The Allostratigraphy and Sedimentology of Lowstand and Transgressive Incised Shorefaces and Their Relationship to Incised Valleys in the Lower Cretaceous (Albian) Viking Formation, Alberta, Canada

Cape St. Mary's Pays for All.........

The Allostratigraphy and Sedimentology of Lowstand and Transgressive Incised Shorefaces and Their Relationship to Incised Valleys in the Lower Cretaceous (Albian) Viking Formation, Alberta, Canada

By

Terrence Robert Wiseman, B.Sc. (Hons.)

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AUTHOR: Terrence Robert Wiseman, B.Sc. (Hons.) (Memorial University of Newfoundland)

SUPERVISOR: Dr. R.G. Walker

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ABSTRACT

The (Upper Albian) Viking Formation can be divided into highstand, lowstand, and transgressive systems tracts through the recognition of regionally extensive bounding discontinuities. Two complete stratigraphic sequences have been recognised, including lowstand incised valleys and associated lowstand shorefaces, and transgressive valley fill and related transgressive shorefaces.

The oldest systems tract comprises a series of regional coarsening upward cycles. These consist of shelf-to-lower shoreface successions that form southeastward thinning progradational highstand systems tract. These successions merge with and possibly downlap onto the top of the underlying Joli Fou shale.

Two approximately 30m deep incised valleys at Crystal field are interpreted to have formed in response to fluvial downcutting across an exposed shelf during two separate falls of relative sea level, each being at least 30m in magnitude. Backfilling of the valleys by brackish-to-marine sediments indicate that each relative 30m fall was succeeded by a rise of 30m or more. Several long, narrow, en-echelon, sand bodies encased in

marine shales occur in the vicinity of the Crystal field and up to 100 kilometers to the northeast. The isolated, linear sandbodies rest within elongate, northwest-southeast trending asymmetric scours. The steep side of each scour faces northeast. Close to the steeper side of the scour, the sandbodies rest sharply on an erosion surface and comprise a coarsening upward succession of bioturbated, muddy sandstone to cross bedded sandstone. Four to five kilometers northeast of the steep edge of the scour the facies succession is more gradational; it begins with bioturbated silty shale, and then coarsens upward into cross bedded sandstone. The nature of the successions along with the morphology of the asymmetrical scours suggests deposition in an incised shoreface.

The relationship between lowstand valley incisions at Crystal and the development of lowstand shorefaces has been determined from correlation of well logs and cores throughout the study area. The base of sequence 1 is characterised by a lowstand incised valley (Crystal incision #1) and the development of the Lindbrook (LBK) lowstand shoreface. A rise in relative sea level followed by stillstand moved the shoreline slightly to the west, where the Joarcam (J'CAM) sandbody was deposited as a transgressive incised shoreface succession. Renewed transgression brought the shoreline to Crystal, where sediments backfilled (fill #1) the previously incised valley from the Sunnybrook 'A' (SBK 'A') transgressive shoreface. Renewed transgression moved the shoreline to Chigwell (CHIG) where a third transgressive shoreface was incised.

The base of sequence 2 was formed during a second fall in sea level. The Crystal valley was re-incised (Crystal incision #2) and the shoreface moved 90 kilometers to the northeast and incised at Beaverhill Lake (BHL). Rise in relative sea level moved the shoreface southwestward to Crystal, where sediment again backfilled the incision (fill #2) from the Sunnybrook 'B' (SBK 'B') transgressive shoreface. Resumed transgression cut a ravinement surface across the top of the Crystal and Sunnybrook 'B' sandbodies and moved the shoreline out of the study area and to the southwest.

The incised shorefaces formed either at lowstand (LBK, BHL) or during pauses in an overall transgression (J'CAM, SBK 'A', CHIG, SBK 'B'). Lowstand shorefaces can be correlated with lowstand incised valleys, and transgressive shorefaces can be directly correlated with the transgressive systems tract deposits in the two incised valleys at Crystal. These internally consistent correlations recognise two sequences at Crystal rather than the one suggested in published illustrations.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

This study was initiated in 1991 with the intention to study several elongate, northwest-southeast trending, isolated sandbodies of the Late Albian Viking Formation in south central Alberta. In general, the Viking Formation forms an important reservoir unit in western Canada with estimates of 295.9 x $10^6 m^3$ (47.0 mbbl.) of oil and 362,869 x $10^6 m^3$ (12879.6 bcf.) of original gas in place (ERCB, 1992). In the study area, several of the Viking sandbodies form important hydrocarbon reservoirs (table 1.1), making abundant geophysical well logs and cores available for study.

Initially, the thesis work was focussed on the detailed sedimentology and stratigraphic relationships between sandbodies at Joarcam and Chigwell fields as well as two water-wet sandbodies named Sunnybrook 'A' and Sunnybrook 'B'. The project was later expanded to include the Beaverhill Lake field and another water-wet sandbody named Lindbrook. Through this research, the relative stratigraphic positions of these six sandbodies were shown to be intimately related to the development of two incised valleys at Crystal field described by Pattison (1991). A comprehensive story has

Table 1.1 Original reserves in place and production to date from the Viking Formation in the study area.

Field Name	Original Reserves in Place[1]		Production to Date[1]	
	Gas	Oil	Gas	Oil
Joarcam field	$6713 \times 10^6 m^3$	$42,646 \times 10^3 m^3$	$1522 \times 10^6 m^3$	$17,627 \times 10^3 m^3$
Beaverhill Lake Field	$8493 \times 10^6 m^3$	$150 \times 10^3 m^3$	$4869 \times 10^6 m^3$	$0.4 \times 10^3 m^3$
Crystal Field	$1343 \times 10^6 m^3$	$18,816 \times 10^3 m^3$	$304 \times 10^6 m^3$	$2770 \times 10^3 m^3$
Chigwell Field	nil	$11,170 \times 10^3 m^3$	nil	$594 \times 10^3 m^3$
Total	$16,549 \times 10^6 m^3$	$72,782 \times 10^6 m^3$	$6695 \times 10^6 m^3$	$20,991 \times 10^6 m^3$

1. ERCB, 1992

emerged which details two full stratigraphic sequences within the 'upper' Viking sediments, each comprising lowstand incised valleys and associated lowstand incised shorefaces, and transgressive valley fill and related transgressive shorefaces.

This thesis represents a continuation of the extensive research conducted at McMaster University on different fields of the Viking Formation in Alberta. There have been many individual studies on this formation in this region, several of them in the recent literature; this study attempts to tie together the relationship between lowstand incised shorefaces and incised valleys, and between transgressive incised shorefaces and valley fills.

1.2 Location of Study

The study area (figure 1.1) encloses a 16,000 km^2 area from townships 40 to 51 and ranges 16 W4 to 4W5. The study overlaps several past and ongoing studies undertaken on the Viking Formation at McMaster University (Power, 1988 at Joarcam; Raychaudhuri,1989 at Chigwell; Pattison, 1991 at Crystal; and Bartlett, 1994 at Beaverhill Lake).

1.3 Data Base and Method

The data base included 144 drill cores (Appendix 1), the locations of which are illustrated by the solid circles in figure 1.2. All cores are of public

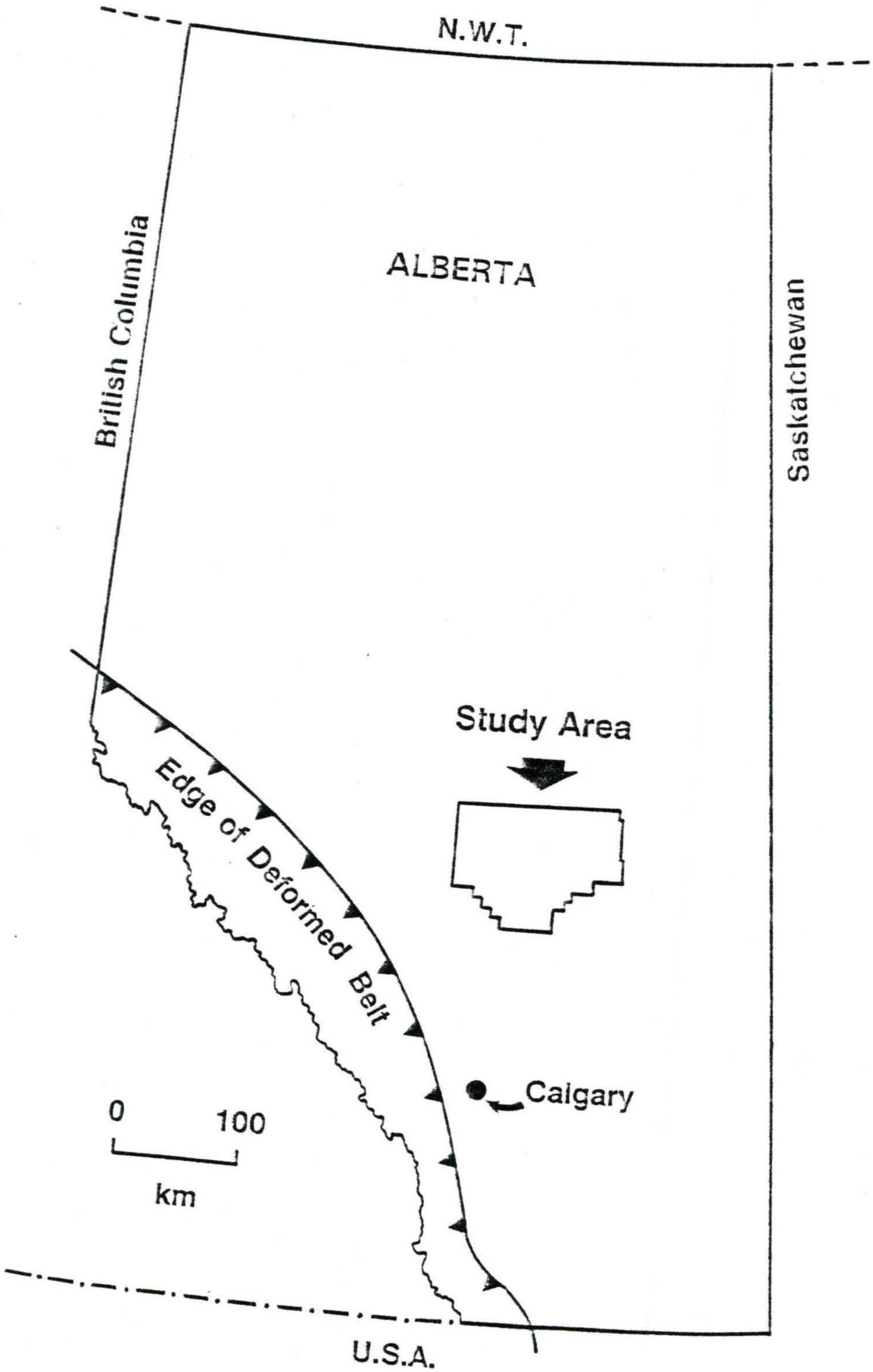
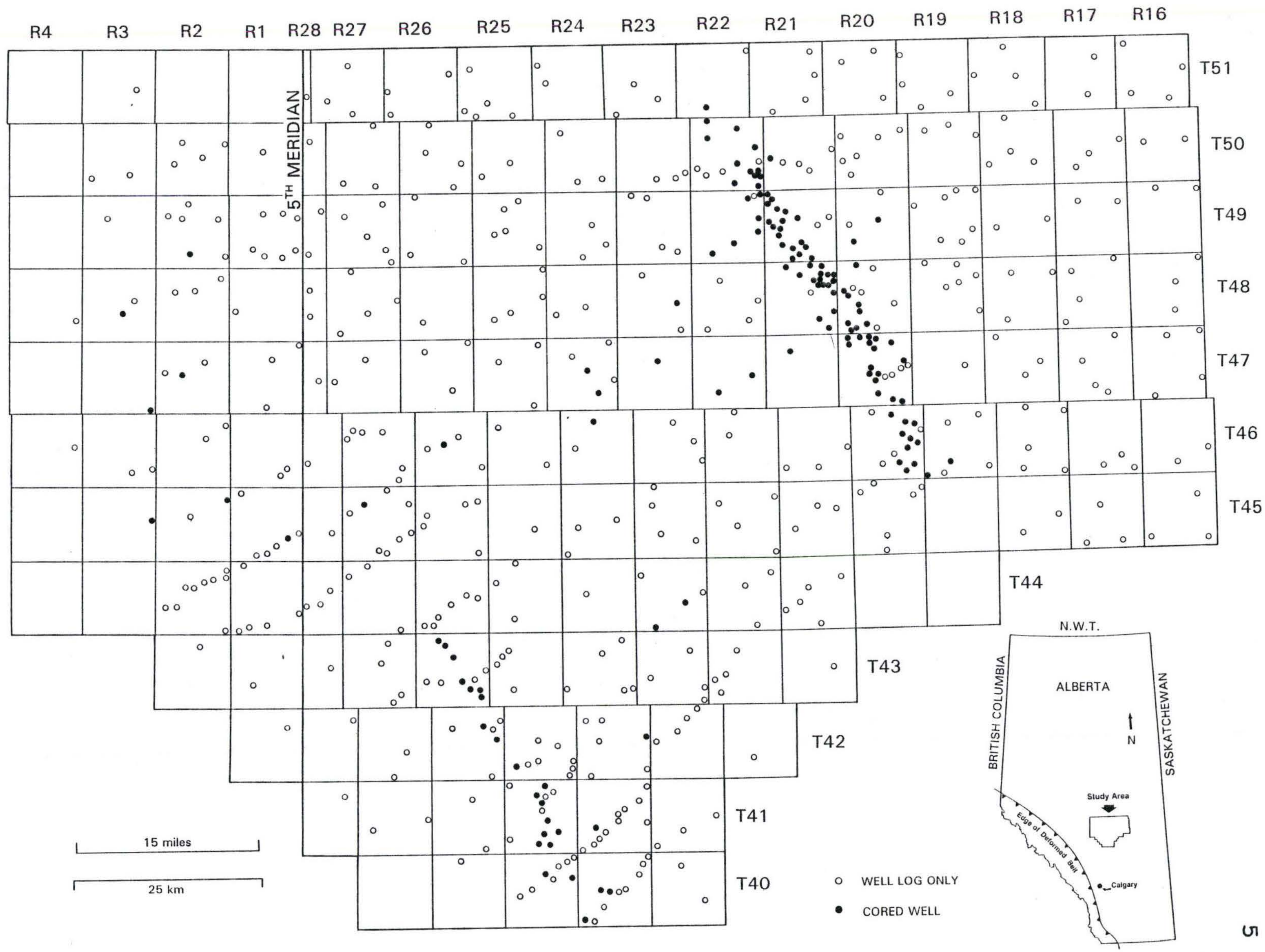


Figure 1.1 Location of the study area in Alberta.

Figure 1.2 Location of core and well logs utilised in the study. The area has been gridded to illustrate townships and ranges, each grid is approximately 6 mi. x 6 mi. (~10 km x 10 km), the total area represented is over 16,000 km^2. Inset map shows the location of the study area in Alberta.



R4 R3 R2 R1 R28 R27 R26 R25 R24 R23 R22 R21 R20 R19 R18 R17 R16
5TH MERIDIAN
T51
T50
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T48
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WELL LOG ONLY
CORED WELL
N.W.T.
ALBERTA
BRITISH COLUMBIA
SASKATCHEWAN
N
Study Area
Edge of Deformed Belt
Calgary

domain and were examined at the Energy Resources Conservation Board in Calgary in the Summer of 1991 and 1992. The cores were studied in detail to determine grain sizes, grain size trends, physical and biogenic structures, facies and facies contacts. Close up photographs of each individual facies and facies contacts were taken from numerous core throughout the study area. The numerous individual facies recorded at the core lab were assembled into several representative facies associations which represent generally predictable facies successions. Photographs of entire core boxes from various well locations were also taken to illustrate changes within and between the facies associations.

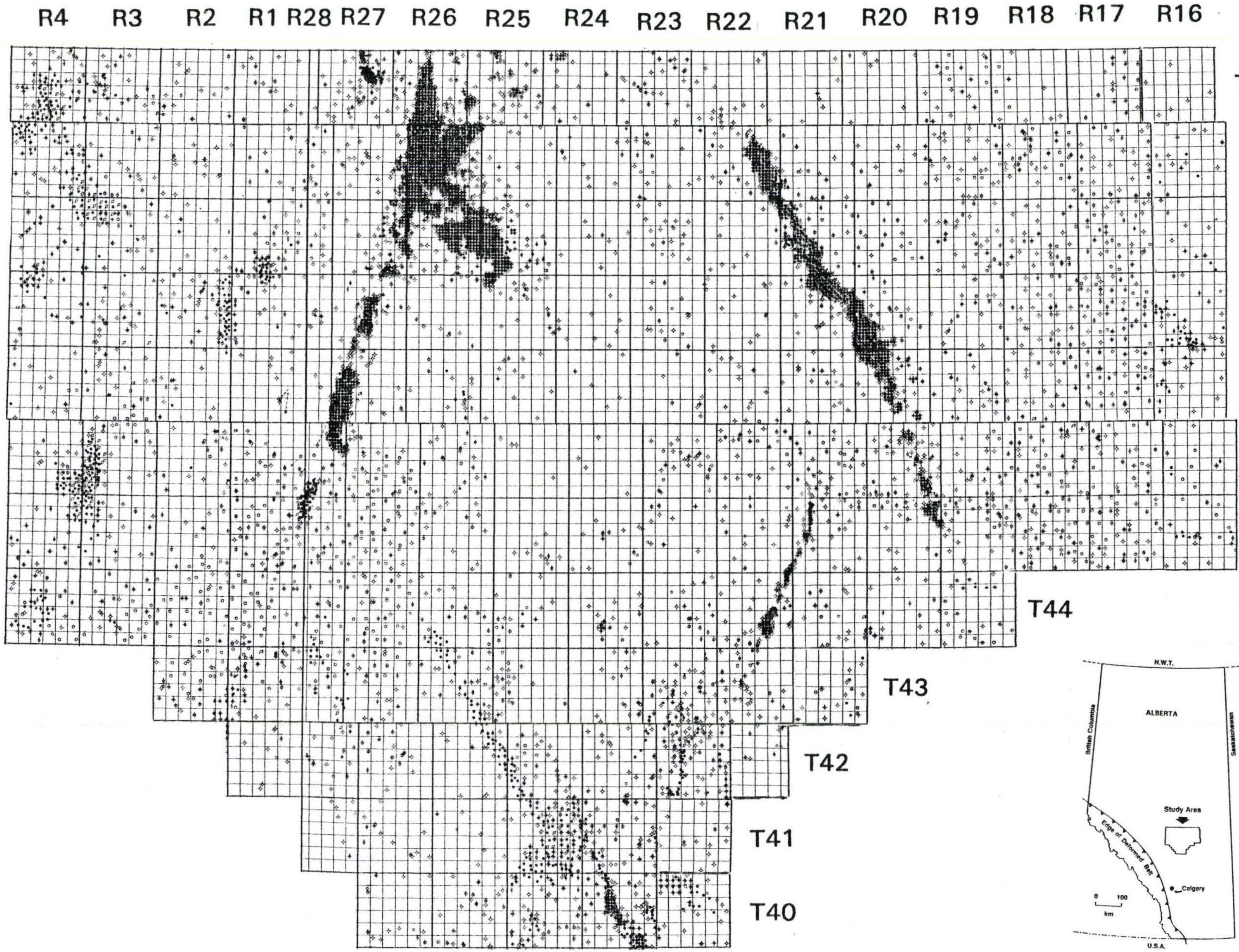
Over 600 spontaneous potential, gamma ray and resistivity well logs were used to match log signatures with sedimentary facies associations observed in cores or for the construction of cross sections and total isopach maps. The locations of wells whose logs were used for this study are shown by the open and closed circles in figure 1.2. The best log for correlation of all aspects of the Viking Formation is the gamma ray log, however, this was not available in all wells. The spontaneous potential log provides a less than ideal substitute for the gamma ray log because it cannot always satisfactorily differentiate 'lower' and 'upper' Viking sediments from one another. Overall, the resistivity curve provides the best tool for correlation as it is present in every well and has a sufficiently high resolution, therefore providing a consistent correlatable log character for the Viking Formation throughout the study area. These geophysical well logs represent approximately 10% of the over 6000 well logs available for study in the area (figure 1.3).

