
16-33-34-3	2108.0-2126.0 m
6-34-34-3	2111.0-2133.3 m
6-35-34-3	2103.0-2114.2 m
16-35-34-3	2065.0-2083.0 m
11-36-34-3	8480.0-8530.0 ft.
14-36-34-3	2064.0-2082.0 m
10-3-34-4	7490.0-7553.0 ft.
12-5-34-4	7690.0-7740.0 ft.
10-7-34-4	7645.0-7696.0 ft.
1-4-34-5	8172.0-8192.0 ft.
11-6-34-5	2606.0-2620.0 m
6-14-34-5	7840.0-7900.0 ft.
12-26-34-5	8045.0-8095.0 ft.
6-29-34-5	8275.0-8325.0 ft.
8-15-34-6	2671.1-2685.1 m
14-17-35-1	1850.0-1866.2 m
6-6-35-2	2028.0-2054.8 m
3-15-35-2	1930.2-1948.6 m
9-3-35-3	2102.4-2084.0 m
7-4-35-3	2108.5-2126.5 m
6-5-35-3	2134.0-2141.5 m
16-5-35-3	2115.3-2118.5 m
8-7-35-3	2130.0-2139.0 m
14-7-35-3	2139.2-2170.4 m
14-8-35-3	2112.6-2130.0 m
16-8-35-3	2122.0-2140.5 m
6-9-35-3	2125.0-2143.2 m
8-9-35-3	2094.0-2119.2 m
14-9-35-3	2114.0-2134.0 m
6-11-35-3	2063.0-2081.1 m
6-15-35-3	2074.8-2093.0 m
8-17-35-3	2127.0-2153.0 m
8-18-35-3	2148.7-2166.9 m
6-19-35-3	2148.0-2160.5 m
6-20-35-3	2095.0-2113.0 m
14-1-35-4	2204.0-2222.0 m
14-20-35-3	2095.0-2119.0 m
16-2-35-4	2215.6-2234.0 m
6-6-35-4	2370.0-2388.0 m
6-11-35-4	2237.0-2249.3 m
14-11-35-4	2207.0-2223.5 m
1-12-35-4	2175.0-2189.0 m
6-12-35-4	2205.0-2216.0 m

6-13-35-4	2182.0-2187.4 m
10-13-35-4	2167.5-2183.2 m
14-14-35-4	2197.0-2210.0 m
7-21-35-4	2257.0-2272.0 m
14-21-35-4	2256.0-2276.0 m
6-23-35-4	2186.0-2200.0 m
8-24-35-4	2168.0-2185.0 m
11-24-35-4	2168.0-2181.2 m
1-25-35-4	2142.0-2154.0 m
6-34-35-4	2191.0-2209.5 m
6-11-35-5	2436.0-2454.0 m
8-12-35-5	2393.0-2419.0 m
6-36-35-5	2351.0-2363.0 m
2-8-35-6	2716.0-2732.0 m
1-16-35-6	8690.0-8750.0 ft.
3-19-35-6	8920.0-8980.0 ft.
10-27-35-6	8440.0-8490.0 ft.
10-29-35-6	8650.0-8710.0 ft.
4-33-35-6	8625.0-8685.0 ft.
7-1-35-7	2772.0-2790.8 m
11-11-35-7	2785.0-2798.4 m
4-13-35-7	2780.0-2785.8 m
10-23-35-7	9048.0-9108.0 m
10-24-35-7	8962.0-9022.0 ft.
11-28-35-7	9200.0-9265.0 ft.
1-35-35-7	2704.4-2718.8 m
16-20-36-2	1900.0-1918.0 m
11-21-36-2	6230.0-6281.5 m
6-29-36-2	1916.0-1927.8 m
6-32-36-2	1890.0-1908.0 m
16-12-36-3	6439.0-6551.0 ft.
4-32-36-4	2185.0-2203.4 m
14-4-36-5	2349.2-2359.8 m
7-15-36-5	2330.0-2346.6 m

APPENDIX II - DATA BASE

The well locations are sorted according to township and range. The depths to resistivity well log markers BFS, E1, E2, top of E3, E3, top of E4, E4, top of E5, E5, CM2, VE4, and VE3 are listed for each well. The depths are recorded in both feet and meters, depending on how they are recorded on well logs; all numerical values greater than 4000 refer to feet.

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
7033301	1931	1942	0	1950.5	1951	0	0	0	0	1953	1991.5	1994
8133301	1853.5	1865	1870.5	1874	1874	0	0	0	0	1876.5	1918.5	1921
10163301	1945.5	1958	1962	1965	1965	0	0	0	0	1967	2009	2011.5
10193301	6480	6513	6534	6542	6542	0	0	0	0	6548	6678	6690
16213301	6356	6394	6406	6416	6416	0	0	0	0	6422	6552	6572
6283301	6374	6403	6422	6434	6434	0	0	0	0	6438	6578	6588
10303301	1972	1984	1987	1989	1989	0	0	0	0	1992	2033	2036
2353301	6166	6206	6218	6234	6234	0	0	0	0	6242	6358	6366
10043302	6704	6733	6750	6758	6758	0	0	0	0	6767	6881	6892
10053302	6854	6890	6900	6912	6912	0	0	0	0	6920	7042	7052
2063302	2093	2103.5	2107	2110	2110	0	0	0	0	2112.5	2148	2151
10073302	6938	6976	6986	6996	6996	0	0	0	0	7006	7120	7130
10083302	6815	6845	6860	6870	6870	0	0	0	0	6878	7000	7010
7103302	6683	6715	6730	6742	6742	0	0	0	0	6750	6872	6880
7113302	6542	6574	6593	6600	6601	0	0	0	0	6610	6728	6737
16123302	6514	6550	6562	6580	6580	0	0	0	0	6587	6702	6710
16133302	1982	1992	1997	2000	2000	0	0	0	0	2003.5	2039.5	2042
11163302	6698	6730	6748	6760	6760	0	0	0	0	6772	6890	6902
10193302	6904	6940	6960	6968	6968	0	0	0	0	6976	7093	7106
11203302	2057	2067	2074	2075	2077	0	0	0	0	2078	2114	2117
10233302	6524	6560	6579	6572	6574	0	0	0	0	6596	0	0
11283302	6686	6728	6740	7644	6746	0	0	0	0	6758	6874	6885
6323302	6640	6675	6689	6695	6696	6704	6706	0	0	6712	6826	6838
6333302	2045	2055	2060	2063	2063.5	2066.5	2066.5	0	0	2067	2104	2107.5
8023303	2163	2172	2177	2179	2179.5	2182.5	2182.5	0	0	2182.5	2219	2222
6033303	7060	7092	7103	7111	7112	0	0	0	0	7120	7234	7244
13053303	7331	7364	7376	7380	7385	7390	7392	0	0	7394	7500	7510
6063303	2256.5	2265	2269	2271	2272.5	0	0	0	0	2274	2307.5	2311
6073303	7397	7422	7437	7442	7445	0	0	0	0	7452	7566	7576
6083303	2225	2234	2238	2239.5	2241	0	0	0	0	2243	2276.5	2279.5
6123303	2162.5	2173	2177	2179	2180	2181.5	2181.5	0	0	2182	2216.5	2220
6133303	7084	7115	7130	7137	7139	7149	7149	0	0	7154	7264	7275
6143303	2171	2180	2185	2188	2188	2189.5	2190	0	0	2191.5	2224	2228
6153303	7123	7153	7168	7176	7178	7185	7185	0	0	7187	7296	7306
10173303	7254	7280	7298	7304	7308	7312	7314	0	0	7316	7418	7425
7193303	7415	7440	7458	7463	7468	7472	7474	0	0	7480	7575	7586
11203303	7306	7336	7350	7354	7358	7366	7368	0	0	7373	7466	7480
2213303	7062	7092	7110	7115	7118	7125	7127	0	0	7130	7230	7242
7223303	7197	7228	7243	7249	7252	7258	7260	0	0	7266	7370	7379
10233303	7160	7188	7204	7216	7216	7224	7224	0	0	7230	7339	7350
10263303	2176	2185	2190.5	2193.5	2193.5	2196	2196	0	0	2198	2225.5	2234
16293303	7266	7298	7310	7317	7319	7326	7326	0	0	7334	7431	7442
10303303	2280	2289	2294	2291.5	2296.5	2299	2299.5	0	0	2301	2331	2333
7313303	2272	2280.5	2285.55	2287.5	2288	2290	2291	0	0	2292.5	2321	2325
11323303	2249	2258.5	2263	2265	2267	2268	2269	0	0	2270	2301	2305
6333303	2200.5	2210	2214	2216	2217	2219	2220	0	0	2221	2253	2262
11343303	7002	7036	7049	7058	7058	7066	7067	0	0	7070	7176	7190
5043304	7698	7728	7737	7741	7743	0	0	0	0	7750	7869	7879
1053304	7808	7836	7849	7852	7854	0	0	0	0	7858	7980	7988
4063304	2458	2465	2469	0	0	0	0	0	0	2473	2510	2513
9073304	7922	7948	7963	7975	7982	0	0	0	0	7975	8094	8104
9083304	7707	7730	7745	7750	7752	0	0	0	7756	7875	7886	
3093304	7634	7659	7672	7680	7680	0	0	0	0	7686	7804	7804
10103304	7780	7804	7820	7826	7828	7831	7833	0	0	7836	7948	7958
11113304	7717	7736	7752	7758	7762	7766	7767	0	0	7768	7880	7890
7143304	7685	7708	7723	7728	7734	7737	7739	0	0	7740	7846	7856
5163304	2326	2332.5	2338	2338	2339.5	0	0	0	0	2342	2377	2379.5
1173304	7705	7730	7746	7753	7754	0	0	0	0	7760	7874	7884
1183304	7920	7947	7960	7965	7966	0	0	0	0	7972	8085	8095
7193304	7922	7948	7960	7966	7970	7973	7974	0	0	7976	8084	8093
1203304	7670	7694	7708	7714	7716	0	0	0	0	7724	7832	7843

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
10223304	7728	7754	7770	7775	7780	7783	7785	0	0	7788	7894	7902
6243304	7608	7634	7650	7654	7658	0	0	0	0	7667	7763	7773
11263304	7628	7656	7674	7678	7682	7687	7690	0	0	7698	7792	7804
10273304	7646	7676	7688	7695	7698	7705	7706	0	0	7710	7810	7820
16283304	2306	2314	2319	2320.5	2321.5	2323.5	2324	0	0	2325	2355	2358
7293304	7658	7680	7699	7703	7705	7710	7710	0	0	7715	7818	7829
1303304	2406	2414	2419	2420	2422	2423.5	2424	0	0	2425	2455	2458
11313304	2374.5	2382	2386	7385	2387.5	7389	2391	0	0	2391.5	2423	2426
11323304	7766	7790	7806	7809	7813	7818	7818	0	0	7824	7930	7942
6343304	7536	7564	7578	7583	7588	7596	7596	0	0	7604	7694	7706
11353304	7598	7628	7645	7649	7654	7660	7662	0	0	7668	7767	7779
6023305	2483	2491	2495	0	0	0	0	0	0	2498.5	2532	2535
11083305	2611	2617	2622	0	0	0	0	0	0	2624	2662	2665
14093305	6440	6462	6474	0	0	0	0	0	0	6482	6602	6612
14103305	2469	2477.5	2481.5	0	0	0	0	0	0	2483	2522	2524
10113305	2480	2487.5	2492	0	0	0	0	0	0	2495	2532	2535
9123305	2446	2453.5	2458	0	0	0	0	0	0	2460	2498	2501
7133305	6024	6050	6064	0	0	0	0	0	0	6073	6188	6200
6143305	2421	2428	2434	0	0	0	0	0	0	2435	2471	2473
6163305	2555	2562	2566	0	0	0	0	0	0	2568	2604	2606.5
11193305	2634	2642.5	2647	0	0	0	0	0	0	2648	2685	2688
6203305	2568	2575	2579	0	0	0	0	0	0	2581	2615	2618
9223305	7932	7958	7968	0	0	0	0	0	0	7976	8090	8100
3243305	2448	2456	2459	2460	2461	0	0	0	0	2463	2498	2501
7243305	2443	2450	2455	2455.5	2457	0	0	0	0	2458	2493	2497
3253305	7992	8016	8032	8040	8044	0	0	0	0	8050	8156	8165
5263305	2404	2412	2416	2416	2419	0	0	0	0	2421	2452	2455
14273305	2455	2463	2467	2467	2468	2468.5	2470.5	0	0	2472	2503	2506
16283305	2509	2517	2520	2520.5	2521.5	2522.5	2524	0	0	2526	0	0
6313305	2602.5	2610	2614	2615.5	2616.5	0	0	0	0	2617	2651	2654
8323305	2544.5	2551.5	2556	2556	2557	2558	2559	0	0	2560	2592	2596
14333305	2498	2505	2509	2509.5	2511.5	2513	2514	0	0	2516	2548	2551
1343305	7947	7974	7990	7993	7995	7999	8004	0	0	8010	8106	8116
1353305	7862	7888	7904	7907	7910	7914	7916	0	0	7920	8020	8030
5363305	7827	7852	7867	7870	7871	7877	7878	0	0	7881	7980	7990
7043306	2719	2726	2728	0	0	0	0	0	0	2729	2767	2770
6133306	2678	2686	2689	0	0	0	0	0	0	2690	2731.5	2734
9143306	2690	2696	2699	0	0	0	0	0	0	2700	2743	2747
12213306	8986	9000	9014	0	0	0	0	0	0	9020	9154	9160
14223306	2732	2739.5	2742	0	0	0	0	0	0	2744	2778	2781
6233306	2707.5	2714	2717	0	0	0	0	0	0	2719	2757	2760
11243306	2657	2665	2669	0	0	0	0	0	0	2671	2708	2711
6253306	2638.5	2647	2650	0	0	0	0	0	0	2653	2687	2690
11263306	2695	2702	2706	0	0	0	0	0	0	2708	2740	2743
10273306	2739	2746	2750.5	2751.5	2751.5	0	0	0	0	2753	2786	2789
6283306	2774	2781	2785	0	0	0	0	0	0	2786	2822	2824
10323306	2788.5	2795	2801	0	0	0	0	0	0	2803	2834.5	2837
11333306	9092	9115	9133	0	0	0	0	0	0	9142	9242	9250
7343306	8908	8930	8948	8950	8952	0	0	0	0	8955	9062	9072
6353306	2689	2697	2701	2700	2702	0	0	0	0	2703	2735	2739
6013307	2744	2751	0	0	0	0	0	0	0	2753	2791	2795
4033307	2745	2752.5	0	0	0	0	0	0	0	2754	0	0
15053307	2911	2918	0	0	0	0	0	0	0	2923	2956	2958
10083307	2622	2630	0	0	0	0	0	0	0	2634	2670	2671
4093307	2557	2563	0	0	0	0	0	0	0	2568	2600	2604
10123307	9024	9050	9058	0	0	0	0	0	0	9060	9182	9194
7173307	7740	7763	0	0	0	0	0	0	0	7770	7888	7900
6243307	2768	2776	2780	0	0	0	0	0	0	2782	0	0
11253307	2819	2827	2831	0	0	0	0	0	0	2833	2863	2866
6293307	2948	2955	2959.5	0	0	0	0	0	0	2960	2988	2990
6313307	9035	9054	0	0	0	0	0	0	0	9070	9156	9165
11353307	9088	9118	0	0	0	0	0	0	0	9128	9224	9234

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