1.4 Scientific Problem

Recent studies of the Viking Formation (table 1.2) have concentrated on several prolific oil and gas reservoirs formed within long (tens of kilometers), narrow (few kilometers) and relatively thin (tens of meters) sand and conglomerate bodies. These forms are enclosed in marine mudstones and oriented in an en-echelon manner, northwest - southeast, sub-parallel or parallel to the inferred orientation of paleoshorelines. These studies have shown the importance of identifying and correlating bounding discontinuities within and between individual fields. Many of the sandbodies have been interpreted as shorefaces incised during short stillstand events superimposed on an overall rise of relative sea level.

The discovery of several Viking reservoirs which differ in overall thickness, orientation, and internal complexity from the incised shoreface sand and conglomerate bodies resulted in their close scrutiny by several workers (Reinson et al, 1988; Boreen,1989; Pattison ,1991; Pattison and Walker, 1994). These fields are generally 30m or more in thickness,

Figure 1.3 Base map illustrating the wells which penetrate the Viking Formation in the study area. Approximately 6000 penetrations occur from which either well logs, core or both were available for study.


R4
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N.W.T.
ALBERTA
British Columbia
Saskatchewan
Study Area
Edge of Deformed Belt
Calgary
0 100
km
U.S.A.

Table 1.2 Chronological listing of select studies on the Viking Formation in the region of this study.

Reference	Field	Interpretation
Beaumont, 1984	Joffre-Joarcam	Offshore Sand Ridges
Downing & Walker, 1988	Joffre	Transgressive Incised Shoreface
Power, 1988	Joarcam	Regressive Shoreface
Raddysh, 1988	Gilby 'A'	Transgressive Incised Shoreface
Reinson et al., 1988	Crystal	Incised Valley Fill
Posamentier & Chamberlain, 1989	Joarcam	Lowstand Incised Shoreface
Raychaudhuri, 1989	Chigwell	Lowstand Incised Shoreface
Boreen & Walker, 1991	Willesden Green	Incised Valley Fill
Pemberton et al, 1992	Crystal	Incised Valley Fill
Raychaudhuri et al, 1992	Chigwell	Transgressive Incised Shoreface
Pattison & Walker, 1994	Regional Study	Incised Valleys & Shorefaces
Leckie & Reinson, 1994	Regional Study	Incised Valleys & Shorefaces
Walker and Wiseman, in press	Joarcam-Beaverhill Lake	Incised Shorefaces

commonly trend northeast-southwest, and comprise sharp based marine to brackish water successions. These have been interpreted as incised valleys and their complex internal stratigraphy is a result of tripartite facies zonation or multiple cut and fill events.

The most recent work in the Viking Formation on both incised shorefaces and incised valley fills has suggested the importance of relative sea level fluctuations in exerting primary control on the development of these producing reservoirs. The incised valleys in the Viking Formation, and equivalent units in the United States, has been interpreted by several authors (Weimer, 1983, 1984, 1988; Reinson et al; 1988; Boreen, 1989; Pattison and Walker, 1990, 1994; Martinson,1992; Box, 1993) to have formed in response to a major eustatically controlled lowstand of relative sea level that occurred approximately 97 my. ago. Pattison (1991) and Pattison and Walker (1994) interpreted two major lowerings of relative sea level from evidence of two distinct valley incisions at Crystal field. They suggest that during major lowstand events, incised valleys are cut by fluvial erosion and sediment bypasses the eroded valleys and is deposited at a lowstand shoreline. Deposition in the valley generally occurs during a subsequent rise in relative sea level when stratigraphically complex, tidally influenced successions backfill the valley from its marine end. Though several examples of incised valleys from the Viking Formation and its equivalents have been described in the literature, documented occurences of lowstand shorefaces associated with the development of the valleys has not been presented

. Thus, the scientific problem which was approached in this research concerns correlation of regional erosion surfaces between incised shorefaces and incised valleys, with a view to the identification of lowstand and transgressively incised shorefaces and how each type of shoreface relates, in particular, to the two Crystal incised valleys. In its essence, this study provides a further refinement of the comprehensive, and increasingly basinwide Viking Formation allostratigraphy initially put forth by Boreen (1989) and amended by Pattison (1991), Hadley (1992), Pattison and Walker (1994) and Walker and Wiseman (in prep.).

CHAPTER 2: STRATIGRAPHY

2.1 Structural Setting

The Viking Formation in south central Alberta occurs approximately 800 to 1550 m below the surface and has a regional dip to the southwest of about 0.3°. The study area occurs within the tectonically undeformed portion of the western Canadian sedimentary basin, approximately 80 kilometers east of the Cordilleran fold and thrust belt. No evidence of any structural disturbance was found. The major structural elements of the Alberta foreland basin include the Peace River Arch, the Sweetgrass Arch, and the eastern edge of the deformed belt (figure 2.1).

2.2 General Stratigraphy

The Upper Albian Viking Formation of central Alberta and Saskatchewan is part of the Upper Cretaceous Colorado Group (figure 2.2). The formation comprises an extensive tongue of dominantly westerly derived marine shale, sandstone and conglomerate encased between two marine shales, the underlying Joli Fou and the overlying Westgate Formation (Bloch et al., 1993). The Joli Fou and Viking Formations together record an extensive transgressive - regressive cycle of sedimentation in the Western

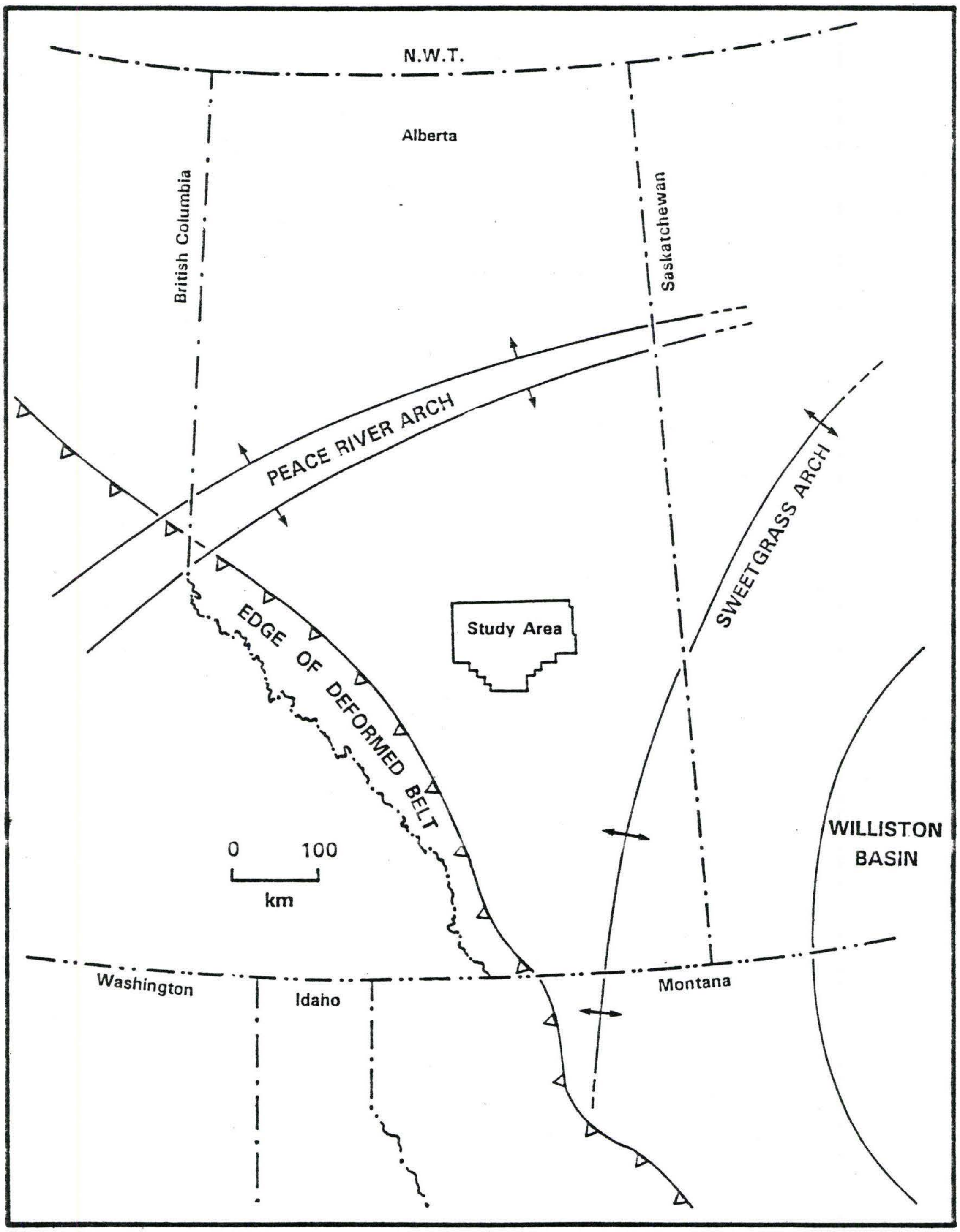
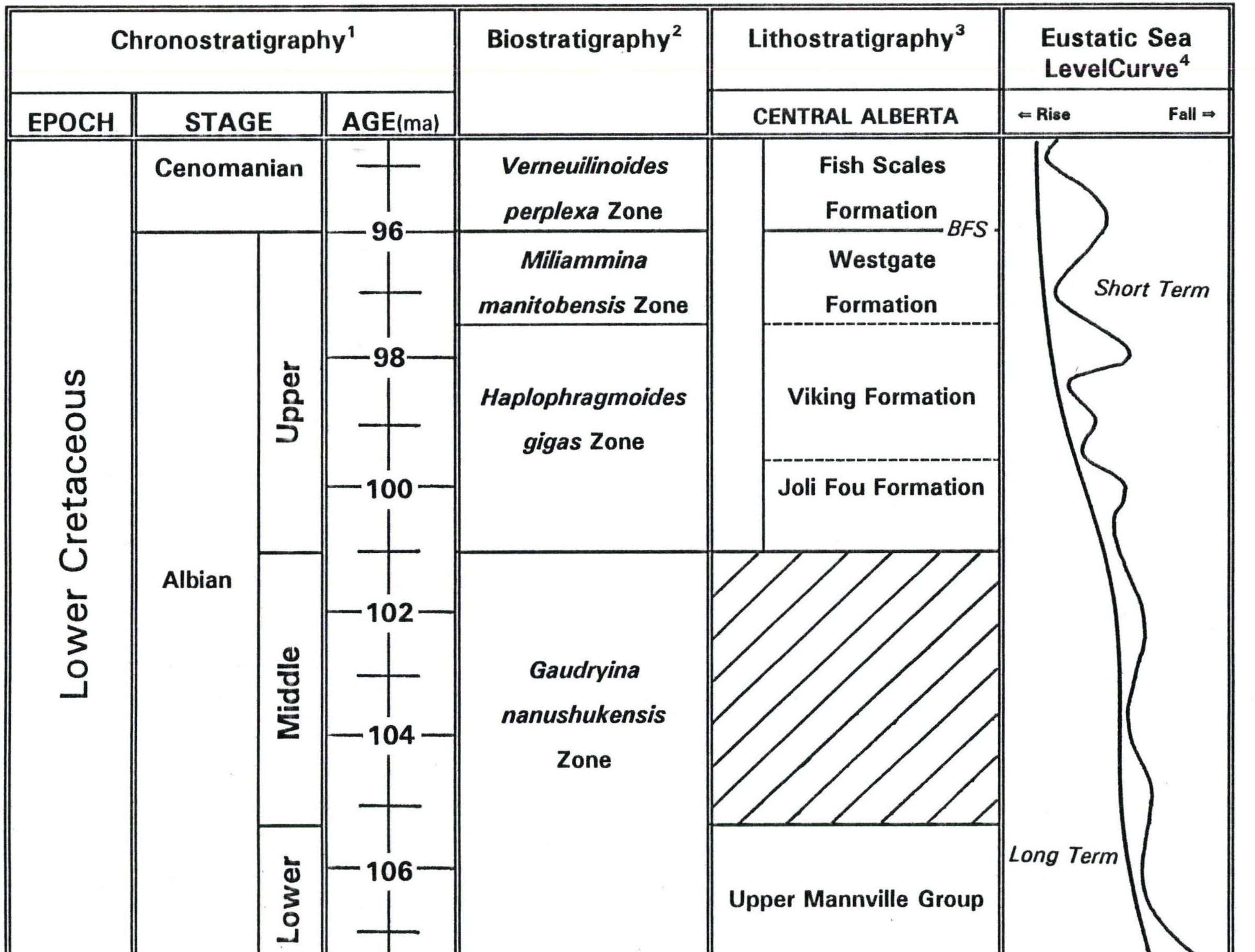


Figure 2.1 Major Precambrian structural elements in western Canada and the northwestern United States.

Figure 2.2 Bio-, litho- and chronostratigraphy of the Albian Stage in south central Alberta with eustatic sea level curve (modified from Pattison, 1991)



1. Bloch et al., 1993; 2. Koke and Stelck, 1985; 3. ERCB, 1988; 3. Haq et al., 1987, 1988

Interior basin that has been termed the Kiowa-Skull Creek marine Cycle (Caldwell, 1984). The shales of the Westgate Formation record a subsequent widespread transgression of the Greenhorn Marine Cycle (Caldwell, 1984). As a result of the widespread transgressive - regressive - transgressive event, the Joli Fou Formation, the Viking Formation and the Westgate Formation and their equivalents are recognised throughout the interior plains of North America.

2.2.1 The Joli Fou Formation

The name Joli Fou was coined by Wickenden (1949) for a black shale in northeastern Alberta, the unit was raised to formation status by Stelck (1958).

In Western Canada, the Joli Fou equivalents include the Lower Hasler Shale of northeastern British Columbia (Stelck and Koke, 1987), part of the Peace River Formation in northwestern Alberta, a portion of the Bow Island Formation in southern Alberta, and part of the Ashville Formation in Manitoba (figure 2.3). In the United States, the Joli Fou equivalents include the shales of the Skull Creek Member in Colorado and North and South Dakota (McGookey et al, 1972; Weimer, 1984) and the Thermopolis Member of Wyoming and Montana (Caldwell, 1984) (Figure 2.4).

The Joli Fou Formation is 18-36m thick in central Alberta (Leckie and

Figure 2.3 Stratigraphic equivalents of the Albian in western Canada.

Stage		Lithostratigraphic Equivalents of the Albian in Western Canada					
		Central Alberta[1]	South Alberta[2]	NW Alberta[3]	British Columbia[3]	Saskatchewan[2]	Manitoba[4]
Cenomanian		Base Fish Scale Marker Zone					Ashville Formation
Albian	Upper	Lower Colorado Shale		Lower Shaftsbury	Upper Hasler Shale	Lower Colorado Shale	Ashville Formation
Albian	Upper	Viking Formation	Bow Island Formation	Paddy Member	"Viking" Marker Bed	Viking Formation	Silt Member (Ashville Formation)
Albian	Upper	Joli Fou Formation	Basal Colorado Sandstone		Lower Hasler Shale	Joli Fou Formation	Ashville Formation
Albian	Middle			Cadotte Member	Basal Hasler Shale		Ashville Formation
Albian	Middle			Cadotte Member	Cadotte Member		Ashville Formation
Albian	Middle			Harmon Shale	Hulcross Fm.		Ashville Formation
Albian	Lower	Upper Mannville Group	Upper Mannville Group	Spirit River Formation	Gates Formation	Upper Mannville Group	Swan River Formation
Albian	Lower	Upper Mannville Group	Upper Mannville Group	Spirit River Formation	Moosebar Fm.	Upper Mannville Group	Swan River Formation

1. Pattison, 1991; 2. Vuke, 1984; 3. Stelck and Koke, 1987; 4. Robb, 1985

Figure 2.4 Stratigraphic equivalents of the Albian in the western United States.

Stage		Lithostratigraphic Equivalents of the Albian in the United States				
		Central Alberta[1]	Wyoming[2]	Montana[2]	N & S Dakota[2]	Colorado[3]
Cenomanian		Base Fish Scales	Mowry Shale			Graneros Formation
Albian	Upper	Lower Colorado Shale				
		Viking Formation	Muddy Sandstone	Newcastle Sandstone		'J' Sandstone
		Joli Fou Formation	Thermopolis Shale		Skull Creek Shale	
			Greybull Sandstone	Rusty Beds	Fall River Sandstone	Planview Sandstone
	Middle					
	Lower	Upper Mannville Group	Upper Cloverly Group	Kootenai Formation	Lakota Formation	Lytle Formation

1. Pattison, 1991; 2. Vuke, 1984; 3. Weimer, 1984

Reinson, in press). The formation thins towards the west until the overlying Viking Formation sediments merge with that of the Mannville Group (Amajor and Lerbekmo, 1980). To the south the Joli Fou grades into the Bow Island Formation (Gammell, 1958).