10023401	6156	6190	6211	6223	6223	0	0	0	0	6237	6364	6372
6033401	6258	6293	6313	6323	6325	0	0	0	0	6334	6466	6478
9043401	6265	6303	6322	6333	6333	0	0	0	0	6344	6466	6484
8093401	6226	6266	6280	6293	6293	0	0	0	0	6302	6426	6439
2133401	6073	6116	6132	6144	6144	0	0	0	0	6166	6280	6300
6143401	6110	6148	6166	6180	6180	0	0	0	0	6189	6305	6328
7163401	6175	6214	6232	6244	6244	0	0	0	0	6256	6368	6395
14173401	6212	6246	6266	6278	6278	0	0	0	0	6294	6402	6426
3193401	1951	1963	1967	1971.5	1971.5	0	0	0	0	1974	2007	2015
15203401	6112	6147	6163	6180	6180	0	0	0	0	6189	6300	6323
9213401	6176	6218	6230	6238	6240	0	0	0	0	6255	6366	6374
11223401	6148	6194	6206	6218	6218	0	0	0	0	6228	6338	6360
10243401	6080	6120	6133	6149	6149	0	0	0	0	6162	6280	6300
4263401	6118	6158	6170	6184	6184	0	0	0	0	6196	6307	6330
5283401	6163	6198	6215	6228	6228	0	0	0	0	6240	6356	6370
1293401	6104	6140	6156	6170	6170	0	0	0	0	6183	6292	6304
15293401	6101	6136	6154	6166	6166	0	0	0	0	6177	6296	6310
7333401	6216	6256	6279	6288	6288	0	0	6294	6294	6298	6406	6420
5343401	6168	6209	6227	6236	6236	0	0	6249	6249	6253	6366	6382
2013402	6505	6540	6556	6564	6564	0	0	0	0	6570	6700	6710
2023402	2012	2023	2027	2031	2031	0	0	0	0	2032	2072	2075.5
6033402	1977	1987	1993	1996	1996	0	0	0	0	1997	2035	2039
10093402	6516	6550	6569	6573	6575	0	0	0	0	6584	6706	6715
14113402	2092.5	2103.5	2108.5	2111	2111	2114.5	2114.5	0	0	2116	2147	2150.5
5143402	2005.5	2015	2018.5	2022	2022	2024	2024.5	0	0	2026	2064	2067
6193402	2032	2041	2047	2049.5	2050.5	2052.5	2052.5	0	0	2054	2086.5	2090
16193402	2033	2044.5	2050	2052.5	2052.5	0	0	0	0	2056	2087	2091
14203402	2000	2010	2015.5	2018.5	2019.5	2020.5	2021	0	0	2022	2054	2058
11233402	6430	6464	6483	6494	6494	0	0	0	0	6504	6620	6632
7263402	1939.5	1949	1955.5	1958	1958	0	0	0	0	1961	1996.5	2002
6303402	2025.5	2036	2041	2044	2044	0	0	0	0	2047	2080	2084
13303402	2026.5	2036.5	2041.5	2044.5	2045	0	0	0	0	2046.5	0	0
16323402	6413	6448	6462	6471	6471	0	0	0	0	6482	6594	6608
7333402	6418	6456	6467	6480	6480	0	0	0	0	6487	6604	6608
7343402	6330	6364	6382	6388	6388	0	0	0	0	6398	6516	6528
3023403	2107.5	2117.5	2121	2125	2125	2127	2128	0	0	2129	2160.5	2162
6033403	2141.5	2153	2156.5	2159.5	2160	2161	2162	0	0	2163.5	2195	2198.5
6043403	7257	7290	7308	7316	7318	7323	7325	0	0	7328	7428	7442
3053403	7311	7346	7358	7363	7366	7373	7375	0	0	7378	7480	7492
15053403	7206	7238	7255	7263	7265	7270	7272	0	0	7276	7379	7392
16063403	7272	7300	7318	7324	7327	7334	7336	0	0	7338	7438	7452
3073403	7312	7344	7359	7366	7370	7376	7376	0	0	7379	7477	7490
3083403	7220	7255	7270	7277	7279	7288	7288	0	0	7292	7393	7406
6093403	7121	7156	7172	7180	7182	7187	7188	0	0	7193	7296	7309
7103403	7008	7046	7060	7070	7070	7080	7080	0	0	7086	7180	7194
4113403	2143	2153	2159	2162	2162	2165	2165	0	0	2166.5	2198	2202.3
14113403	2092.5	2103.5	2108.5	2010.5	2111	2114	2114.5	0	0	2116	2146.5	2150.5
16113403	2078	2087.5	2093.5	2096	2096.5	2098	2098	0	0	2099	0	0
6133403	2061.5	2072	2077	2079.5	2080.5	2081.5	2081.5	0	0	2083	0	0
16133403	2047	2057	2062.5	2064	2065	2067.5	2067.5	0	0	2068.5	2103	0
14143403	2088.5	2098	2103.5	2105.5	2106.5	0	0	0	0	2108	2142	2146
16143403	2077	2086	2091.5	2094	2095	0	0	0	0	2097	2130	2134
4153403	7004	7035	7055	7065	7065	7072	7074	0	0	7078	7175	7188
14153403	2122	2132	2138	2139	2140	0	0	0	0	2143	2175	0
6163403	7070	7103	7122	7129	7131	7140	7142	0	0	7146	7240	7253
6173403	7156	7189	7208	7218	7218	7224	7226	0	0	7233	7324	7338
10183403	7210	7242	7260	7172	7272	7279	7280	0	0	7283	7376	7388
6193403	7208	7240	7259	7266	7268	7274	7276	0	0	7282	7374	7387
12203403	7107	7137	7156	7165	7165	0	0	0	0	7176	7274	7288
4213403	7033	7064	7078	7089	7090	0	0	0	0	7102	7198	7213
16213403	2121	2131.5	2135.5	2137	2138	0	0	0	0	2140.5	0	0
6223403	2123	2132	2137.5	2139.5	2140	2141.5	2141.5	0	0	2143	2177	2181

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
6233403	2089.5	2100	2104	2107	2107.5	0	0	0	0	2110	2144	2149
16233403	2080	2089	2095	2097.5	2098	0	0	0	0	2100	2132.5	2137
3243403	2061.5	2072	2076	2079	2080	0	0	0	0	2082	2116	2120
7243403	2052.5	2062.5	2068	2070	2071.5	0	0	0	0	2073	0	0
6253403	2058.5	2070	2075	2076.5	2076.5	0	0	0	0	2080	2113	2117
16253403	2046.5	2056	2061	2064	2065	0	0	0	0	2067	0	0
6263403	2080	2091	2096	2098	2099	0	0	0	0	2101.5	0	0
8263403	2067.5	2078	2084	2086.5	2087	0	0	0	0	2089	2123.5	2128
6273403	2106	2116	2121	2122.5	2123.5	0	0	0	0	2126.5	0	0
16273403	2081.3	2091.5	2097	2098.5	2099.5	0	0	0	0	2102	2135	2139
16283403	2107.5	2118	2122.5	2124.5	2125.5	0	0	0	0	2128	0	0
6293403	7086	7124	7135	7142	7144	0	0	0	0	7154	7260	7274
6303403	2170	2180	2186	2188	2188.5	0	0	0	0	2192	2221.5	2225.5
14323403	2109	2118	2123.5	2126	2127	0	0	0	0	2129.5	0	0
8333403	2109	2119.5	2124.5	2126	2127	0	0	0	0	2129	2162	2166
16333403	2096	2105	2110.5	2112.5	2113	0	0	0	0	2115	2148.5	2153
6343403	2096	2106	2110	2113	2114	0	0	0	0	2116	2150	2154
6353403	2080	2091	2096.5	2099	2099	0	0	0	0	2101	2135	2140
16353403	2048.5	2059	2064.5	2067.5	2068.5	0	0	0	0	2069	2103	2107.5
14363403	2047	2057	2062.5	2065	2065	0	0	0	0	2067	2102	2106
6013404	7427	7457	7474	7481	7484	7492	7493	0	0	7497	7596	7608
10033404	7468	7500	7516	7250	7525	7530	7533	0	0	7540	7629	7642
6043404	2295	2303.5	2307.5	2309	2311	2312.5	2313	0	0	2315.5	2344	2347.5
12053404	7650	7679	7692	7697	7705	7709	7713	0	0	7719	7826	7837
2063404	2351	2360	2363	2365	2367	2369	2369	0	0	2370	2400	2406
2073404	2317	2326	2328.5	2330.5	2332	2333.5	2334.5	0	0	2337	2368	2371.5
4083404	2333	2342.5	2347	2348	2350	2351.5	2352.5	0	0	2354	2385	2388.5
6103404	2259	2268	2273	2274	2276	2277	2278	0	0	2279	2308	2312
7123404	7381	7411	7430	7434	7439	7446	7447	0	0	7450	7548	7560
6133404	7368	7398	7416	7423	7425	7431	7433	0	0	7436	7535	7547
11143404	7238	7273	7287	7294	7296	7303	7303	0	0	7306	7406	7418
11153404	7348	7284	7400	7405	7408	7414	7414	0	0	7418	7512	7526
16173404	2328	2338	2342.5	2344	2346	2347.5	2348	0	0	2350	2379	2383
6233404	7217	7249	7269	7274	7277	7280	7285	0	0	7288	7388	7401
6243404	7196	7232	7247	7254	7256	7264	7265	0	0	7271	7362	7374
6273404	2244	2255.5	2259	2261	2262	2263.5	2264	0	0	2266	2292.5	2296
3303404	2352	2361	2366	2368	2369	2370.5	2372	0	0	2373	2402	2405.5
6323404	2301	2310	2314	2316	2317	2319	2320	0	0	2322	2349.5	2353
14363404	2156	2166	2171	2172	2173.5	2176	2176	0	0	2177	2205	2208
8013405	2356.7	2365	2369	2371	2371.5	2373	2373	0	0	2375	2405	2408
9023405	7784	7812	7825	7828	7832	7840	7840	0	0	7846	7932	7944
12033405	8058	8083	8096	8097	8100	8108	8110	0	0	8114	8205	8217
6043405	2489	2496	2500.5	2501	2502	2503	2504	0	0	2505.5	2536	2539
11063405	2585	2592.5	2596.5	2597.5	2598.5	0	0	0	0	2600	2631.5	2636
11093405	8056	8082	8094	8097	8098	8106	8106	0	0	8112	8206	8218
11103405	7966	7998	8008	8013	8015	8022	8022	0	0	8028	8120	8132
7113405	2396	2405	2408	2410	2411	2413	2413	0	0	2414	2442.5	2446
7123405	2362	2369	2372.5	2374	2375.5	2377.5	2378	0	0	2379	2407.5	2411
12133405	2376	2383	2388	2389.5	2390	2393	2393	0	0	2395	2421.5	2425
6143405	7780	7808	7820	7828	7831	7838	7838	0	0	7844	7935	7946
6153405	2414	2421	2425	2426	2427	2428.5	2429	0	0	2431	2460	2469
11163405	2454	2462	2466	2467	2468	2469.5	2470	0	0	2472	2500	2504
9173405	2462	2470	2473.5	2474.5	2475.5	2477	2477.5	0	0	2480	2509	2513
6183405	2588.5	2596	2601	2603	2604	2607	2608	0	0	2611	2634	2637.5
12193405	2491	2497	2501	2502	2504	2506	2506.5	0	0	2508	2535.5	2539
14203405	2479	2485.5	2489.5	2491	2493	2494	2494	0	0	2497	2526.5	2529.5
6213405	8027	8056	8066	8073	8078	8084	8085	0	0	8090	8184	8196
2223405	7922	7948	7962	7965	7970	7973	7975	0	0	7984	8074	8086
11233405	2430	2438	2440.5	2445	2446	2448	2448	0	0	2450	2477	2479
14253405	2373	2382.5	2387.5	2389	2390	2391	2392.5	0	0	2394	2422	2425
10273405	2451	2460.5	2463	2465	2467	2468	2469	0	0	2471	2496	2500
6293405	8224	8254	8266	8272	8278	8284	8284	0	0	8294	8372	8392

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
13303405	2549	2557	2561.5	2562.5	2564	2566	2566	0	0	2569	2594	2598
11323405	2527	2536.5	2541	2542.5	2544	2546	2546	0	0	2548	2573	2577
10333405	8090	8120	8136	8140	8143	8145	8150	0	0	8158	8242	8256
10353405	2387	2396	2401	2402.5	2404	2405.5	2406.5	0	0	2408	2433.5	2437
6363405	2373	2383	2388	2389.5	2391	2393	2394	0	0	2395	2421	2425
6033406	2715	2722	2726.5	0	0	0	0	0	0	2729	2759	2762.5
6053406	2790	2797	2801	0	0	0	0	0	0	2804	2832	2837
9073406	2746	2754	2758	0	0	0	0	0	0	2760.5	2789	2792
11083406	2712	2719	2724	0	0	0	0	0	0	2727	2755	2758
6093406	2712.5	2720	2725	0	0	0	0	0	0	2727	2756	2760
7123406	8567	8590	8603	0	0	0	0	0	0	8608	8723	8734
8153406	2659	2665.5	2669	0	0	0	0	0	0	2671	2703	2707
10163406	8879	8901	8915	0	0	0	0	0	0	8918	9024	9035
16173406	2760	2767	2771.5	0	0	0	0	0	0	2773	2804.5	2807.5
16243406	2548	2556	2559	2560	2562.5	0	0	0	0	2564.5	2594	2598
7253406	2538	2545	2548	2550	2552.5	2555	2555	0	0	2556.5	2583	2586
4263406	2623	2631	2635.5	2635.5	2637.5	2638	2639	0	0	2640	2668	2672
5283406	2698.5	2706	2709	0	0	0	0	0	0	2710	0	0
10313406	2724	2730	2735	0	0	0	0	0	0	2737.5	2765	2770
7323406	2694	2702	2706.5	0	0	0	0	0	0	2708	0	0
6343406	2674	2682	2686	2687	2689	0	0	0	0	2692	2717	2721
7353406	8526	8550	8566	8572	8576	8583	8584	0	0	8588	8672	8684
11363406	8440	8470	8484	8492	8494	8504	8504	0	0	8509	8584	8596
7053407	2928.5	2936	2940	0	0	0	0	0	0	2941	2967	2969
4063407	2542	2547.5	2553	0	0	0	0	0	0	2555	0	0
11093407	2851	2858	2862.5	0	0	0	0	0	0	2864.5	2891.5	2894
8143407	9316	9338	9356	0	0	0	0	0	0	9365	9459	9468
8193407	2992	2998	0	0	0	0	0	0	0	3006	3033	3035
8243407	2011	2018	2021	0	0	0	0	0	0	2023	2054	2057
7303407	2837	2845	2849	0	0	0	0	0	0	2851	2879	2881
16363407	2775.5	2783	2787.5	0	0	0	0	0	0	2790	2819	2822
13023501	5938	5973	5992	6006	6008	0	0	6016	6017	6019	6023	6114
11033501	6020	6053	6068	6086	6086	0	0	6095	6095	6100	6104	6202
5043501	6046	6083	6100	6116	6116	0	0	0	0	6126	6128	6214