2.2.2 The Viking Formation

The name 'Viking' was first used by Slipper (1918) in a study of the Viking - Kinsella gas field in east central Alberta. Initially designated as a member of the lower Colorado Group (Hunt, 1954; Reasoner and Hunt, 1954) it was assigned formation status by Stelck (1958).

In western Canada, the Viking equivalents include the Paddy Member of the Peace River Formation in northwestern Alberta (Stelck and Koke, 1987; Leckie and Reinson, in press), a "Viking" marker bed within the Hasler Shale in British Columbia (Stelck and Koke, 1987), part of the Bow Island Formation of Southern Alberta (Glaister, 1959), and the Silt Member of the Ashville Formation in Manitoba (Rudkin, 1964) (figure 2.3). In the United States, Viking equivalents include the Muddy Sandstone or Newcastle Formation of Montana, Wyoming and the Dakotas (Beaumont, 1984; Vuke, 1984) and the 'J' Sandstone of Colorado (McGookey et al, 1972) (figure 2.4).

The Viking ranges in thickness from 15-30m thick in most of central

Alberta (Reinson et al, 1988). The formation thickens to the west and southwest where it merges with the thick undifferentiated Bow Island Formation while to the east and northeast the Viking becomes progressively thinner and finer grained gradually comprising little more than a silty shale northeast of Edmonton (Rudkin, 1964; Beaumont, 1984; Reinson and Foscolos, 1986; Reinson et al, 1988).

The nature of the base of the Viking Formation and its equivalents appears to be somewhat controversial. The contact is generally considered gradational by workers in Alberta (Amajor, 1980) but it has been reported as suprisingly sharp in both outcrop and subsurface in Saskatchewan and in equivalents of the United States. Table 2.1 summarises the interpretations of various authors regarding the nature of this contact. In this study, the Viking Formation is assumed to have a sharp but conformable lower contact with the Joli Fou Formation. The upper contact of the Viking Formation is sharp and unconformable with the Westgate Formation and other equivalent formations (Robb, 1985).

2.2.3 Westgate Formation

Several informal names have been used for this formation in central Alberta these include the Lloydminister Shale (Tizzard and Lerbekmo, 1975; Amajor and Lerbekmo, 1980), Colorado Formation (Boethling, 1977b;

Table 2.1 Nature of Contact Between Transgressive and Regressive Phases of the Kiowa - Skull Creek Marine Cycle (Caldwell, 1984) as interpreted by various authors.

Reference	Joli Fou or Equivalent	Viking Formation or Equivalent	Nature of Contact
Beaumont, 1984	Joli Fou	Viking	Sharp and Erosive
Berg, 1976	Skull Creek	Muddy	Erosional Unconformity
Boreen & Walker, 1991	Joli Fou	Viking	Possible depositional Discontinuity
Evans, 1970	Joli Fou	Viking	Slight Disconformity
Hadley, 1993	Joli Fou	Viking	Correlative Conformity
Leckie & Reinson, 1994	Joli Fou	Viking	Gradational
Leckie & Smith, 1992	Joli Fou	Viking	Gradational
Pattison, 1991	Joli Fou	Viking	Gradational
Posamentier et al, 1992	Joli Fou	Viking	Erosional Unconformity?
Reinson et al, 1988	Joli Fou	Viking	Gradational?
Scott, 1970	Glencairn Shale	Dakota	Sharp and Disconformable
Stapp, 1967	Skull Creek	Newcastle	Regional Disconformity
Stone, 1972	Skull Creek	Muddy	Sharp and Erosive
Weimer, 1984	Skull Creek	'J' Sandstone	Transitional
This Study	Joli Fou	Viking	Sharp but Conformable

Beaumont, 1984) and the unnamed shale member of the Colorado Group (Evans, 1970). In addition, they have been termed the Post Viking shales (Stelck and Koke, 1987) and finally the Lower Colorado Shales (Leckie and Reinson, in press). Recently Bloch et al. (1993) have proposed a revised stratigraphic nomemclature for the entire Colorado Group, formally naming the shales conformably overlying the Viking Formation as the Westgate Formation. Equivalents of the Westgate in the United States include the Mowry Formation in Montana, Wyoming, and the Dakotas (Stelck and Koke, 1987) and the Graneros Shale of Colorado (McGookey et al, 1972; Caldwell, 1984) (Figure 2.4).

The Westgate Formation is generally 35-50 m thick in the study area with the thickest occurrence in the northeast and thickest in the west and southwest of the study area. The base of the shales is conformable with the top of the Viking Formation sandstones, the top of the shales is marked by an organic rich, radioactive shale unit called the Fish Scales Formation (Bloch et al., 1993) the base (BFS) of which marks the Albian - Cenomanian boundary (Leckie et al, 1992; Stelck and Armstrong, 1981). This zone comprises a persistent sandstone, or sandstone and siltstone bed, containing abundant phosphatic fish skeletal debris (Price, 1964; Caldwell, 1984). It is easily identified on gamma ray and resistivity logs and forms a gentle, southwest dipping marker unit throughout the Canadian Western Interior

(ERCB, 1992).

2.3 Age

2.3.1 Chronostratigraphy

Radiometric dates of the Viking Formation have been obtained by Tizzard and Lerbekmo (1975) from sanidine and biotite mineral separates obtained from bentonites in the Suffield area of southern Alberta. Using a K-Ar technique they obtained a wide scatter of ages ranging from 105 m.a. to 94 m.a. settling on the 'best' date for the Viking Formation of 100 m.a. ± 2 m.a. Workers in the United States have obtained dates from bentonites of the Mowry Shale which occur stratigraphically just above the Muddy Sandstone. By extrapolation a date for the Muddy sandstone was determined to be about 98 m.a. which is in good agreement with the Viking date (Tizzard and Lerbekmo, 1975).

2.3.2 Biostratigraphy

The general lack of foraminifera within the Viking Formation has in the past hindered resolution of a biostratigraphic age date. Calcareous foraminifera are virtually absent, perhaps representing secondary action of acidic formation fluids that have destroyed any forms which may have been originally present (Stelck and Koke, 1987). Arenaceous foraminifera, however, have been successfully used for dating in spite of the relatively low numbers that the Viking has yielded.

Stelck and Koke (1987) were able to assign the Viking Formation to the late Albian based upon arenaceous formaminifera obtained from shaly Viking equivalents (Hasler Formation) in northeastern British Columbia. Their work agreed with that of Caldwell et al (1978) who placed the Joli Fou shale and the Viking Formation within the *Haplophragmoides gigas* Zone (figure 2.2). The Viking interval is thought to contain general species continuity throughout suggesting no sudden faunal change or extreme break occurring during its deposition (Bullock, 1950; Caldwell et al, 1978; Stelck and Koke, 1987). The Westgate Formation which overlie the Viking Formation has been assigned to the *Milliammina manitobensis* Zone (Stelck, 1958; Caldwell et al, 1978; Stelck and Koke, 1987).

2.4 Allostratigraphy

An allostratigraphic unit is defined as "a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities" (NASCN, 1983). Boreen and Walker (1991) were the first to propose an informal allostratigraphy for the Viking in the Caroline to Willesden Green area (figure 2.5) which was based upon the recognition and correlation of four bounding discontinuities. The discontinuities were

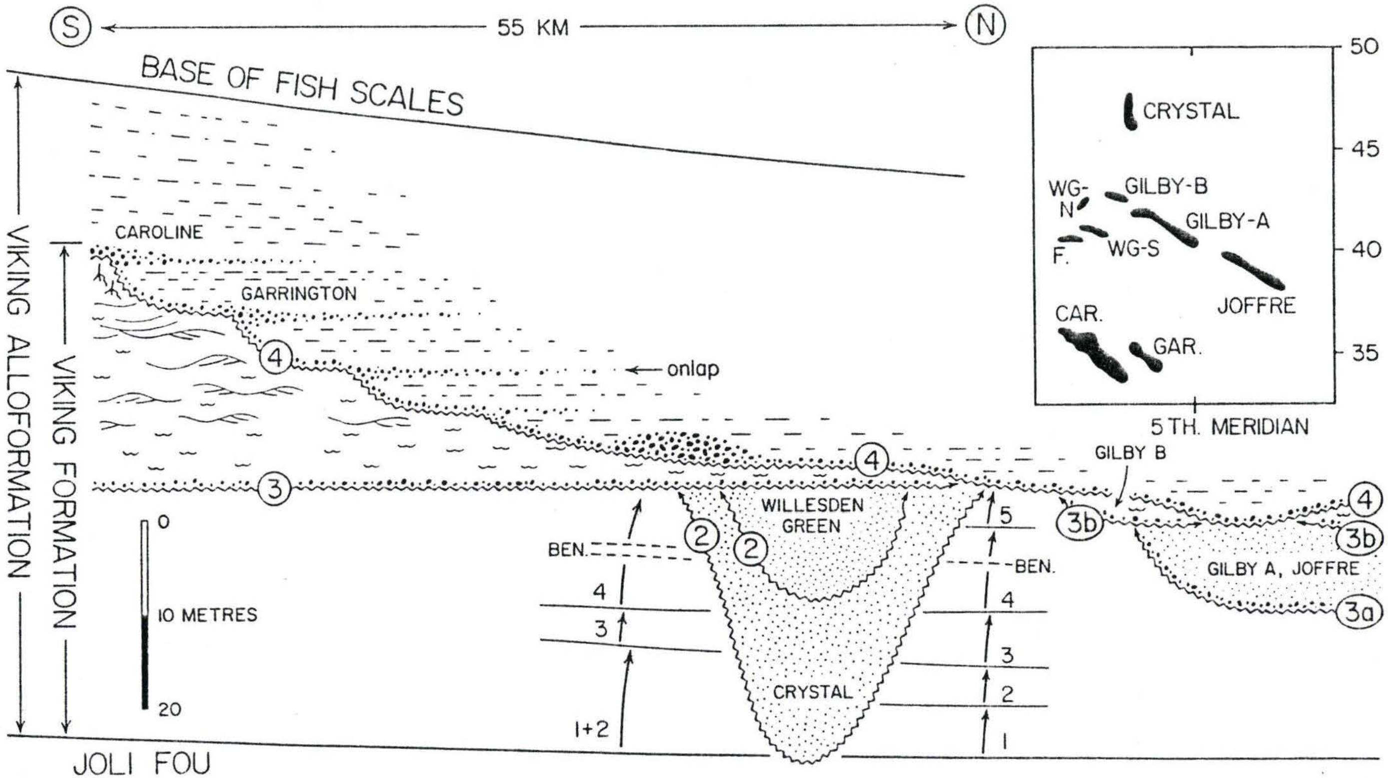


Figure 2.5 Viking allostratigraphy in the Caroline - Willesden Green area (see inset map). Bounding discontinuities (VE surfaces) are labelled 1through 4 and regional successions (1 through 5) are illustrated with arrows (from Boreen and Walker, 1991).

labelled VE (Viking erosion) and numbered consecutively upward from one through four. The VE surfaces define five allomembers, labelled A through E, each of which comprise distinctive facies associations within the Viking.

Allomember A/B is bounded by the base of the Viking Formation and above by the VE2, VE3 or VE4 erosion surface. The allomember is composed of a series of coarsening upwards facies successions which become progressively sandier upwards through the stack. Allomember A is separated from allomember B by the VE1 erosion surface which is thought to be an erosive contact in north central Alberta (A.D. Reynolds, pers. com. to R.G. Walker, 1989). This surface appears to be a correlative conformity in the Willesden Green, Crystal, Garrington, Harmattan, and Garrington areas (Boreen, 1989; Pattison, 1991; Davies, 1990; Hadley, 1992).

Allomember C is bound below by the VE2 or a VE3 erosion surface and above by a VE3 or VE4 surface. This allomember is composed of a diverse assemblage of mudstones, sandstones and conglomerates which may form coarsening or fining upward facies associations (Boreen, 1989; Pattison and Walker, 1994). The VE2 surface defines broad incised valleys in the Willesden Green, Crystal, Cyn-Pem and Sundance-Edson areas and is interpreted as a major regressive surface of erosion (RSE) (Boreen and Walker, 1991; Pattison, 1991; Leckie and Reinson, in press). The VE3 erosion surface is a transgressive surface of erosion (TSE) that in places modifies the VE2 surface to form elongate northwest-southeast trending scours that underlie many marine sandbodies that have been interpreted as incised shorefaces (i.e. Downing and Walker, 1988; Raddysh, 1988; Raychaudhuri, 1989).

Allomember D is bounded below by the VE3 erosion surface and the VE4 surface above. It is composed of mudstone, sandstone and local thin coal or coaly mudstone (Hadley, 1992) which are interpreted as a wave - dominated, progradational shoreface to non-marine succession. The VE3 erosion surface defines a fairly subdued topography which gradually rises stratigraphically to the west. This discontinuity is interpreted to have formed during transgression following the VE2 lowstand event. The VE4 surface cuts into allomember D throughout the basin. The discontinuity is interpreted as a transgressive surface of erosion whose main topographic irregularities are 'steps' or 'scarps' which punctuate an overall smooth stratigraphic rise to the west (Boreen and Walker, 1991; Davies, 1990; Hadley, 1992).

Allomember E is bounded below by the VE4 erosion surface and above by the Fish Scale Formation. This allomember contains marine black shale with interbedded sandstone, granule sandstone and conglomerate (Boreen and Walker, 1991; Davies and Walker, 1993). The entire package is interpreted as transgressive, but minor stillstands during the overall rise of relative sea level enabled short lived progradational events to form tongues of coarse sediment which onlap the VE4 surface (Davies and Walker, 1993; Hadley, 1992). The base of the Fish Scales Formation (BFS) is interpreted as a condensed horizon (MxFS) possibly formed during maximum marine transgression (Boreen and Walker, 1991; Leckie et al, 1992).

Since the original definition of allomembers for the Viking Formation, subsequent research carried out at McMaster University (Davies, 1990; Pattison, 1991; Hadley, 1992) has resulted in an expansion of Boreen and Walker's (1991) allostratigraphy (figure 2.6 and 2.7). Several amendments have been made to allow for the application of the allostratigraphic scheme to each study. However, as yet, no new allomembers have been defined and the fundamental allostratigraphy that was proposed has remained unmodified.

2.5 Recent Viking Formation Studies: Directed Reading

Excellent summaries of the early and more recent Viking Formation studies are provided in Downing (1986), Raddysh (1986), Power (1987), Boreen (1989), Davies (1990), Pattison (1991) and Hadley (1992); readers are directed to these sources.

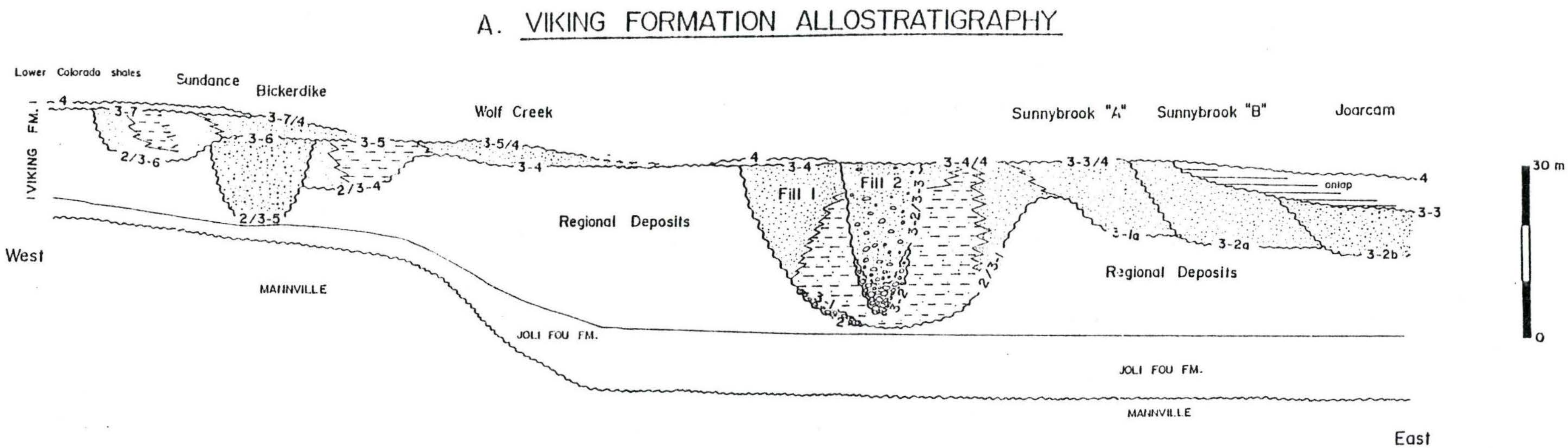
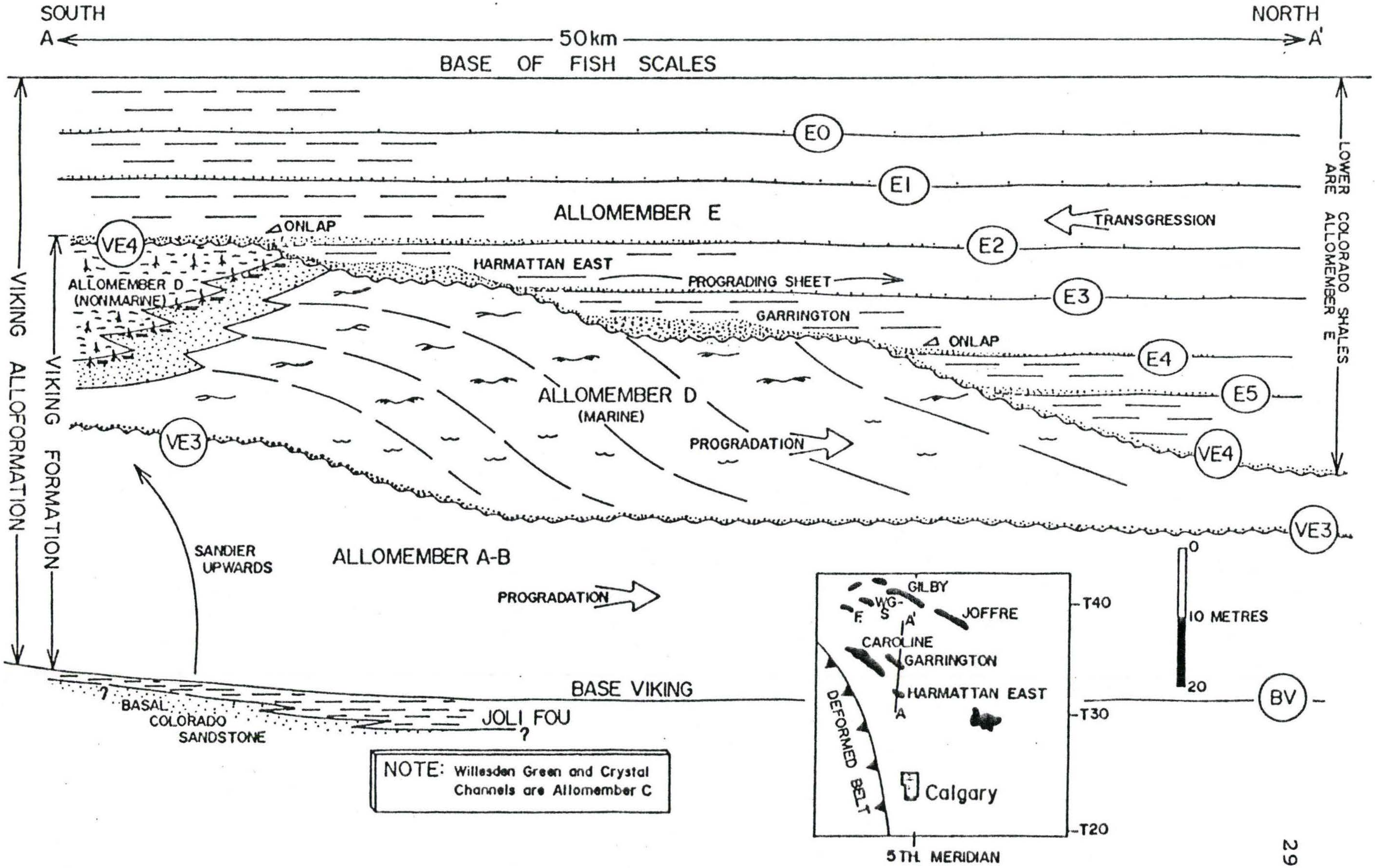


Figure 2.6 Viking allostratigraphy in the Sundance to Joarcam area. Notation is similar to figure 2.5 (from Pattison, 1991).