1083501	5997	6032	6048	6068	6068	0	0	6076	6076	6080	6086	6161
15093501	5924	5960	5978	5995	5995	0	0	6006	6006	6009	6014	6086
15103501	5886	5925	5939	5956	5956	0	0	5965	5965	5970	5973	6057
13113501	5868	5904	5922	5938	5938	0	0	5946	5946	5954	5958	6040
5143501	5884	5916	5936	5953	5953	0	0	5962	5962	5972	5975	6053
13153501	5848	5888	5907	5925	5925	0	0	5934	5934	5942	5946	6024
15153501	5848	5885	5905	5922	5922	0	0	5930	5930	5939	5944	6024
5163501	5950	5988	6006	6021	6023	0	0	6036	6038	6044	6046	6114
11173501	6000	6038	6057	6070	6070	0	0	6076	6076	6086	6090	6170
1203501	5910	5947	5967	5986	5986	0	0	5993	5993	6003	6005	6082
5213501	5896	5932	5950	5970	5970	0	0	5975	5975	5986	5990	6065
3223501	5843	5880	5902	5918	5918	0	0	5926	5928	5934	5936	6015
11273501	5847	5885	5904	5920	5920	0	0	5923	5925	5936	5938	6008
1283501	1797	1808	1815.5	1820	1820	0	0	1822	1823	1825.5	1826.5	1846.5
1293501	6006	6040	6060	6082	6082	0	0	6087	6087	6098	6101	6174
14313501	5959	5998	6013	6026	6026	0	0	6038	6038	6048	6050	6121
1323501	5909	59443	5962	5982	5982	0	0	5990	5990	5998	6000	6071
7333501	5860	5900	5920	5933	5933	0	0	5944	5944	5952	5956	6024
3353501	5736	5772	5793	5807	5809	0	0	5817	5817	5822	5910	5923
7363501	1728	1739	1745.5	1750	1751	0	0	1753	1753	1754.5	1784	1788
11023502	1910.5	1920	1926	1931	1931	0	0	0	0	1933.5	1964	1968
6063502	2017	2027.5	2032	2036	2036	0	0	0	0	2037	2072	2076.5
12113502	1909	1919	1925	1931	1931	0	0	0	0	1933	1963	1968
11143502	1902.5	1914	1918	1924	1924	0	0	0	0	1927	1954	1959
3153502	1903.5	1913	1919.5	1924	1924	0	0	1927	1928	1929	1954.5	1960
5203502	1955.5	1967	1972.5	1975	1975	0	0	1977.5	1977.5	1979	2005	2009
6233502	1902.5	1913.5	1920	1923	1924	0	0	1926	1927	1928	1953.5	1958.5
15243502	1873	1884	1890.5	1897	1897	0	0	1899	1899	1901	1927	1933

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
10263502	1883	1894.5	1900	1904	1904	0	0	1907	1907	1910	1936	1940
7283502	6292	6326	6346	6366	6366	0	0	6373	6373	6379	6456	6471
12293502	1939.5	1950	1956	1961	1961	0	0	1962	1962	1964	1989	1995
11313502	6412	6446	6464	6478	6478	0	0	6486	6486	6490	6579	6594
11323502	6348	6384	6404	6418	6418	0	0	6426	6426	6429	6512	6529
12363502	1845.5	1857	1862.5	1867	1867	0	0	1870	1870	1873	1896	1900
3013503	2030	2040	2044.5	2047	2047	0	0	0	0	2050	2085	2089.5
10023503	2051.5	2062	2067	2068	2068	0	0	0	0	2071.5	2105	2110
9033503	2067.5	2077	2082	2085	2085	0	0	0	0	2082.5	2121	2126
6043503	2088.5	2097.5	2103	2106	2106	0	0	0	0	2108.5	2143	2146
7043503	2092.5	2102.5	2107	2109	2109	2111	2111	0	0	2112	2146	2150
12043503	2088.5	2098	2104	2106	2106	2107	2107.5	0	0	2108.5	2141	2145
6053503	2110.5	2121	2126	2127.5	2127.5	2129	2129.5	0	0	2131	2165.2	2169
16053503	2095.5	2105	2111	2113	2113	2115	2115	0	0	2116	2149	2153
8073503	2107.5	2116	2122	2124	2124	0	0	0	0	2127	2160.5	0
14073503	2133	2142	2149.5	2151	2151	2153	2153	0	0	2154.5	2188	2192
16073503	2110	2119	2125.5	2127.5	2127.5	2129	2129	0	0	2130	2164	0
16063503	2117	2128	2133	2135	2135	2136	2136.5	0	0	2137.5	2170	0
6083503	2103	2112.5	2117.5	2119	2119	2120	2120	0	0	2122	2155	2159
8083503	2083.5	2094	2099.5	2101	2101	2102	2102	0	0	2104	2138	2141
14083503	2096.5	2107	2112.5	2114	2114	2116	2116	0	0	2117	2150	2154
16083503	2108	2118.5	2123	2125	2125	2126.5	2126.5	0	0	2128	2161	2166
6093503	2104	2114	2118.5	2121	2121	2122.5	2122.5	0	0	2123.5	2156	2160
8093503	2078	2088	2093.5	2095	2095	2097	2097	0	0	2098.5	2130	2135
14093503	2095.5	2105	2111	2113	2113	2114.5	2114.5	0	0	2116.5	2148.5	2153
6103503	2067	2077	2082	2084.5	2084.5	2085	2086	0	0	2087	2119	2124
6113503	2048	2057	2063	2064	2064	2066	2066	0	0	2067.5	2101	2105
3123503	2025	2036	2041	2042.5	2042.5	2044.5	2044.5	0	0	2046	2077	2084
14143503	2042.5	2053	2058.5	2061	2061	2064	2064	0	0	2064.5	2096	2101
6153503	2060.5	2069	2075.5	2077	2077	2080	2080	0	0	2081	0	0
6163503	2083	2094.5	2100	2101	2101	2103	2103	0	0	2104	2136.5	2140
11163503	2083	2094	2098	2099	2099	2101	2101	0	0	2103	2135	2139
14173503	2080	2091	2095	2097	2097	1099.5	2099.5	0	0	2101	2131.5	2136
8183503	2130.5	2140	2146	2148	2148	2150	2150	0	0	2152	2184	2187
6193503	2129	2140	2145	2147	2147	2150	2150	0	0	2152	0	0
6203503	2081	2091	2096	2097	2098	2100	2100	0	0	2102	2131	2135
14203503	2092	2102.5	2106	2108	2108	2111	2111	0	0	2113	2138.5	2143
6213503	2076.5	2087.5	2092.5	2094	2094	2097	2097	0	0	2100.5	0	0
11233503	6676	6708	6726	6738	6738	0	0	0	0	6751	6846	6862
10253503	1986	1997	2002	2005	2005	0	0	2008.5	2009	2012	2036	2041
11283503	2052	2061.5	2067	2069	2069	2072	2072	0	0	2076	2101	2106
10293503	6739	6774	6790	0	0	0	0	0	0	6806	6902	6914
6303503	2103	2114	2120	2122.5	2122.5	0	0	2125	2125	2126	0	0
11313503	2076	2087	2092.5	2095	2095	0	0	2098	2098	2099.5	2126	2131
16353503	2003	2013	2019	2021	2021	0	0	2024	2024	2026	2052.5	2057
14013504	2182.5	2193	2198	2200.5	2201.5	0	0	0	0	2205	2234	2237
16023504	2200	2210	2215	2217	2218	2220	2220	0	0	2222	2250	2254