Figure 2.7 Viking allostratigraphy in the Gilby to Harmattan east area (see inset map). Onlapping markers are labelled E0 through E5, all other notation similar to figure 2.5 (from Hadley, 1993).


SOUTH
A
50 km
NORTH
A'
BASE OF FISH SCALES
E0
E1
ALLOMEMBER E
TRANSGRESSION
LOWER COLORADO SHALES ARE ALLOMEMBER E
VE4
ONLAP
E2
HARMATTAN EAST
PROGRADING SHEET
ALLOMEMBER D (NONMARINE)
E3
GARRINGTON
ONLAP
E4
E5
ALLOMEMBER D (MARINE)
VIKING ALLOFORMATION
VIKING FORMATION
VE3
PROGRADATION
VE4
VE3
SANDIER UPWARDS
ALLOMEMBER A-B
PROGRADATION
0
10 METRES
20
GILBY
WG
F
S
A'
JOFFRE
CAROLINE
GARRINGTON
HARMATTAN EAST
A
DEFORMED BELT
Calgary
T40
T30
T20
5TH. MERIDIAN
BASE VIKING
BV
BASAL COLORADO SANDSTONE
JOLI FOU
?
NOTE: Willesden Green and Crystal Channels are Allomember C

CHAPTER 3: FACIES ASSOCIATIONS, BOUNDING DISCONTINUITIES AND INTERPRETATIONS

3.1 Introduction

Seven facies associations have been identified within the Viking alloformation. Individual facies which were originally identified in examination of core, comprise the 'building blocks' within the associations. Since many of the facies tended to occur in a generally predictable vertical succession they have been incorporated into one or another of the facies associations to make a more succinct analysis of depositional environments within each succession and between individual successions. Each facies association is defined above and below by a bounding discontinuity across which there is generally a significant change in style and type of sedimentation. Thus, individual sedimentary facies within any facies association represent deposits of genetically related depositional environments. Genetically related in this sense means that no significant breaks have occurred during sedimentation and that all facies are vertically transitional into one another.

These associations may form coarsening or fining upward successions or non-sequential packages of sediment. One facies association is identified within the regional deposits, two are included in the incised shoreface deposits, and four are categorised as being 'transgressive'.

A legend of all symbols used in facies association type-wells and core sections throughout the thesis is provided in figure 3.1.

3.2 Facies Association 1: Regionally Extensive, Coarsening Upward, Shale to Shaly Sandstone Succession

Facies association 1 (FA 1) is composed of moderately to thoroughly bioturbated mudstones, muddy siltstones and muddy sandstones that form a series of stacked coarsening upward successions. The type well for this facies association is located at 6-20-47-2W5; figure 3.2 illustrates the log and schematic core character of the successions in the type well. A photomontage of the core from this well is illustrated in figure 3.3 Descriptions of the facies that make up this association have been made by numerous authors, these are summarised in table 3.1. Within the study area, there are 5 stacked coarsening upward facies successions that have been recognised in cores and logs. The type well for this facies association has 2 coarsening upward successions.

The stacked successions comprise black mudstone at the base, muddy siltstone in the middle, followed by muddy sandstone at the top. The volume of silt and sand may vary from zero to 5% at the base, to more than 95% at the top of any succession. The sand size can vary between *very fine- at the base to fine-grained at the top, with any one succession*

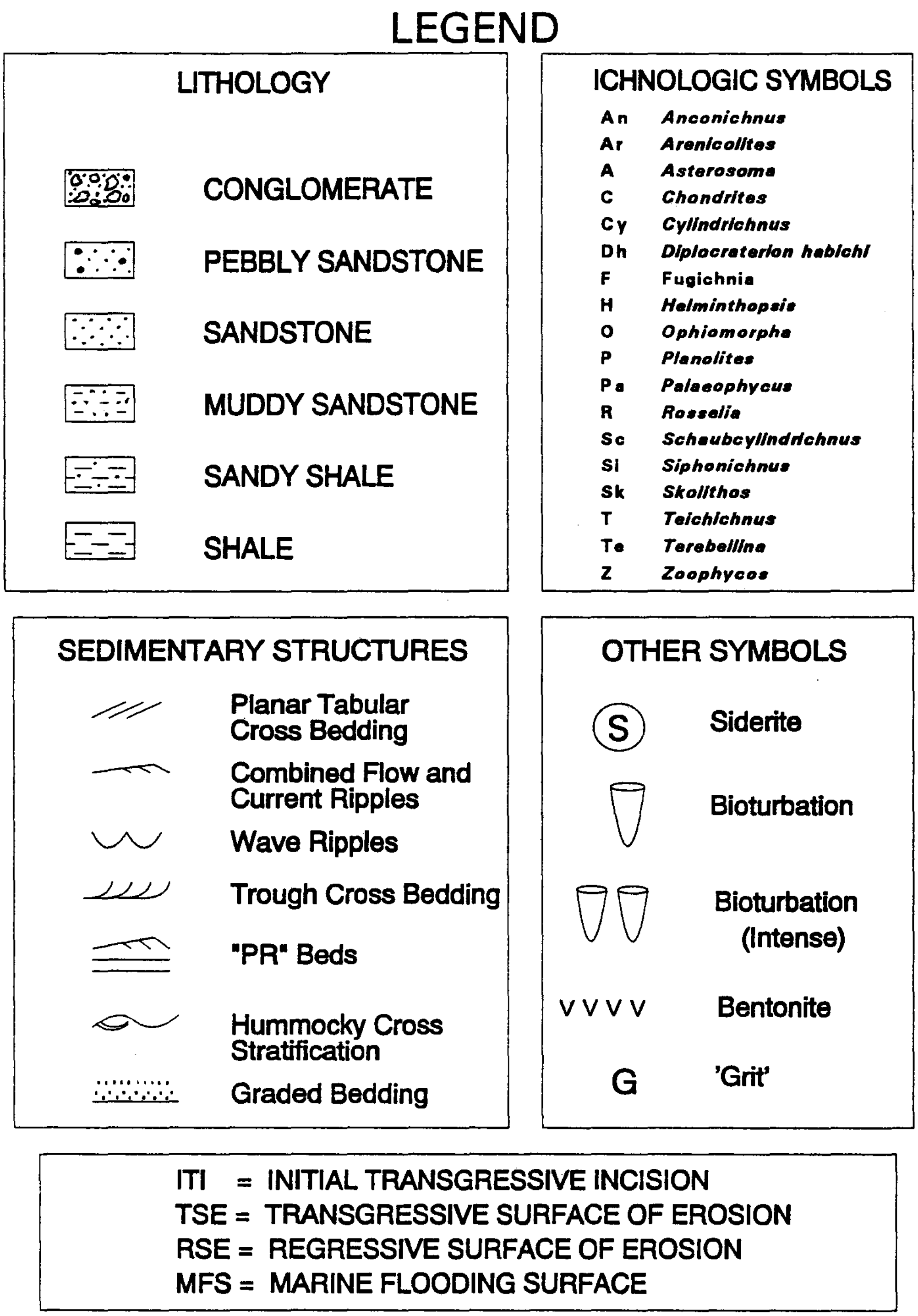


Figure 3.1 Legend of symbols and text used in the thesis.

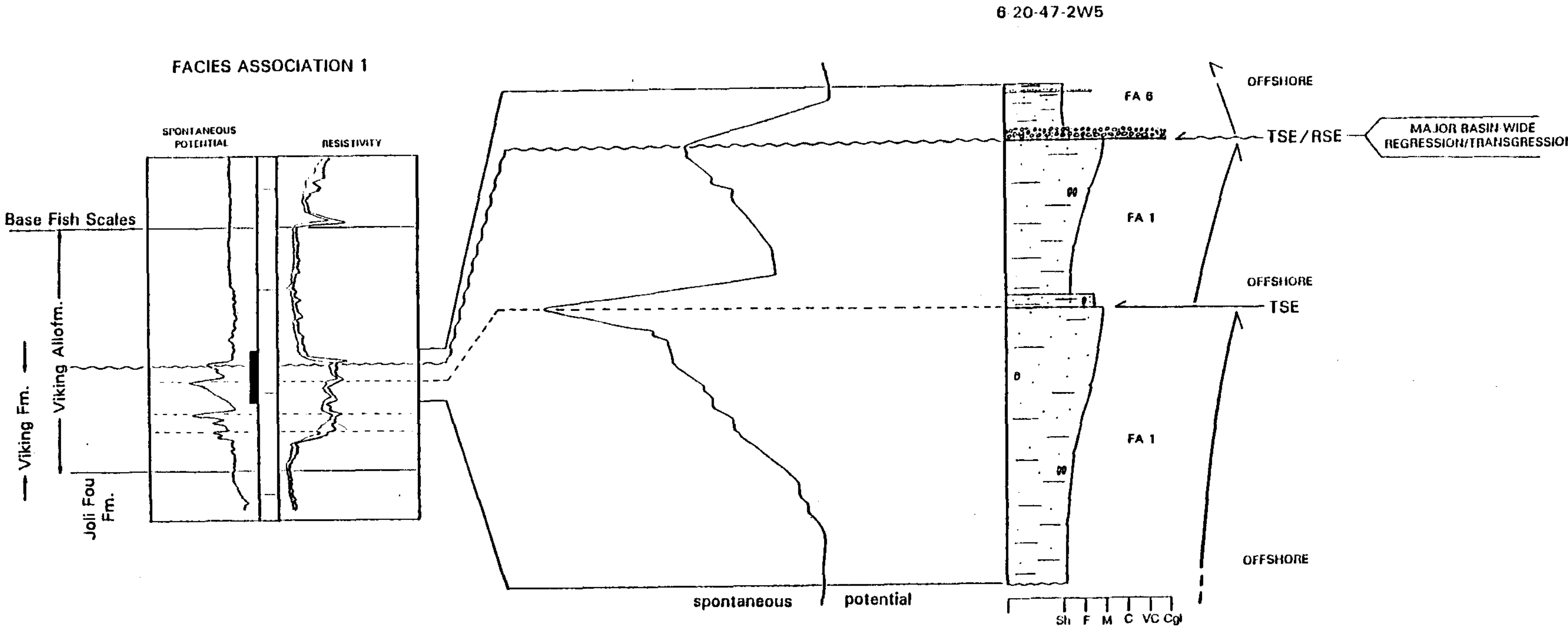
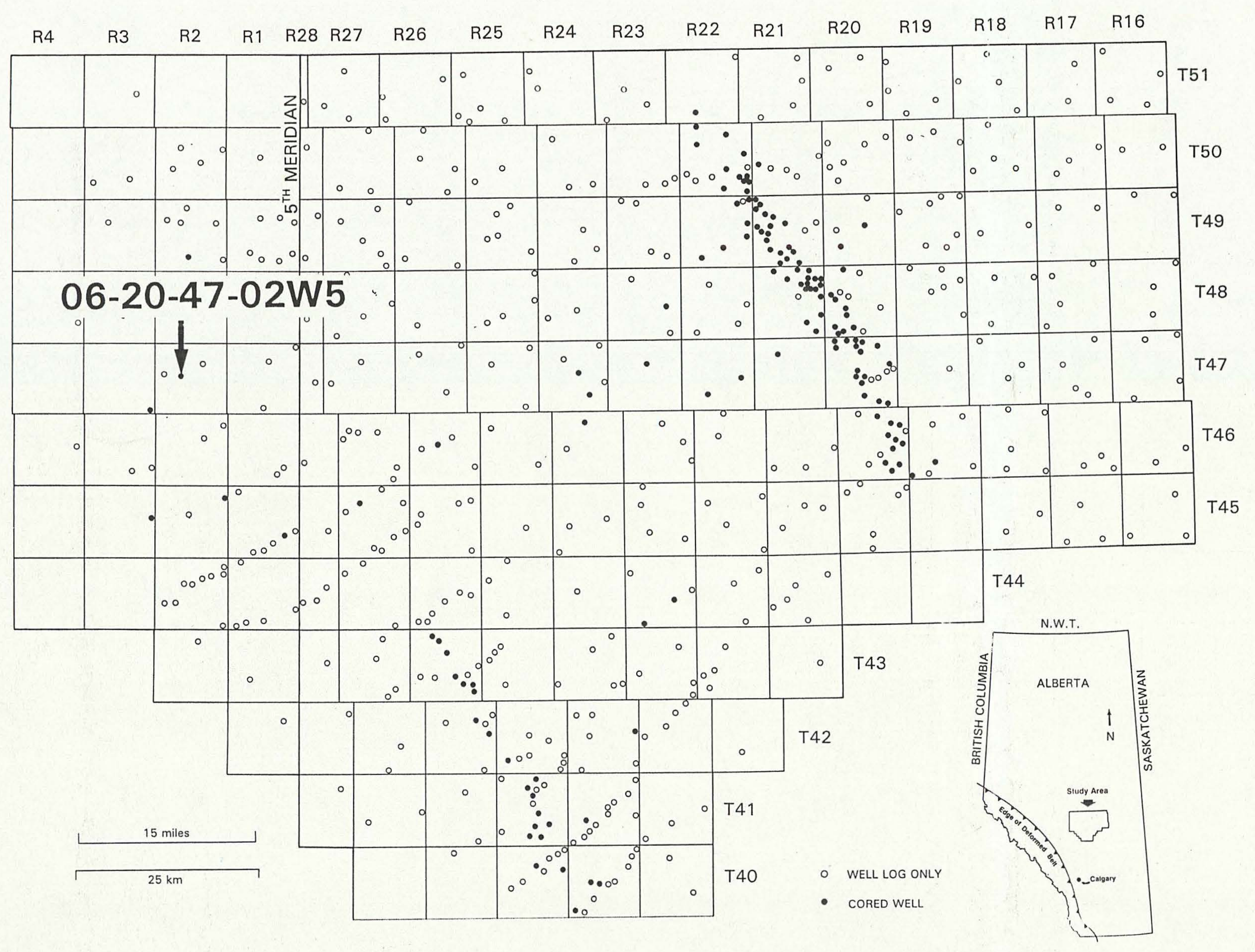


Figure 3.2 Type well for facies association 1 from 06-20-47-02W5 (1559 -1542m) which illustrates two coarsening upward facies successions. The corresponding spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

Figure 3.3 Core photographs of the type core for facies association 1 with bounding discontinuities indicated. Location of the core is provided on the map.