2043504	2261.5	2271	2276	2277	2278.5	2281.5	2282	0	0	2284	2311	2313
6063504	2361	2371	2375.5	2377	2378.5	2381	2382.5	0	0	2384.5	2412.5	2414.5
6083504	2326	2336	2341.5	2343	2344	0	0	0	0	2349.5	2375	2379
16103504	2235	2245	2250	2253	2253.5	0	0	0	0	2256	2287	2290
6113504	2215	2225	2230.5	2233	2234	0	0	0	0	2237	2266	2270
1123504	2152	2162	2167	2170	2171	0	0	0	0	2173	2204	2207
6123504	2190.5	2200	2206.5	2208.7	2209.5	0	0	0	0	2211	2241.5	2245
11123504	2175	2185	2191	2192	2193	0	0	0	0	2195.5	2227.5	2231
6133504	2165.5	2175	2180	2182	2182	0	0	0	0	2185	0	0
10133504	2146	2158	2162	2165	2165	0	0	0	0	2168	2199	2202
5143504	2197	2206.5	2212	2214	2214	0	0	0	0	2216	2248	2252
8143504	2183	2191.5	2198	2199	2199.5	0	0	0	0	2202	0	0
11143504	7195	7227	7244	7256	7256	7262	7264	0	0	7268	7360	7370
8153504	2213	2222.5	2228	2230.5	2230.5	2233	2233.5	0	0	2234	0	0
7183504	2340	2350.5	2354	2357	2359	2362	2362	0	0	2364	2388.5	2392

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
6193504	2321	2331	2336	2339	2339	2343	2343	0	0	2344	2369	2374
7213504	2238	2247	2252	2254.5	2254.5	2256	2257	0	0	2259	2286	2290
14213504	2237.5	2247.5	2252	2254	2254	2257	2257	0	0	2259	2287	2290.5
14223504	2189	2200	2205	2207	2207	0	0	0	0	2211	2241	2245
2233504	7100	7135	7148	7160	7160	0	0	0	0	7176	7256	7270
6233504	2165.5	2174	2179.5	2182.5	2182.5	2184.5	2185	0	0	2187.5	2214.5	2218
3243504	2155.5	2166	2169	2173	2173	0	0	0	0	2177.5	2204	2208
8243504	2146	2156.5	2162	2165	2165	0	0	0	0	2170	0	0
11243504	2151	2162	2165.5	2169	2169	0	0	0	0	2173.5	2201	2205
1253504	2126	2136	2140	2143	2143	0	0	0	0	2147.5	2177	2181
11273504	7184	7217	7234	7246	7246	0	0	0	0	7260	7348	7360
2283504	7288	7324	7337	7345	7345	0	0	0	0	7358	7457	7466
11293504	7450	7484	7496	7506	7508	0	0	0	0	7520	7612	7624
6303504	2304	2315	2318.5	2322	2322	0	0	0	0	2326	2353	2356
10313504	7547	7583	7602	7610	7610	7615	7617	0	0	7620	7710	7716
10323504	7294	7329	7345	7359	7359	0	0	0	0	7370	7462	7470
10333504	7162	7196	7214	7226	7226	0	0	0	0	7236	7326	7334
6343504	2168	2178	2184	2188	2188	0	0	0	0	2190.5	2222	2224
2363504	2111	2121	2127	2129	2129	0	0	0	0	2132	2161.5	2165
6013505	2375	2385	2388	2390	2392	2393.5	2394.5	0	0	2396.5	2422	2424.5
16013505	2391	2400	2405	2406.5	2407.5	2409.5	2410.5	0	0	2413	2439.5	2442
6023505	2408	2416.5	2421.5	2422.5	2425	2427.5	2427.5	0	0	2429	2453	2456
14043505	2326.5	2336	2343	2343	2344.5	2347	2347	0	0	2350	2383	2385
6053505	8313	8345	8358	8363	8366	8370	8374	0	0	8383	8470	8484
12073505	8346	8378	8385	8392	8403	8408	8410	0	0	8416	0	0
2083505	2510	2519.5	2524	2525	2527	2529	2530	0	0	2531	2557	2561
6093505	8116	8148	8160	8165	8170	8179	8179	0	0	8186	8272	8282
3103505	2443.5	2453	2458	2459	2461	2462.5	2463.5	0	0	2465	2490.5	2493.5
6113505	2422.5	2432	2437	2438.5	2439.5	2442.5	2443.5	0	0	2444.5	2471.5	2473
8123505	2385	2396	2400	2402	2402.5	2405	2406	0	0	2408	2432.5	2436
16133505	2382	2392	2396.5	2400	2402	2404	2404	0	0	2407	2429	2433
6143505	2427	2437.5	2441	2443	2444	2447.5	2448.5	0	0	2450	2474	2477
10153505	2448	2458.5	2462.5	2465	2466.5	2470.5	2470.5	0	0	2472	2495	2498
6163505	8018	8050	8064	8072	8076	8082	8085	0	0	8096	8170	8180
11173505	2480	2489	2494	2495	2497	2499	2500	0	0	2502	2527	2529.5
6213505	8081	8114	8125	8137	8144	0	0	0	0	8158	8230	8238
5223505	2447	2457	2462	2465.5	2467	2469	2469	0	0	2471	2493	2496.5
8233505	2393	2402.5	2408	2413	2414	2415	2415	0	0	2417	2438	2443
16243505	2340.5	2350	2355	2357	2357	2360	2360	0	0	2362	2389	2393
6253505	2336	2345	2350.5	2353	2353	2356	2356	0	0	2357.5	2385	2389
14263505	2357.5	2365	2371.5	2376	2376	2378	2378	0	0	2379	2406	2409
6273505	2396	2405	2411	2415	2416	2418.5	2419	0	0	2420.5	2443	2445
6283505	2429	2438	2443.5	2448	2448.5	2450	2451	0	0	2452.5	2473	2476
10293505	7988	8018	8032	8047	8050	8056	8058	0	0	8062	8129	8138
10303505	8090	8122	8139	8150	8150	8162	8162	0	0	8167	8233	8247
5323505	2441.5	2451	2456	2460.5	2461.5	0	0	0	0	2466	2487.5	2489
14333505	2397	2406	2412	2416	2416	0	0	0	0	2420.5	2444	2447
8343505	2362.5	2372.5	2378.5	2381	2382	2384.5	2384.5	0	0	2385.5	2412	2415
6353505	2343.5	2353.5	2359	2362	2362.5	2365	2365	0	0	2366.5	2394	2397
6363505	2329	2338	2343.5	2347	2347	2349	2349	0	0	2351.5	2378	2381
11013506	8500	8529	8542	3548	8553	0	0	0	0	8560	8567	8637
5023506	8636	8662	8678	8686	8690	0	0	0	0	8694	8705	8770
7033506	8657	8680	8700	8709	8709	0	0	0	0	8718	8726	8798
3043506	2686	2695	2698	0	0	0	0	0	0	2703	2706	2726
6053506	2707	2716	2721	0	0	0	0	0	0	2723	2725	2750
3073506	2738	2746	2749	2753	2753	0	0	0	0	2756	2758	2778
16093506	8644	8668	8676	8686	8692	8696	8700	0	0	8708	8715	8780
6103506	2643	2652	2656	2656.5	2659	2661	2661	0	0	2662	2665	2684
6113506	8622	8652	8660	8668	8673	8676	8680	0	0	8690	8694	8760
1123506	2562	2570	2575.5	2576	2578	2579	2580.5	0	0	2582	2583	2608
10133506	8427	8456	8468	8474	8483	8490	8492	0	0	8496	8503	8576
10143506	8513	8540	8556	8560	8566	8471	8574	0	0	8580	8584	0