06-20-47-02W5

(3" Slabbed Core)

TYPE CORE: FACIES ASSOCIATION 1

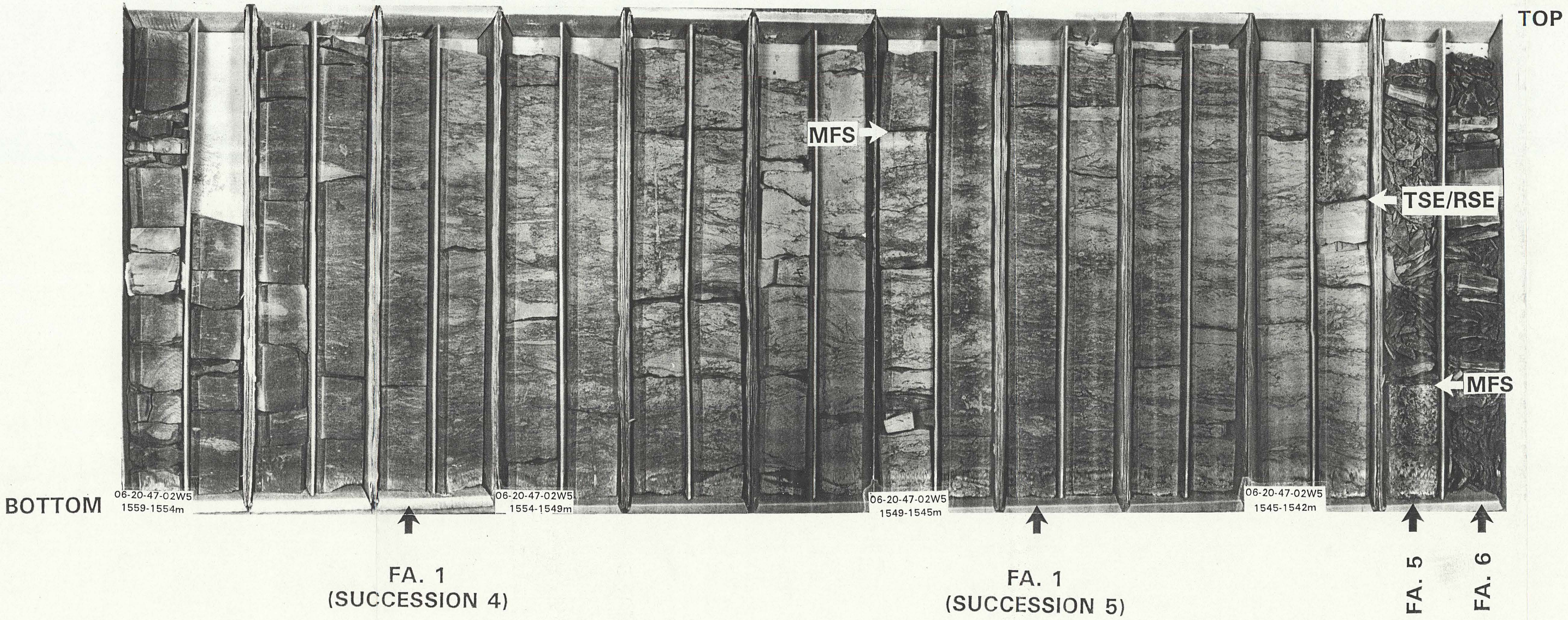


Table 3.1 Facies equivalents of past workers

FA 1: Regional Coarsening-Upward Shale to Shaly Sandstone Succession		
Reference	Field	Facies Designation (s)
Posamentier & Chamberlain (1991)	Joarcam	Member A
Power (1988)	Joarcam	Member A ("third" sand of industry)
Pattison (1991)	Crystal, Cyn-Pem, Sundance-Edson	Facies Association 1: Bioturbated CU Successions
Reinson (1985)	Crystal	Regional Shelf-Shoreface Facies
Boreen & Walker (1991)	Willesden Green	Facies Association 1: Basal Siltstone Assemblage
Raychaudhuri (1989)	Chigwell	Facies 3: Sandy Siltstone
Downing & Walker (1988)	Joffre	Association 1: Basal Siltstones
Raddysh (1988)	Gilby A and B	Facies A: Homogenous Muddy Siltstones
Pozzobon & Walker (1990)	Eureka	Facies B: Bioturbated Sandstones and Mudstones
Hadley (1992)	Harmattan East & Crossfield	Facies 1,2, 3, and 4
Davies (1990)	Caroline & Garrington	Facies 1 and 9

exhibiting an overall gradual increase in sandstone grain size upwards. Rarely, 1-4 cm thick preserved fine-grained sandstone beds displaying hummocky cross stratification (HCS) to wavy laminations may be visible. These beds are generally sharp based, grade upwards into mudstone or sandy mudstone and are unburrowed except near the tops. Minor bentonite layers (1-5 cm thick) and sideritic patches (10-15 cm thick) also occur throughout the succession.

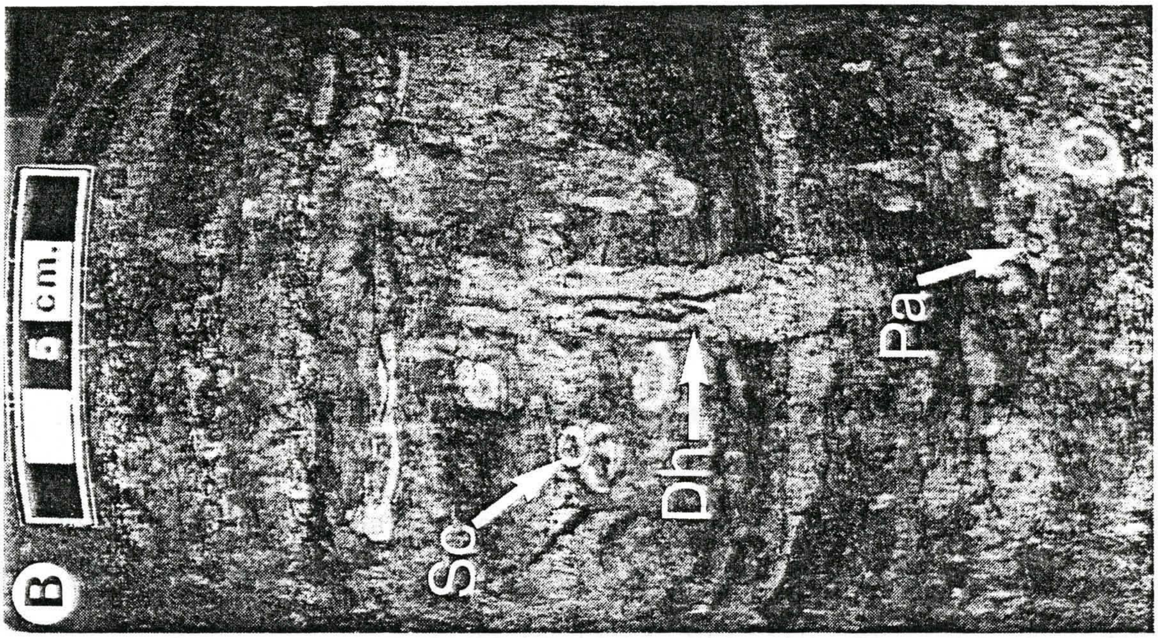
The most characteristic feature of the association, the homogeneous dark grey color and 'shredded' appearance, is due to pervasive bioturbation. The ichnofaunal assemblage is diverse and tends to reach its greatest abundance with increasing sand content. Muddier portions of successions are characterised by *Helminthopsis* and *Chondrites* traces (figure 3.4A). Other common trace fossils include *Planolites, Schaubcylindrichnus, Asterosoma, Arenicolites, Anconichnus, Teichichnus, Palaeophycus* and *Zoophycos.* Less typical traces may include fugichnia, *Diplocraterion habichi* and rare *Ophiomorpha* (figure 3.4B, C, D, E). These trace fossils are typical of the *Zoophycos* and *Cruziana* ichnofacies (Frey and Pemberton, 1984).

Sedimentary structures are rarely preserved in the successions but may include wave rippled sandstone beds in the lower portion of the association and HCS, parallel laminated and cross bedded sandstone beds in the upper half (Pattison, 1991). The combined-flow rippled beds are sharp

Figure 3.4 Facies Association 1

A) Silty to very fine-grained sandy mudstone at the base of a regional succession. The thin sandy horizon is disrupted by unidentified burrowing. *Helminthopsis (H), Chondrites (C),* and *Planolites (P)* are visible throughout. Well 11-11-41-25W4; 1407.6m; 4 inch whole core.

B) Heavily burrowed muddy sandstone showing the 'shredded' appearance of the upper portions of the association due to pervasive bioturbation. This example shows *Schaubcylindrichnus (Sc), Diplocraterion habichi (Dh),* and *Palaeophycus (Pa).* Well 14-25-45-02W5; 1407.6m; 4 inch whole core.


B
5 cm.
So
Dh
Pa

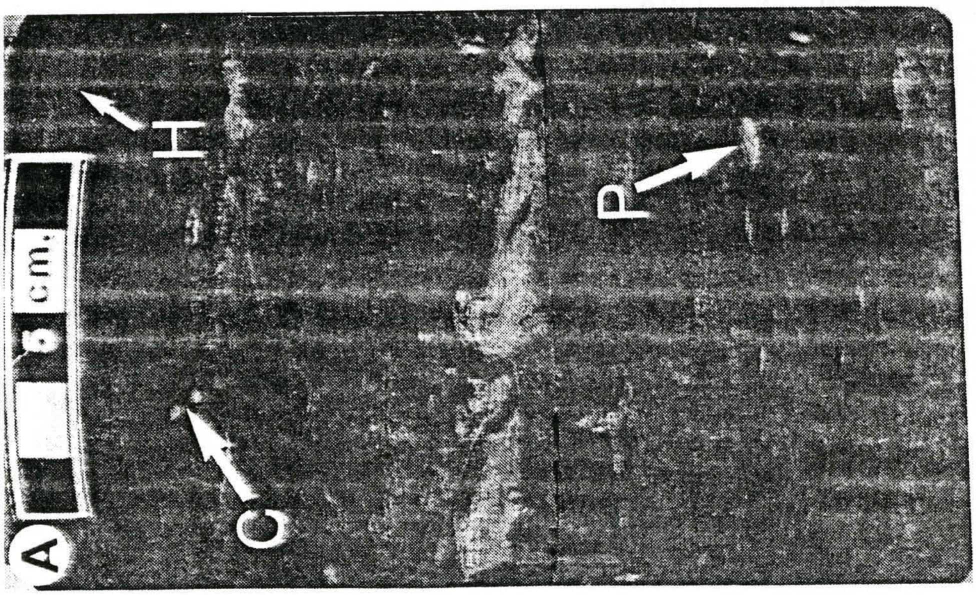

A
5 cm.
H
C
P

Figure 3.4 (cont'd) Facies Association 1

C) Profile view of an *Arenicolites (A)* burrow passively infilled with fine-grained sandstone. Also note the pervasive bioturbation by *Planolites (P)*. Well 10-32-48-21W4; 1022.6m; 3 inch whole core.

D) Profile view of a *Skolithos (S)* burrow which has possibly reworked a portion of a *Diplocraterion habich (Dh)* trace. Well 10-32-48-21W4; 1022.3m; 3 inch whole core.

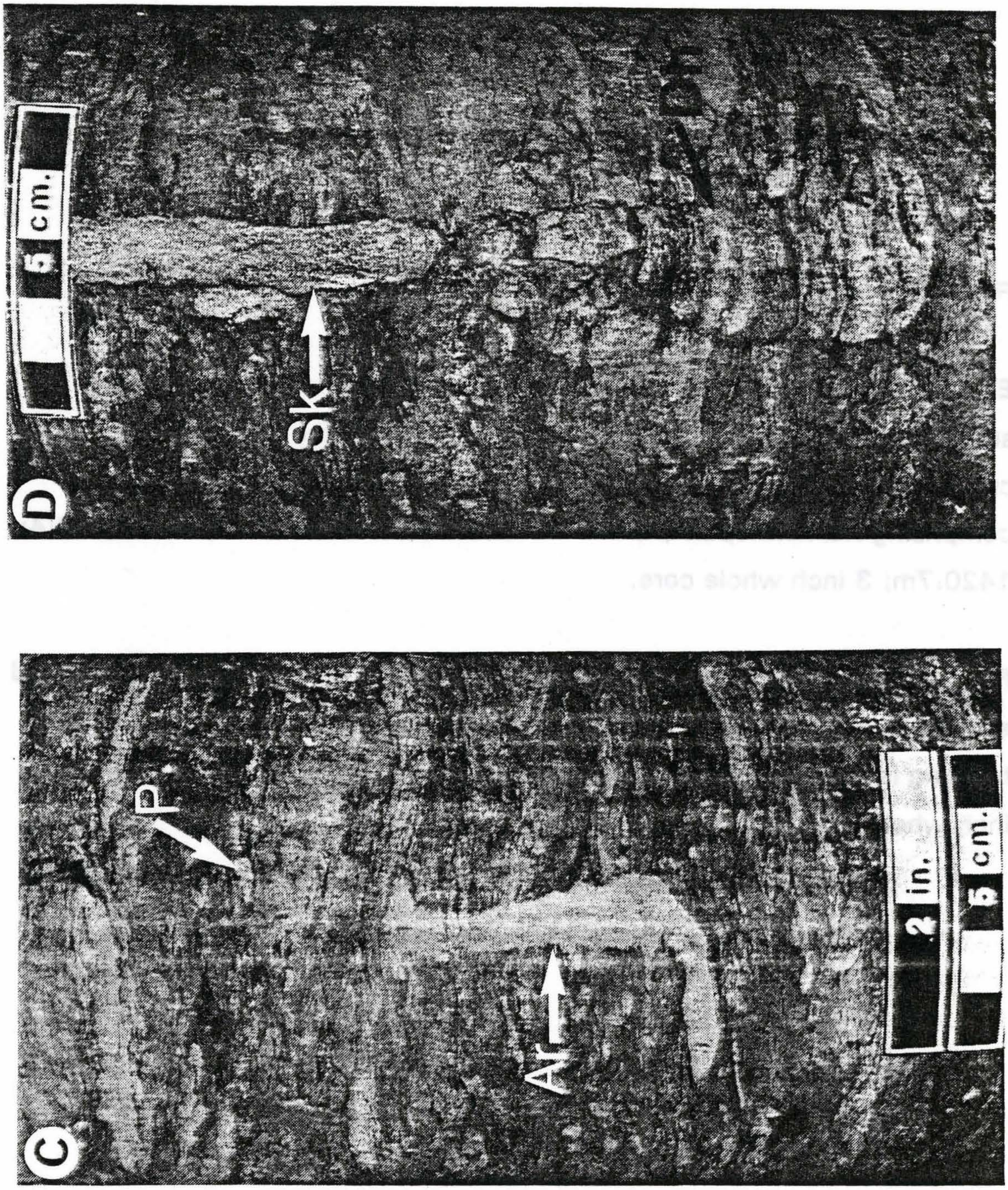
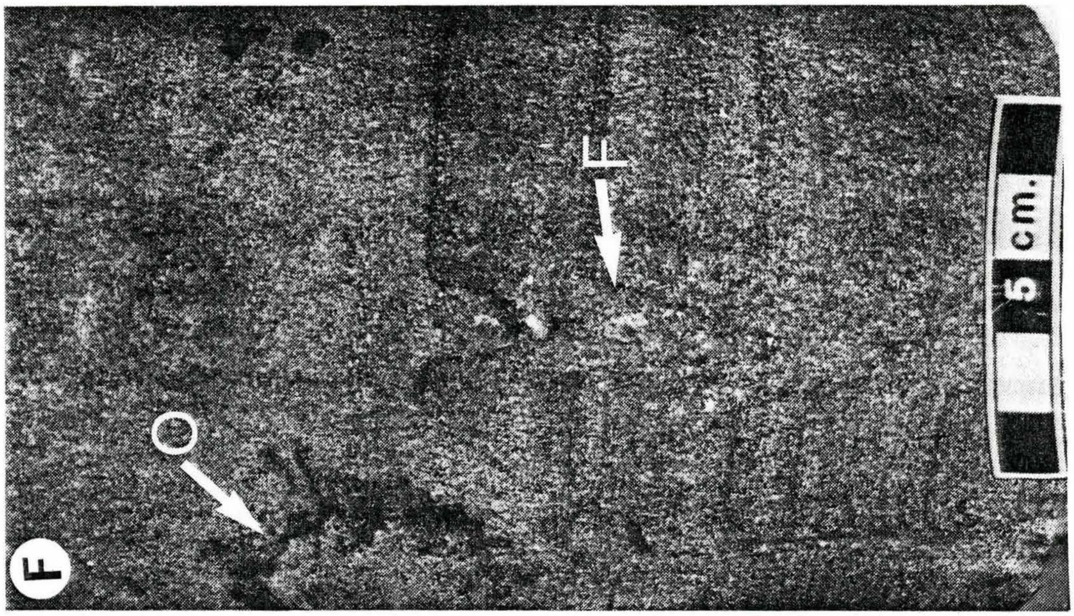
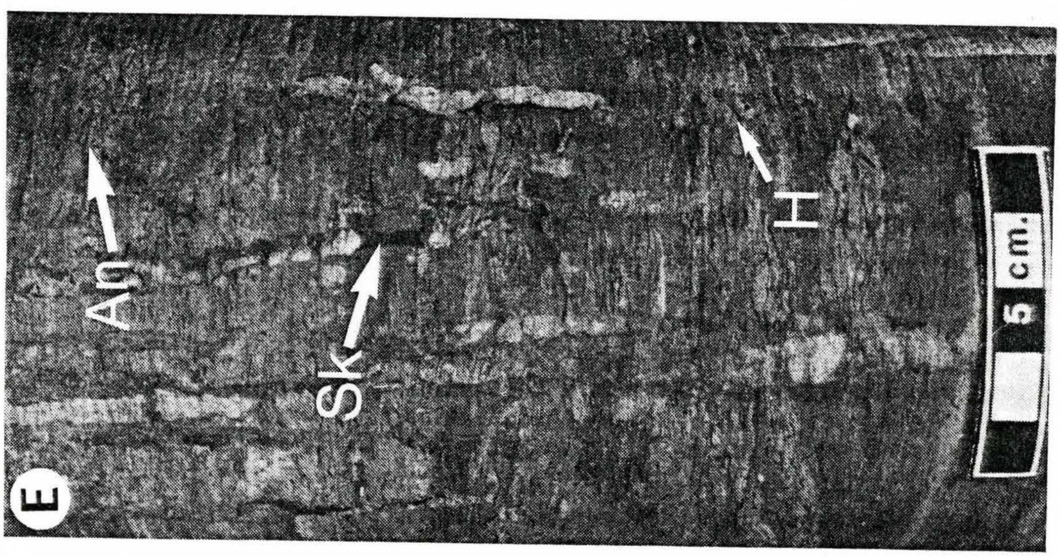

D
5 cm.
Sk
C
P
Ar
2 in.
5 cm.

Figure 3.4 (cont'd)   Facies Association 1

E) Numerous *Skolithos (S)* burrows of the *Glossifungites* ichnofacies subtending from the top of regional succession 4 in the Chigwell area. Note cross cutting relationship of these burrows to the endemic trace fauna comprising *Helminthopsis (H)* and *Anconichnus (An).* Well 14-28-43-26W4; 1420.7m; 3 inch whole core.

F) Fugichnia (F) and *Ophiomorpha (O)* burrows in low angle cross bedded sandstone at the top of regional succession 2 in the Joarcam area. Cross bedding is in fine grained sandstone. Well 10-32-48-21W4; 1018.5m; 3 inch whole core.


F
O
F
5 cm.


E
An
Sk
H
5 cm.

based, normally graded, very fine- to fine-grained and range from 1 to 5 cm thick. The HCS beds are sharp based and grade upwards from fine-grained sandstones to very fine-grained sandstones and siltstones exhibiting wavy or parallel laminations. Whereas the bases of the HCS beds are sharp based and non-bioturbated, the tops exhibit somewhat more bioturbation and have a gradational contact with overlying bioturbated sandy mudstone. Cross bedded sandstones are also sharp based and comprise fine- to medium-grained sandstone which is often crudely interbedded with a structureless, bioturbated muddy sandstone. Cross bed sets vary from 5-20 cm thick but are most commonly about 10cm thick. Of the 5 regional coarsening upward successions in a 'stack', cross bedding is noted only in the upper 2-3 cycles (figure 3.4F) and is completely absent in lower successions.