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
5153506	2630.5	2639	2644	2644	2646	2647.5	2649	0	0	2651	2652	2675
9183506	2723	2730	2733	2735	2737	2738	2739	0	0	2741	2742.5	2763
1193506	8906	8932	8940	8949	8956	8962	8964	0	0	8970	8976	0
12223506	2600.5	2610	2613	2615	2617	2618	2618.5	0	0	2620.5	2621.5	2643
4243506	8435	8468	8482	8487	8493	8500	8504	0	0	8510	8514	0
15273506	2572	2580.5	2585.6	2587	2587	2590.5	2591.5	0	0	2593	2595	2612
4293506	8705	8736	8750	8753	8760	8762	8766	0	0	8772	8776	8838
7013507	2768	2775	2780.5	0	0	0	0	0	0	2782.5	2788.5	2810
6083507	2914	2920	2926	0	0	0	0	0	0	2928	2930.5	2952
11113507	2779	2786	2791	0	0	0	0	0	0	2792.5	2797	2818
4133507	2763.5	2770	2777	2777	2779.5	0	0	0	0	2781	2782	2802.5
10143507	2758	2765	2771	2771.5	2772.5	0	0	0	0	2775	2775.2	2796
7153507	9090	9116	9132	9136	9141	0	0	0	0	9144	9150	9210
10213507	9183	9204	9220	9220	9226	0	0	0	0	9234	9242	9310
12223507	9102	9122	9136	9140	9147	0	0	0	0	9156	9158	9230
10253507	2693.5	2701	2707	2709	2710	2711	2711	0	0	2713	2715	2732
4263507	2728	2734	2740	2740	2742	0	0	0	0	2745	2746.5	2767
2283507	9113	9138	9152	9154	9164	0	0	0	0	9169	9173	0
9293507	9252	9278	9290	9294	9298	0	0	0	0	9301	9310	0
10313507	9283	9313	9326	9333	9336	0	0	0	0	9342	9344	9398
1353507	2693.5	2701	2705	2706.5	2707.5	2708.5	2709	0	0	2711	2714	2731
7363507	8790	8823	8834	8843	8843	8847	8847	0	0	8850	8856	0
16093601	5806	5842	5862	0	0	0	0	5886	5886	5895	5981	5994
14103601	1772	1783	1789	1793.5	1794	0	0	1795.5	1796	1799	1825	1830
12113601	1766	1778	1784	1787.5	1788	0	0	1790	1790	1793	1819	1824
14133601	1733.5	1746	1750	1755	1755	0	0	1758	1758.5	1762	1787.5	1792.5
2213601	1773	1784	1790	1793	1793	0	0	1796	1796	1800.5	1824	1830
10223601	5820	5860	5872	5886	5886	0	0	5901	5901	5916	5984	6006
5233601	1764	1776	1782	1786	1786	0	0	1789.5	1790	1793	1818.5	1824
10233601	5758	5791	5810	5826	5828	0	0	5835	5837	5852	5932	5950
10293601	5874	5915	5924	5940	5940	0	0	5952	5952	5968	6038	6058
10343601	5769	5808	5828	5838	5840	0	0	5854	5856	5866	5936	5958
12353601	1754.8	1765.5	1772	1776	1776	0	0	1779	1780	1785	1806	1815
16363601	1734.8	1746	1752	1755	1755	0	0	1759.7	1760	1764	1786.5	1792
13033602	1887.8	1900	1905.5	0	0	0	0	1913	1913	1916.7	1917.7	1938.3
6043602	1908	1919	1924	1928	1928	0	0	1932	1932	1934	1934.5	1956
6053602	6333	6370	6390	0	0	0	0	6408	6410	6420	6424	6488
10063602	6339	6373	6395	6408	6408	0	0	6418	6418	6429	6431	6498
3073602	6349	6387	6404	6420	6420	0	0	6428	6428	6439	6443	6510
6083602	6296	6330	6349	6362	6362	0	0	6374	6374	6385	6388	6456
16083602	1901	1912	1918.5	1923	1923	0	0	1924	1924	1928	1930.5	1948.7
6093602	1894.5	1905.5	1912	1916	1916	0	0	1918	1918.5	1921.5	1923	1942.8
6153602	1857.5	1867	1873	0	0	0	0	1880.5	1880.5	1884	1885.3	1904
10163602	6154	6190	6211	0	0	0	0	6230	6230	6241	6248	6318
11193602	6312	6350	6372	6380	6380	0	0	6390	6390	6404	6408	6473
10223602	6025	6062	6083	0	0	0	0	6108	6108	6120	6123	6184
16203602	1886	1898	1902.5	1907.5	1907.5	0	0	1909	1910	1914.3	1915	1933.5
11213602	6146	6183	6202	6216	6216	0	0	6222	6224	6238	6243	6302
4273602	1840	1851.5	1856	1860	1861	0	0	1862	1863	1867	1867.5	1887
10283602	6072	6108	6126	6141	6141	0	0	6148	6148	6157	6158	6227
7293602	6130	6168	6188	6202	6202	0	0	6211	6211	6221	6226	6289
8303602	1886.5	1898.5	1904.5	1909	1909	0	0	1912	1912	1915	1915.3	0
7313602	6195	6235	6248	6260	6261	0	0	6271	6271	6285	6288	6344
6323602	1868	1880	1887	1891	1891	0	0	1893	1894	1898	1898.4	1913
6333602	6087	6121	6140	0	0	0	0	0	0	6182	6183	6238
7013603	6463	6494	6514	6527	6527	0	0	6538	6538	6546	6547	6619
10043603	6720	6750	6772	0	0	0	0	0	0	6806	6812	6878
11063603	2071.5	2084	2088.5	0	0	0	0	2096	2096	2098	2099	2121.5
16063603	2074	2085	2090.5	2096	2096	0	0	2098	2098.5	2100.5	2102	2122
10073603	6766	6797	6827	0	0	0	0	6834	6834	6842	6848	0
14083603	2052	2063	2068.5	0	0	0	0	2073	2074	2077	2079	2100.5
16093603	2037	2049	2053.5	0	0	0	0	2060	2060	2062	2063	2088

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
7113603	1998.5	2010	2015	0	0	0	0	2022	2022	2023	2024	2045.5
16123603	6383	6420	6438	0	0	0	0	0	0	6464	6474	6546
3133603	1964	1976	1979.5	0	0	0	0	1987	1987	1989	1990	2013
10143603	1970.5	1981	1986.5	1992	1993	0	0	1994	1995	1997.5	1998.5	2019
10163603	2026	2036	2042	2046	2046	0	0	2047	2048	2052.3	2053	2076
6173603	2054	2063	2069.5	0	0	0	0	2078	2078	2079.5	2080.5	2104
4183603	2071	2082	2086.5	2091	2091	0	0	2094	2094	2098	2099	2117
6193603	2067.5	2079	2084	0	0	0	0	0	0	2095.5	2096	2115
16203603	2039.6	2051.5	2057.5	2062	2062	0	0	2065	2065	2069.5	2070	2088
10213603	6634	6672	6692	0	0	0	0	6710	6710	6728	6730	6800
10223603	2000	2010	2016	2020	2020	0	0	2023	2024	2028	2029	2047
4233603	1986	1997	2002.5	2008	2008	0	0	2011	2011	2014.5	2015	2036
11233603	1984.5	1995	2003	2007	2007	0	0	2009.5	2010	2014.5	2015	2034
10243603	1937	1947.5	1953	1956.5	1957.5	0	0	1960	1960.5	1964	1965	1984