The stacked coarsening upward successions become progressively coarser and sandier from the relatively muddy basal succession to the sandy upper successions. The basal succession has been reported by Pattison (1991) and Weimer (1984) to have a gradational lower contact with the underlying Joli Fou shales. However, several other authors (i.e. Beaumont, 1984; Posamentier et al., 1992) interpret the contact as erosive. No core observed in this study penetrated the "base" of the Viking Formation. The nature of the contact as determined from correlations of well logs in this thesis appears to be sharp but conformable and is at times apparently gradational. Contacts between facies successions are typically sharp and apparently erosive. This is shown by the sudden change in grain size from the sandy top of an underlying succession to the muddy base of the overlying succession (Pattison, 1991). In addition, a thin 'lag' of coarse sand, pebbles or sideritized mud clasts may be present either as a discrete layer or as disseminated particles throughout the upper 10-20cm of the sandy tops of successions. Large *Skolithos, Diplocraterion habichi, Planolites,* or *Arenocolites* burrows may penetrate down from the tops and are commonly passively infilled with medium- to coarse-grained sandstone. These traces have cross-cutting relationships with the softground *Cruziana* and *Skolithos* ichnofacies endemic to the upper portions of the coarsening upward successions. As such, these traces are characteristic of Frey and Pemberton's (1984) *Glossifungites* ichnofacies.

INTERPRETATION: The rare sedimentary structures that are preserved, and the apparent gradation from shales or silty shales to muddy sandstones, suggest a progradational package of sediment formed in an offshore environment. Marine trace fossils are abundant and increase upwards with sand content indicating increasing proximal marine conditions. The tops of the successions are interpreted as marine flooding surfaces on which minor submarine erosion has possibly occurred. A *Glossifungites* trace fauna assemblage indicates the formation of a 'firmground', probably developed during transgression. The stacked nature of the successions and their progressive coarsening upward through the 'stack' suggests that together they form a progradational parasequence set (Van Wagoner et al., 1990).

3.3 Facies Association 2A: Sharp Based, Coarsening Upward, Shaly Sandstone to Sandstone Succession

Facies association 2A (FA 2A) consists of heavily bioturbated muddy sandstones and sandstones that form a coarsening upward facies succession. The type well for this association is located at 8-15-43-26W4. Figure 3.5 is a panel illustrating the gamma, SP and resistivity well log and schematic core character of the type well. A core photomontage of the core from the type well is provided in figure 3.6. A comparison of descriptions of the facies association from this study and studies of past authors is provided in table 3.2A.

This succession is made up of pale muddy sandstones at the base, followed by interbedded muddy sandstones and sandstone in the midsection, passing upwards to sandstone at the top. The volume of sandstone varies from 40% at the base up to 95% at the top of the succession. The sand grain size varies gradationally upwards from very fine- to fine-grained at the base to medium- and very coarse-grained at the top. Occasionally, chert grains (3-8 mm in diameter) and sideritic mudstone rip up clasts (3-6 mm in diameter) may mantle the sharp base of this succession or

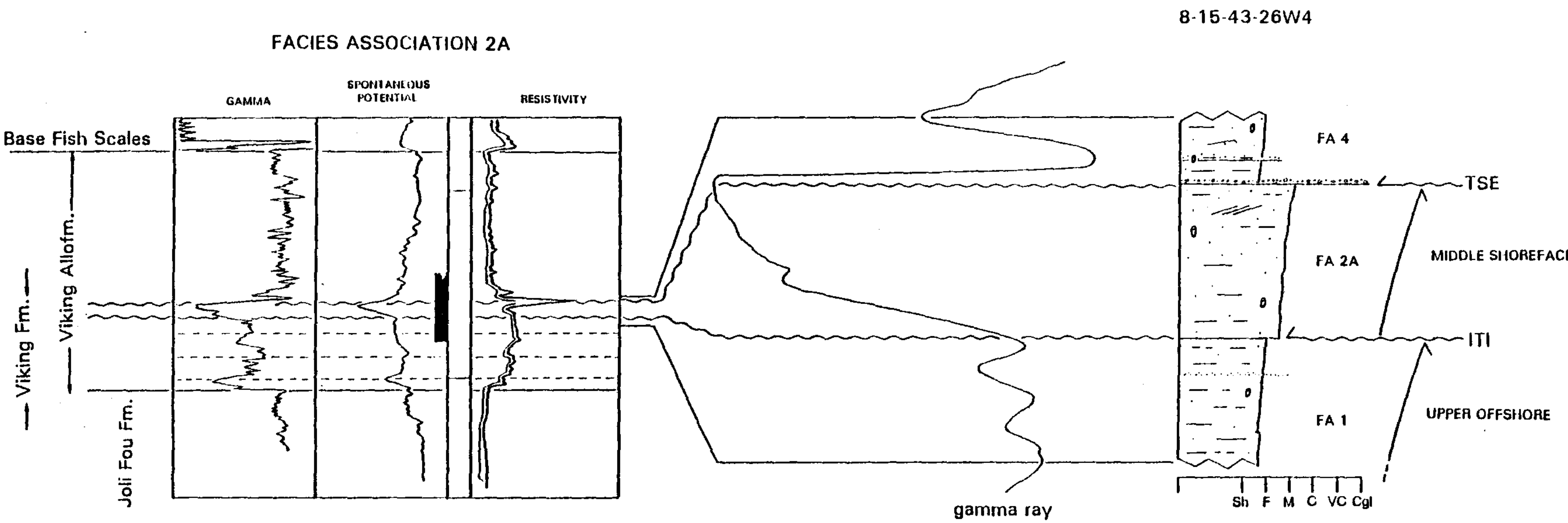
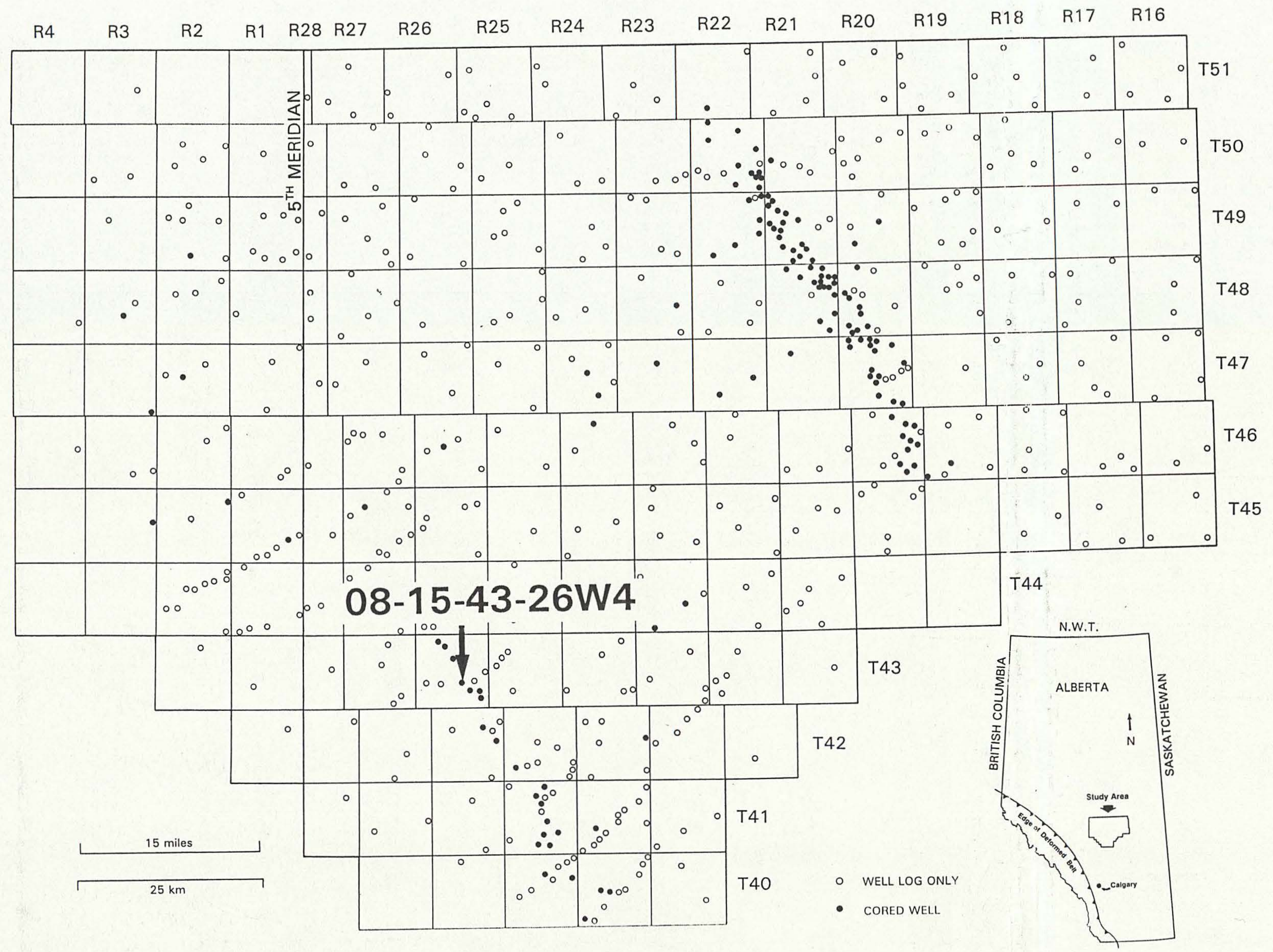


Figure 3.5 Type well for facies association 2A from 08-15-43-26W4 (1436-1428m) which illustrates a sharp based shoreface sandbody underlain by offshore sediments of FA 1 and overlain by transgressive sediments of FA 3. The corresponding gamma ray, spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

Figure 3.6 Core photographs of the type core for facies association 2A with bounding discontinuities indicated. Location of the core is provided on the map.

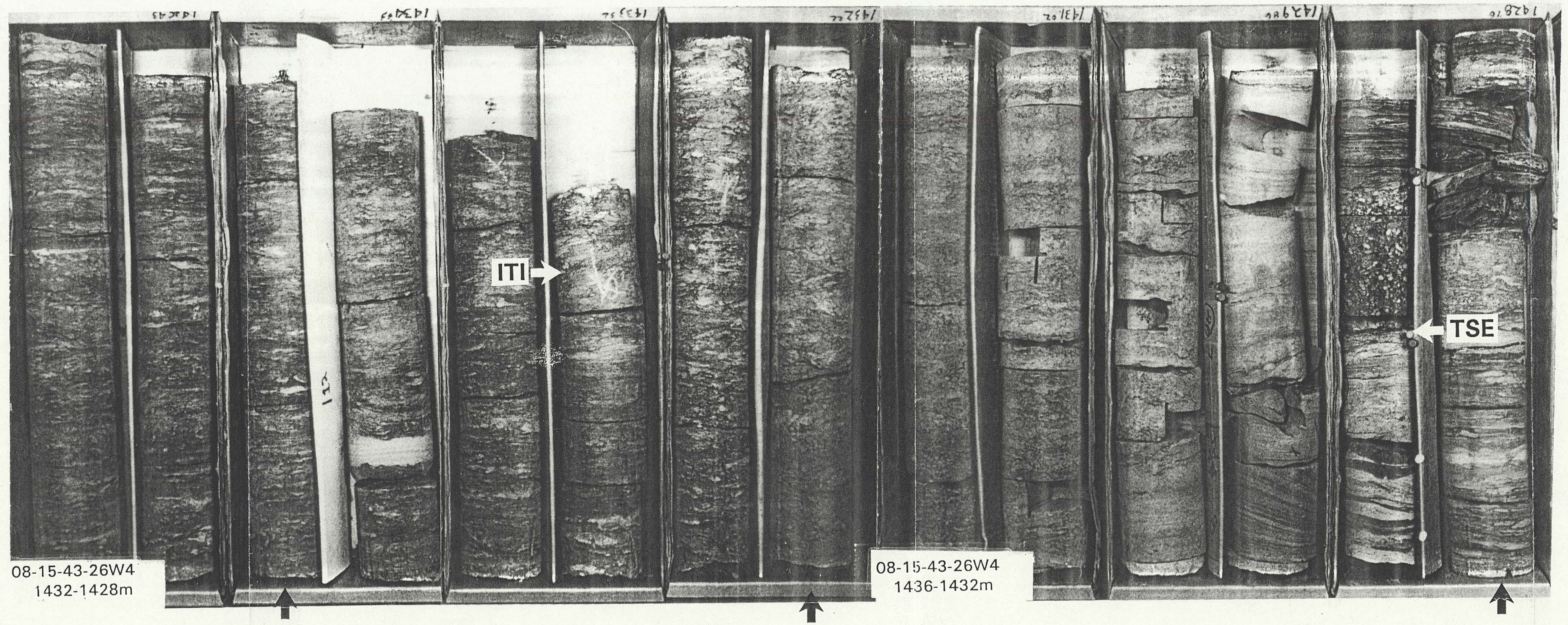


08-15-43-26W4

(4" Whole Core)

TYPE CORE: FACIES ASSOCIATION 2A

TOP



BOTTOM

FA. 1

FA. 2B

FA. 3/4

Table 3.2A: Facies equivalents of past workers

FA 2A: Sharp Based Coarsening-Upward Shaly Sandstone to Sandstone Succession

Reference	Field	Facies Designation (s)
Posamentier & Chamberlain (1991)	Joarcam	No Designation
Power (1988)	Joarcam	No designation
Pattison (1991)	Crystal, Cyn-Pem, Sundance-Edson	Facies Association 9: Sharp Based, Bioturbated Sandstone
Reinson (1985)	Crystal	No Designation
Boreen & Walker (1991)	Willesden Green	No Designation
Raychaudhuri (1989)	Chigwell	Facies 4 and 5A
Downing & Walker (1988)	Joffre	Association 2: Bioturbated Sandstones
Raddysh (1988)	Gilby A and B	Facies B, C, and E
Pozzobon & Walker (1990)	Eureka	Facies D: Bioturbated Glauconitic Sandstone
Hadley (1992)	Harmattan East & Crossfield	No Designation
Davies (1990)	Caroline & Garrington	No Designation

are scattered throughout the lower half of the package. Coaly fragments, 1-4 cm in length, are seen rarely the lower half of the association. Towards the top, glauconite becomes quite abundant and helps define sedimentary structures, especially cross bedding where it tends to become concentrated along foresets.

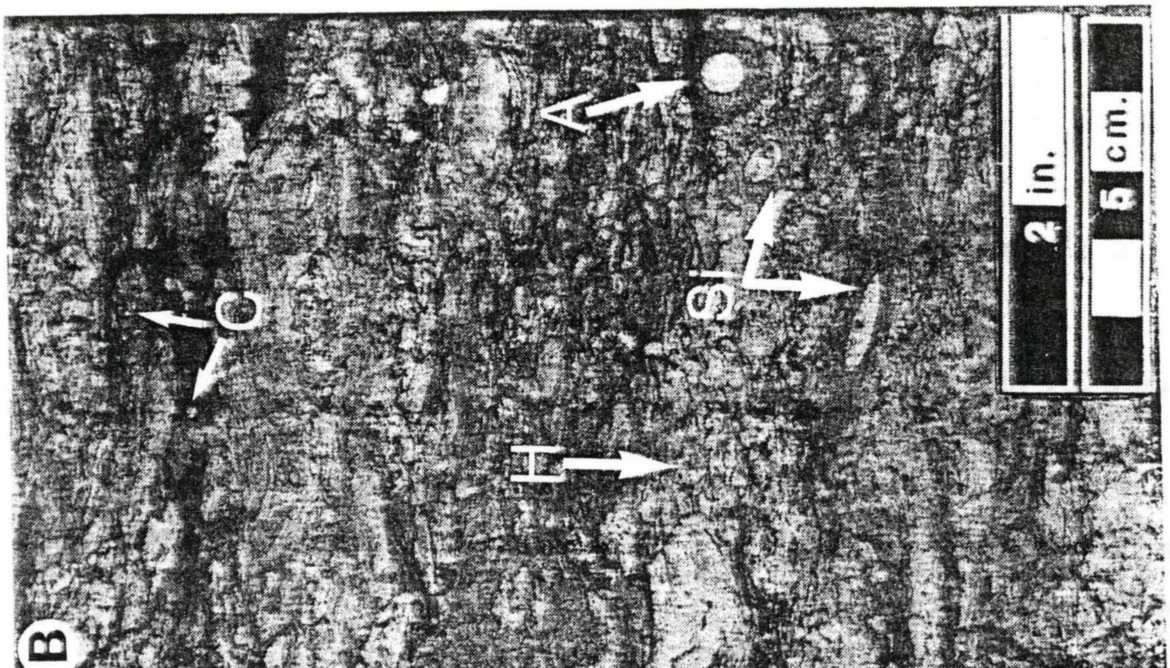
Trace fossils are common within this entire succession, as summarized by Raychaudhuri et al. (1992). The basal portion is characterised by abundant *Ophiomorpha, Chondrites, Siphonichnus, Palaeophycus, Schaubcylindrichnus, Planolites, Asterosoma, Rosselia, Teichichnus, Terebellina* and *Thalasinoides* (figure 3.7A, B, C). Also found are *Skolithos, Diplocraterion habichi* and *Arenicolites* in lesser quantity. These traces make up a softground assemblage typical of Frey and Pemberton's (1984) *Cruziana* and *Skolithos* ichnofacies. Within the succession, there is an upward decrease in the abundance and diversity of bioturbation, which parallels the decrease in percentage of mudstone and increase in sand grain size upward. The top of the succession may only be characterised by poor to moderately well preserved specimens of *Ophiomorpha*.

Sedimentary structures present within the succession occur only in the upper portions, all else having been apparently destroyed by heavy bioturbation in the lower facies. Structureless or massive sandstones

Figure 3.7 Facies Association 2A

A) Core photo illustrating the homogeneous character of muddy sandstones in the basal portions of FA 2A due entirely to heavy bioturbation. Most burrows are unidentifiable except for *Palaeophycus (Pa)*. Well 06-26-42-26W4; 1372.5m; 3 inch whole core.

B) A diverse assemblage of ichnofauna occur within the lower sediments of FA 2A, including: *Arenicolites (A), Chondrites (C), Helminthopsis (H),* and *Siphonichnus (Si)*. Well 10-28-41-25W4; 1461.1m; 4 inch slabbed core.


B
C
H
A
2 in.
5 cm.

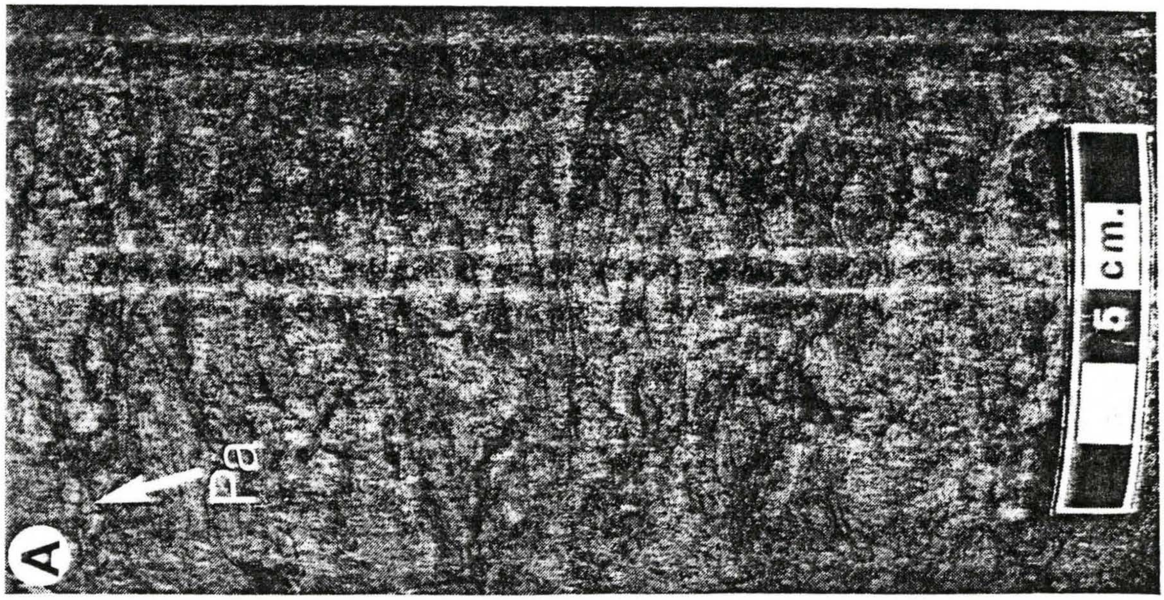
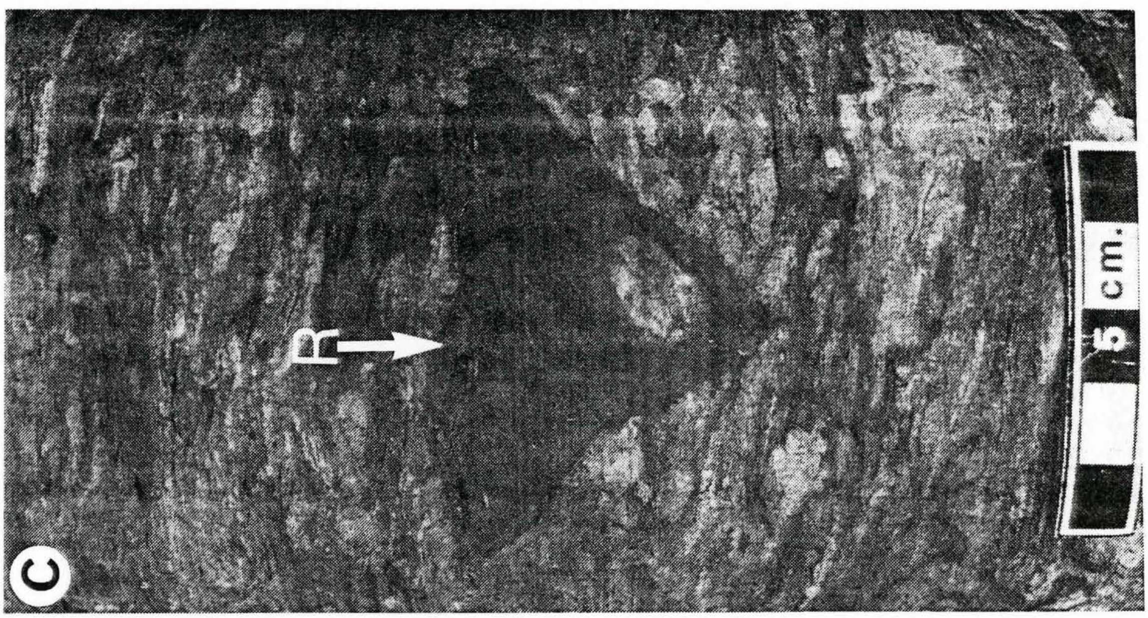

A
Pa
5 cm.

Figure 3.7 (cont'd) **Facies Association 2A**

C) Well developed *Rosselia (R)* are common throughout the association. This example is reburrowed by an unidentified trace. Well 08-32-43-26W4; 1415.0m; 3 inch whole core.

D) Trough cross bedding in medium grained sandstone at the top of the succession. Glauconite commonly mantles foresets as displayed here. Note the sideritised mudstone clast S at the base of the upper cross bed set. Well 10-28-41-25W4; 1458.1m; 4 inch slabbed core.


D
S
2 in.
5 cm.


C
R
5 cm.

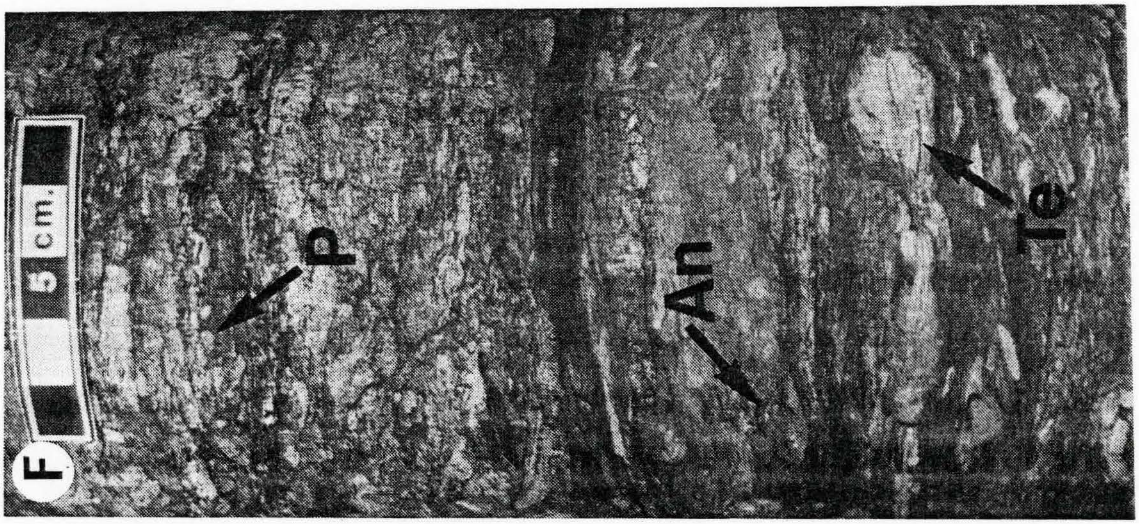
commonly occur in the middle sections, while trough and planar cross bedded sandstones are found in the upper parts of the succession. Massive sandstones are generally found crudely interbedded with bioturbated muddy sandstones. The massive sandstones may have very vague cross bedding within it, but this is the exception rather than the rule. This facies gives way upwards to fully trough or planar cross bedded sandstones that may or may not be interbedded with muddy sandstones. Cross beds may be 10-25 cm thick and are generally moderately high-angled (approximately 20°) as seen in figure 3.7D.

This facies succession has a very sharp contact with the underlying, stacked, coarsening upward successions that is typically marked by: a) distinct change in grain size, b) sharp increase in sand per unit volume, c) the presence of a lag, d) 'hardground' assemblage of trace fossils, and/or e) abrupt change in the style and intensity of 'softground' bioturbation. The apparently erosive boundary typically separates underlying muddy, very fine-grained sandstones of the 'regional' successions from fine- to medium-grained muddy sandstones of the overlying, sharp based succession. Particularly noticeable at the contact is an increase in the percentage of sandstone in the sediments from 20-40% beneath the sharp contact to 50-75% above. A minor lag of chert pebbles (3-12 mm in diameter) and very coarse sandstone is also commonly seen. These may form a fairly coherent layer (1-3 cm thick) or more commonly occur as dispersed grains throughout the lower 10-20 cm of the base of the succession. Commonly, sharp walled and passively infilled burrows are seen extending down from the sharp contact at the base of the succession (figure 3.7E). They are interpreted as *Skolithos* and *Thalassinoides* burrows which represent a firmground *Glossifungites* ichnofacies. These burrows are observed to cross cut the antecedent softground suite of traces. The sharp boundary between the facies is commonly marked by an increase in the diversity and abundance of trace fossils from below to above the contact (figure 3.7F). The apparent difference in the amount of bioturbation appears to be locally controlled by the depth of incision into the underlying stacked coarsening upward (regional) successions. Where erosive incision has removed only a small amount of the sandiest upper portion of a 'regional' succession, the degree of bioturbation from above and below the contact may be similar. In contrast, if the sandy base of the sharp based succession rests directly on the more muddy sediments (lower portions) of a 'regional' succession, the relative change in bioturbation from below to above is considerable. The upper boundary to this succession is similar if not identical in many respects to the upper contact in FA 2B. It is everywhere sharp and erosive and is characteristically overlain by a clast supported conglomerate or a muddy/sandy conglomerate bed (5-40 cm thick).

Figure 3.7 Facies Association 2A

E) The base of the succession is often characterised by sharp walled and passively infilled burrows such as this small *Skolithos (S).* Note the abrupt change in grain size, increase of sandstone per unit volume, and the change in style and intensity of 'softground' bioturbation from below to above the basal discontinuity. The upper facies has been thoroughly bioturbated by *Planolites (P).* Well 14-28-43-26W4; 1409.3m; 3 inch whole core.

F) A similar yet not as pronounced basal contact as the previous photo. Underlying facies is characterised by *Teichichnus (Te),* and *Anchonichnus (An)* while the overlying facies is dominantly burrowed by small *Planolites (P).* Well 16-21-43-26W4; 1414.3m; 3 inch whole core.


F
5 cm.
P
An
Te


E
P
Sk
5 cm.

Within the study area, there are six localities where this succession is developed. This association has been recognised from core data from 2 of these localities (Chigwell and Sunnybrook 'A') .

INTERPRETATION: Within the succession there is a steady progression upwards in sandstone content and grain size as well as preserved sedimentary structures (ie. cross bedding) that suggests a marine progradational succession. Glauconite is present indicating marine conditions and the ichnologic assemblage characterises a *Skolithos* ichnofacies typical of shoreface environments. In all, the package is interpreted as a lower shoreface to middle shoreface facies succession. The sharp base of the succession is interpreted to be an erosional surface onto which the shoreface has rapidly prograded. The upper boundary is interpreted as a marine transgressive surface of erosion upon which a transgressive lag has been deposited. This facies association forms part of the transgressive systems tract in the study area.

3.4 Facies Association 2B: Coarsening Upward, Marine Shale to Sandstone Succession

Facies association 2B (FA 2B) is composed of thoroughly bioturbated silty mudstones, muddy sandstones and sandstones that form a coarsening upward facies succession. The type well for this facies association is located at 6-8-49-21W4. Figure 3.8 illustrates the gamma, SP and

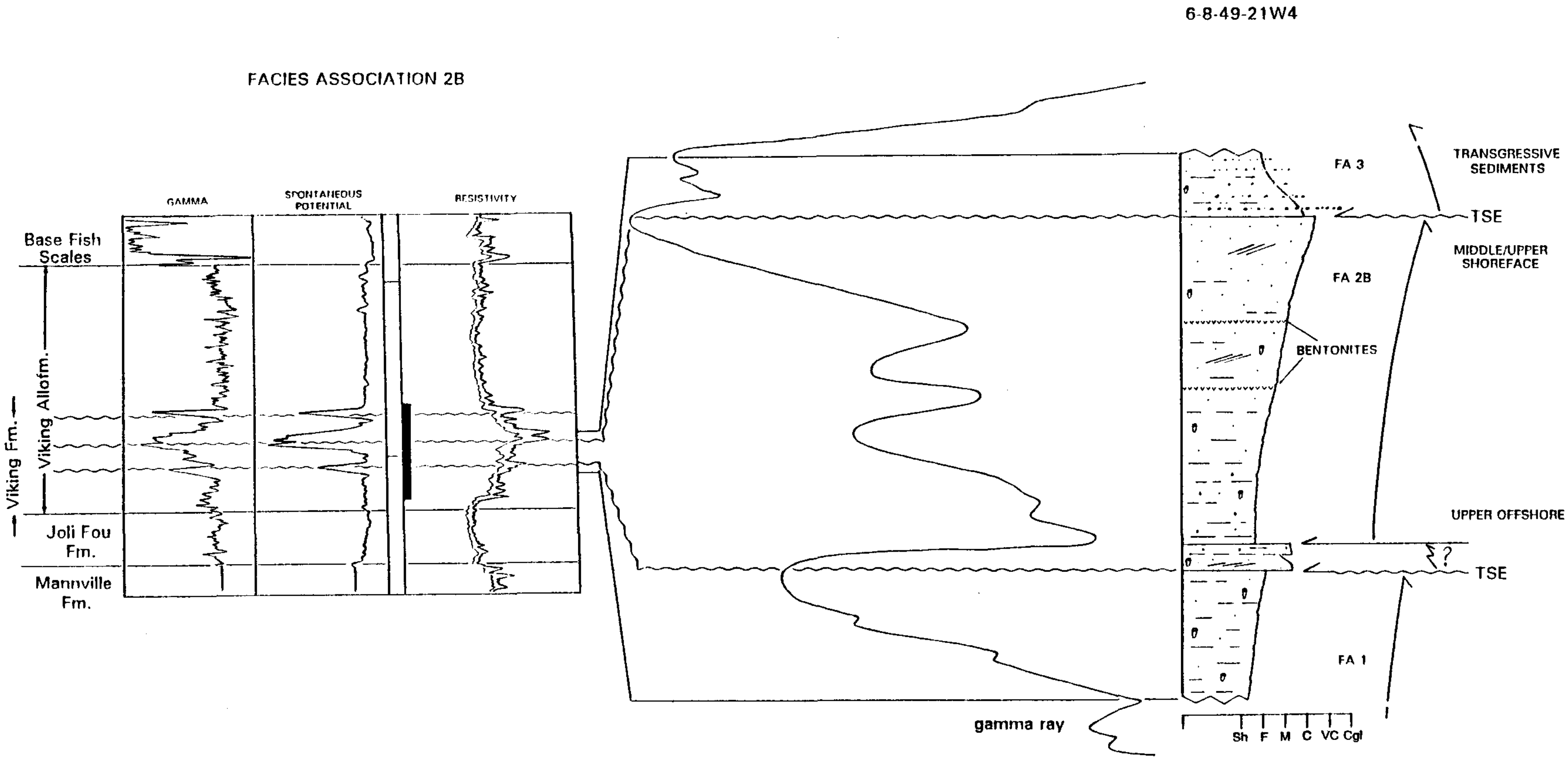


Figure 3.8 Type well for facies association 2B from 06-08-49-21W4 (1005-988m) which illustrates a sharp based offshore to shoreface succession underlain by offshore sediments of FA 1 and overlain by transgressive sediments of FA 3. The corresponding gamma ray, spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

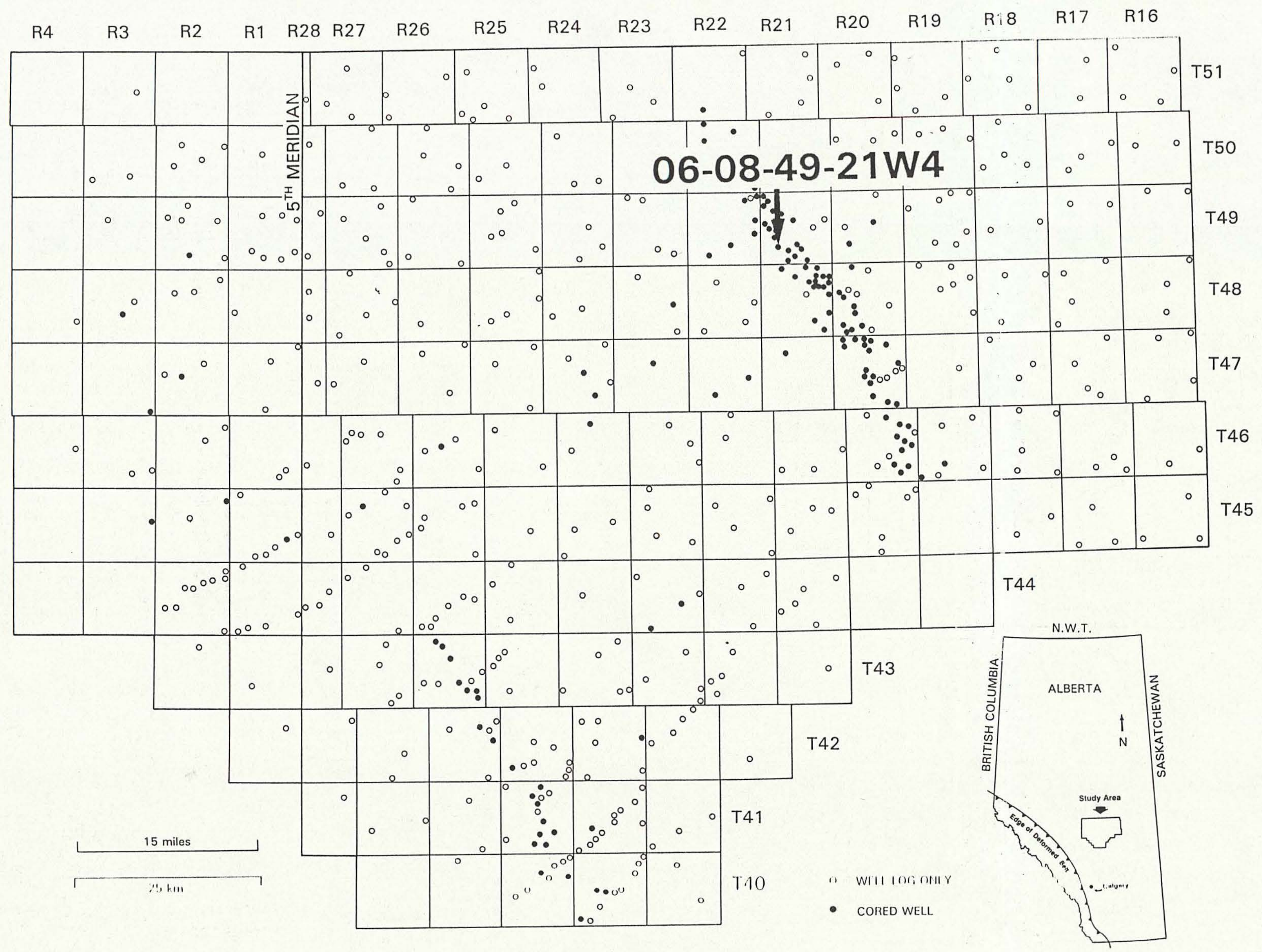
resisitivity well log character and a schematic core log for the type well. A core photomontage of the core from this well is provided in figure 3.9. Similar facies or facies successions have been described by previous workers; these references, study areas and classifications are provided in table 3.2B for reference.