4263603	1981.5	1992.5	1998.5	2001	2001	0	0	2006	2006	2009.5	2011.5	2030
2273603	2000	2012.5	2019	2022	2022	0	0	2024	2024	2028	2031.5	2045
6283603	2023	2034	2040	2045	2045	0	0	2048	2048	2052	2053	2071
8293603	2036	2047.5	2053.5	2058	2058	0	0	2062	2062	2065	2066	2081
8303603	2052.5	2064	2070	2075	2075	0	0	2078	2078	2082	2084	2099
7313603	6703	6742	6762	0	0	0	0	0	0	6790	6793	6856
12333603	6633	6675	6689	6700	6700	0	0	6712	6712	6724	6730	6786
11353603	6426	6464	6484	6496	6496	0	0	6508	6508	6518	6526	6580
6363603	6361	6393	6414	6427	6427	0	0	6436	6438	6453	6454	6512
11013604	6904	6940	6957	6970	6970	0	0	0	0	6994	6996	7061
6023604	7013	7048	7067	7080	7080	0	0	7087	7087	7095	7097	7176
6033604	7056	7092	7110	7115	7115	0	0	7124	7124	7134	7136	7216
10053604	7213	7246	7262	7268	7268	0	0	7278	7278	7294	7296	7387
7073604	7223	7255	7276	7284	7284	0	0	7292	7292	7300	7306	7365
10083604	7142	7170	7192	7200	7200	0	0	7212	7212	7224	7228	7280
10093604	7141	7173	7193	7204	7204	0	0	7214	7214	7224	7227	7286
12113604	6925	6959	6968	6993	6993	0	0	7003	7003	7009	7012	7072
10133604	2083	2094	2099	2104	2104	0	0	2106.5	2107	2110	2112	2132
15153604	6974	7006	7026	7037	7037	0	0	7048	7049	7057	7064	7120
6163604	2146	2156	2162.5	2165	2165	0	0	2168	2168	2171	2172	2193
10193604	2186	2198	2203	2207	2207	0	0	2210	2210	2213	2214	2230
11223604	6977	7011	7032	7042	7042	0	0	7055	7055	7065	7070	7128
10233604	6874	6907	6925	6936	6936	0	0	6947	6949	6957	6963	7018
7263604	6853	6891	6906	6922	6922	0	0	6933	6933	6943	6947	6999
16273604	6902	6938	6946	6967	6967	0	0	6977	6977	6986	6988	7042
11283604	7040	7076	7098	7110	7110	0	0	7120	7122	7131	7136	7191
10293604	2151.5	2165	2169	2172	2172	0	0	2175	2176	2179	2181	2198
10303604	7117	7149	7170	7182	7182	0	0	7193	7195	7206	7208	7263
6313604	7103	7133	7158	7170	7170	0	0	7180	7180	7194	7198	7248
4323604	2157	2168	2174	2177	2177	0	0	2180	2180	2183	2185	2201
5333604	2132.5	2143	2148	2153	2153	0	0	2158	2158	2159	2161	2175
6343604	2106	2116	2122	2124	2124	0	0	2128	2128	2130.5	2132.5	2149
11353604	6861	6893	6907	6925	6925	0	0	6932	6932	6940	6943	6999
8363604	2054.5	2065	2070	2074	2074	0	0	2078	2078	2080	2083	2099
6013605	2294	2305	2311	2314	2314	0	0	0	0	2317	2317.5	2342
6113605	2282.5	2293	2299.5	2302.5	2302.5	2304	2304	0	0	2307.5	2309	2328
10123605	7308	7340	7355	1366	2368	7374	7374	0	0	7381	7387	7450
7133605	7306	7342	7360	7368	7368	7372	7372	7388	7390	7394	7396	7450
6193605	2392	2401.2	2407.5	2410	2410	2412	2412	2413	2413	2415	2418	2432
11213605	2336	2346	2352	2353	2354	2356	2356	2359.5	2359.5	2360.5	2364	2379
11253605	2225	2236	2242.5	2246	2246.5	2248.5	2248.5	2251	2251	2252	2253	2273
4263605	7485	7518	7539	7559	7559	0	0	0	0	7570	7574	7636
5273605	2305	2315	2320	2324	2324	2326	2326	2328	2328	2329	2330	2348
14283605	2320	2329	2335	2340.5	2341	2343	2343	0	0	2345	2347	2361.5
6293605	7680	7710	7728	7746	7748	7754	7755	0	0	7758	7762	7808
8303605	2346	2356	2362	2367	2367	2369	2369	0	0	2370	2371	2386
6333605	2298.5	2309	2315	2318	2318	2320	2320	2322	2322	2323	2324	2341
6353605	2228	2239	2243	2247	2247	2249	2249	2251	2251	2254	2255.5	2272

Well	BFS	E1	E2	Top E3	E3	Top E4	E4	Top E5	E5	CM2	VE4	VE3
11023606	8166	8197	8215	8226	8228	8236	8236	0	0	8246	8249	8300
6043606	2576	2587	2592	2594.5	2595.5	2598	2598	0	0	2600	2601	2618
6053606	2606.5	2615	2622.5	2625	2626	2628	2628	0	0	2630	2630.5	2647
3073606	2620	2630	2635	2736.5	2637.5	2640	2640	0	0	2643	2644.5	2660
6083606	2580	2591	2594	2596	2597	2598	2598	0	0	2601	2603	2619
6093606	2546	2555	2560	2561	2562	2565	2565	0	0	2567.5	2569	2585
14113606	2467.5	2475	2483	0	0	0	0	0	0	2490	2491	2510
10123606	7900	7930	7954	7965	7965	7972	7972	0	0	7976	7982	8042
15133606	2394	2403	2410	2414	2414	2415	2416	0	0	2417	2418.5	2435.5
6143606	2460	2470	2477	0	0	0	0	0	0	2484	2486	2502
2163606	2509	2519	0	2528.5	2528.5	2530.5	2531	0	0	2532.5	2535	0
8173606	2510	2519	2525	0	0	0	0	0	0	2532.5	2533.5	2549
13193606	2536	2545.5	2552	2554	2554	2558	2558	0	0	2559	2562	0
6233606	2437.5	2447	2452	2456	2456	2457.5	2457.5	0	0	2458	2461	2477
6243606	2406	2415	2421	2424.5	2424.5	2427	2427	0	0	2429	2431	2449
10263606	7996	8026	8043	8054	8054	8064	8064	0	0	8072	8078	8132
13293606	2515.5	2524	2530	2534	2534	2536	2536.5	0	0	2539.5	2540.5	2555
11303606	8344	8375	8394	8408	8408	8419	8419	0	0	8424	8428	8478
6323606	2523.5	2532	2538	2543	2543.5	2545.5	2545.5	0	0	2546	2547	2563
10363606	2385	2395	2400	2405	2405	2407	2407	2408	2409	2411	2412	2430
9023607	2663	2673	2676.5	2679	2679.5	2680.5	2681	0	0	2683	0	2705
4083607	2760	2769	2773	2775	2776	2778.5	2778.5	0	0	2779.5	2798	2801
11133607	8480	8508	8525	2538	2538	8549	8549	0	0	8553	0	8610
6213607	2706	2715	2720	2721	2722	2725	2726	0	0	2727.5	0	2746
11223607	2662	2670	2676	2681	2681	2682.5	2683	0	0	2685	2702	0
12283607	8882	8906	8924	8934	8934	8939.5	8940	0	0	8944	0	9016
6353607	8520	8547	8567	8580	8580	8590	8590	0	0	8598	8655	8660