This succession comprises dark silty or sandy mudstone at the base, muddy sandstone in the middle, followed by sandstone or pebbly sandstone at the top. The volume of silt and sand varies from 5 to 20% at the base up to 100% at the top of the succession. The sand grain size varies gradationally upwards from very fine- at the base to very coarse-grained and granule (2-3 mm diameter) sized grains at the top. In some instances, medium-to coarse- grained sand is dispersed throughout the lower portions of the succession. However, these grains do not appear to occur at specific stratigraphic intervals or with any regularity, at least in areas where the succession has been cored. Thick (10-30 cm) and thin (<5 cm) thick bentonites commonly occur within the succession, thicker bentonites are correlateable and provide important time lines within the eastern portion of the study area as shown by Posamentier and Chamberlain, 1991. Sideritic patches and layers (1-3 cm thick) are common in the mid to upper portions of the succession while rare coaly fragments were noted in the lower portions.

Figure 3.9 Core photographs of the type core for facies association 2B with bounding discontinuities indicated. Location of the core is provided on the map.

Table 3.2B: Facies equivalents of past workers

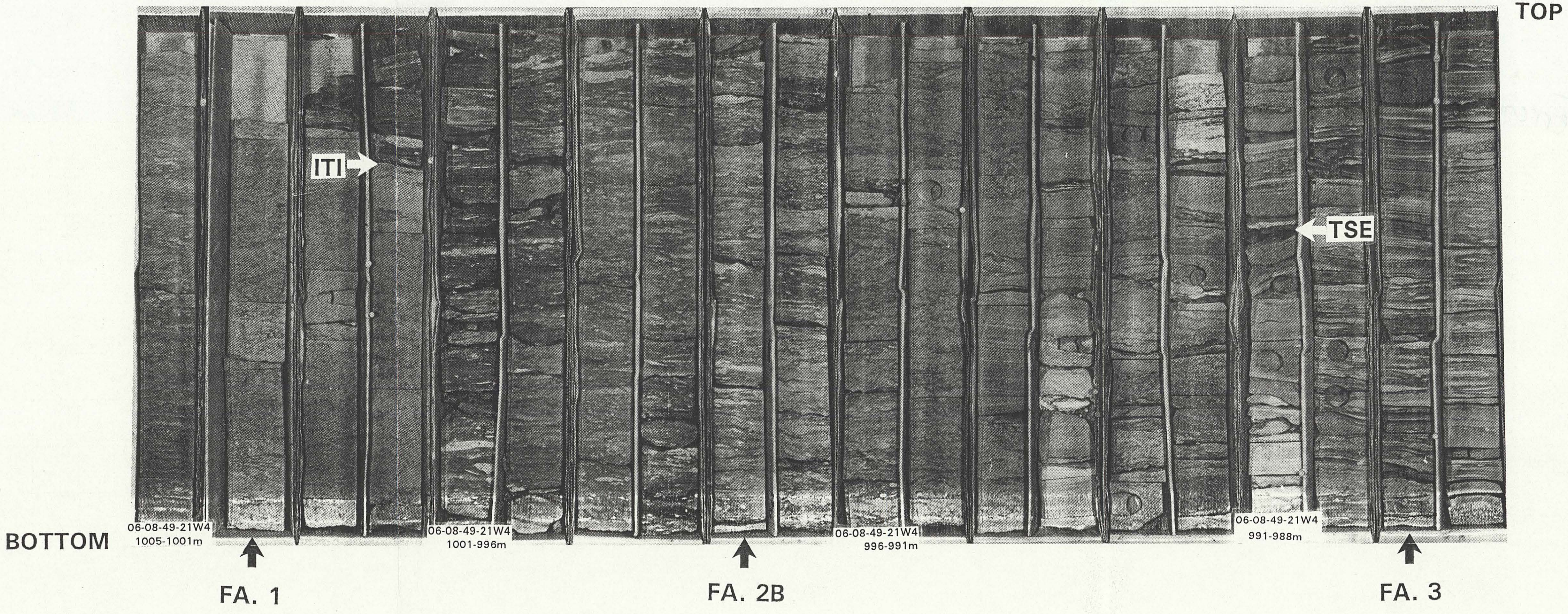
FA 2B: Coarsening-Upward Marine Shale to Sandstone Succession		
Reference	**Field**	**Facies Designation (s)**
Posamentier & Chamberlain (1991)	Joarcam	Member "B" ("Main" sands of
Power (1988)	Joarcam	Member "B"
Pattison (1991)	Crystal, Cyn-Pem, Sundance-Edson	No Designation
Reinson (1985)	Crystal	No Designation
Boreen & Walker (1991)	Willesden Green	No Designation
Raychaudhuri (1989)	Chigwell	No Designation
Downing & Walker (1988)	Joffre	No Designation
Raddysh (1988)	Gilby A and B	No Designation
Pozzobon & Walker (1990)	Eureka	No Designation
Hadley (1992)	Harmattan East & Crossfield	No Designation
Davies (1990)	Caroline & Garington	No Designation



06-08-49-21W4

(3" Slabbed Core)

TYPE CORE: FACIES ASSOCIATION 2B



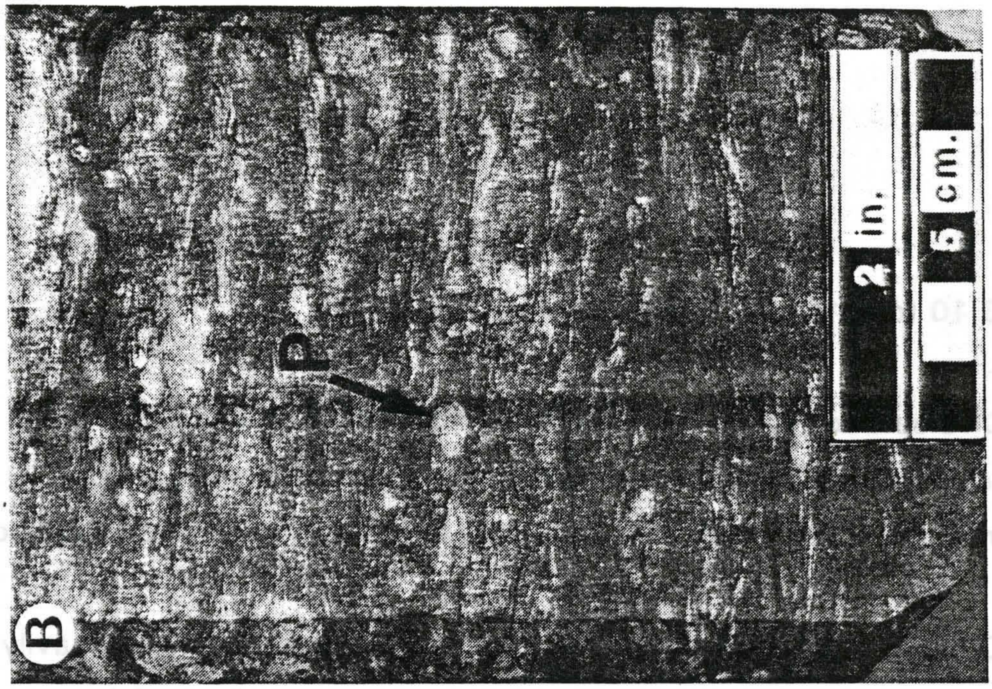
Bioturbation is common throughout the succession. The basal half of the succession is characterised by *Planolites, Skolithos, Asterosoma, Helminthopsis, Chondrites* and *Terebellina* (figure 3.10A, B). These ichnogenera are characteristic of the *Zoophycos* and *Cruziana* ichnofacies (Frey and Pemberton, 1984). The upper portion of the succession typically has larger and more robust traces including *Planolites* and *Skolithos; Diplocraterion habichi* is also common, and comprise 10 to 60cm long vertical tubes, passively infilled by fine- to medium-grained sand. *Cylindrichnus, Teichichnus, Rosselia, Ophiomorpha, Thalassinoides, Arenicolites* and *Rhizocoralium* (figure 3.10C) are also common. The established softground trace fauna assemblage in the upper portion of the succession characterizes the *Cruziana* and *Skolithos* ichnofacies of Frey and Pemberton (1984).

Sedimentary structures are present throughout FA 2B and include wave/combined-flow rippled and wavy laminated sandstone beds in the lower portion and planar and trough cross bedded sandstones in the upper half. The rippled beds have sharp bases and grade normally from very fine- to fine-grained sands at the base to very fine-grained sands and silt at the top. The basal and middle portions of these beds are generally non-bioturbated except for apparent escape traces which cross-cut bedding in places. Organisms endemic to 'background' sedimentation commonly

Figure 3.10 Facies Association 2B

A) Basal portion of FA 2B comprises poorly bioturbated silty mudstones. Very fine-grained sandstone and siltstone 'pinstripe' layers may be disturbed by *Chondrites (C), Helminthopsis (H)* and small *Planolites (P)* trace fauna. Well 03-19-49-21W4; 1006.4m; 4 inch slabbed core; scale bar is 3cm.

B) With increasing sand content the succession tends to take on a 'mottled' texture due to the abundance of *Planolites (P)* burrows. Well 07-05-48-20W4; 988.3m; 3.5 inch slabbed core.


B
P
2 in.
5 cm.

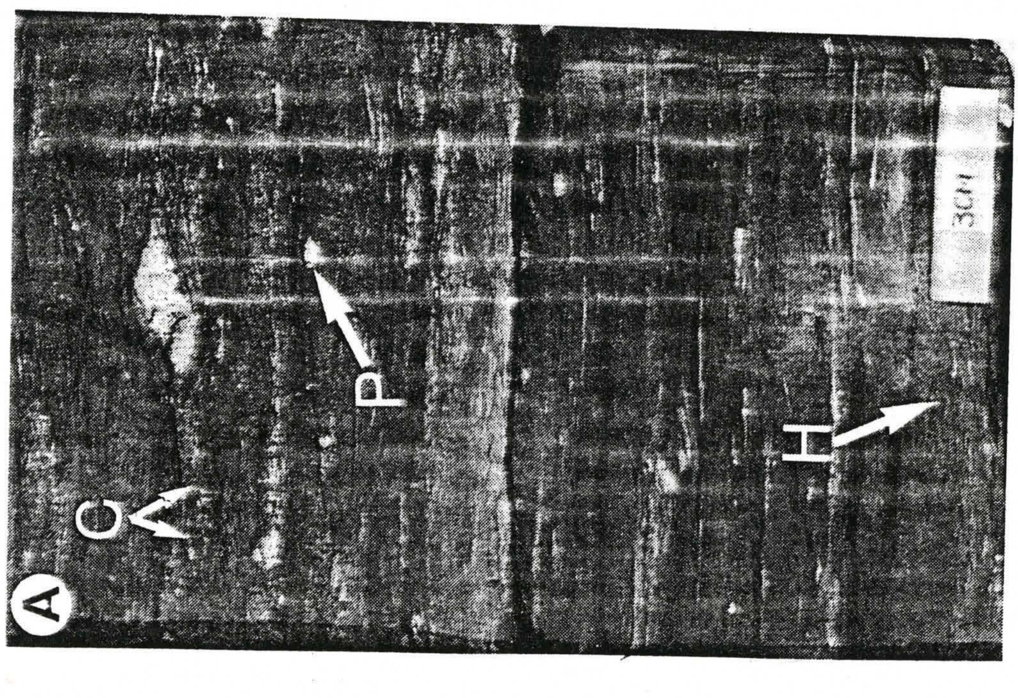
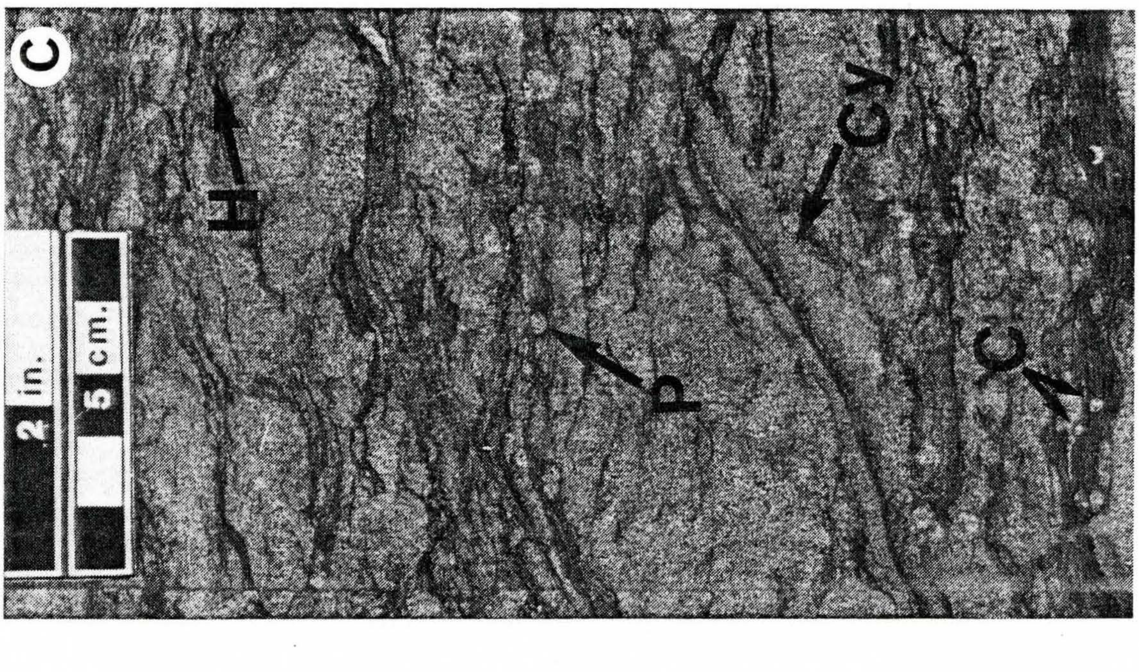

A
C
P
H
3CM

Figure 3.10 (cont'd) **Facies Association 2B**

C) Diverse trace fauna including *Chondrites (C), Helminthopsis (H), Planolites (P),* and *Cylindrichnus (Cy)* are common to lower shoreface sediments of FA 2B. Well 16-12-48-21W4; 987.0m; 4 inch slabbed core.

D) Cross bedded medium grained sandstone sharply overlying heavily bioturbated muddy sandstones. These facies are generally crudely interbedded in the mid to upper parts of the succession. Well 07-21-49-21W4; 989.4m; 3 inch whole core.


D


C
2 in.
5 cm.
H
P
Cy
C

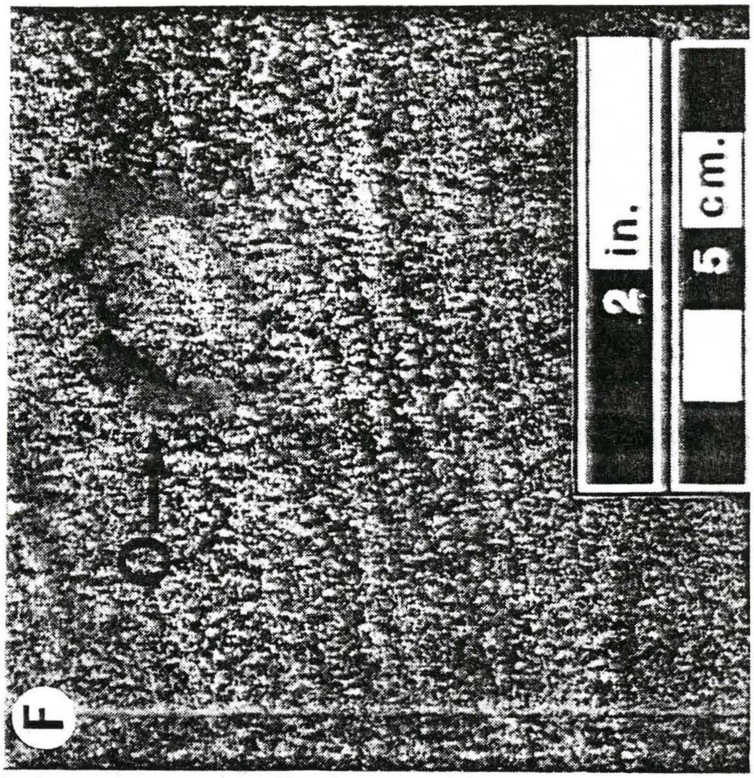
colonise the upper portions of the bed where it grades up to bioturbated sandy mudstone. Cross bedded sandstones are sharp based and comprise medium- to very coarse-grained sandstone and occur in beds 5-25 cm thick (figure 3.10D). There is a gradation upwards in the amount of cross bedding in the top part of the succession. Cross bedding (5-10 cm thick) in medium-grained sandstone is typically first observed crudely interbedded with a heavily bioturbated fine- to medium-grained muddy sandstone. This passes upwards into erosively amalgamated cross bedded, medium- to very coarse-grained sandstone beds (10-25 cm thick). Glauconite is concentrated along foresets, and chert granules (3-4 mm in diameter) may be seen throughout the upper portions of the cross bedded facies (figure 3.10E, F)

This facies succession has a sharp contact with the underlying, stacked, coarsening upward successions (FA 1)(figure 3.10G). Depending upon location in the study area, the basal portion can overlie either one of coarsening upward (regional) succession 2, 3, or 4. The contact typically appears sharp and erosive with the truncated top of the underlying coarsening upward succession and may be marked by abundant disseminated medium- to very coarse-grained sand and pebbles (up to 1 cm in diameter), and well rounded sideritized-mudstone rip up clasts (figure 3.10H). The base of the overlying coarsening upward succession (FA 2B) consists of moderately bioturbated, dark silty shale rich in swelling clays.

Figure 3.10 (cont'd) **Facies Association 2B**

E) High angle cross bedding in pebbly, medium grained sandstone. Granules and pebbles up to 9mm in diameter are not uncommon in the upper part of the succession at Joarcam. Well 05-20-49-21W4; 997.4m; 4 inch slabbed core.

F) *Ophiomorpha (O)* burrow in trough cross bedded medium grained sandstone. Note the sideritized nodular material that coats the burrow walls and the medium grained sand which infills the structure. Well 07-05-48-20W4; 979.5m; 4 inch slabbed core.


F
2 in.
5 cm.

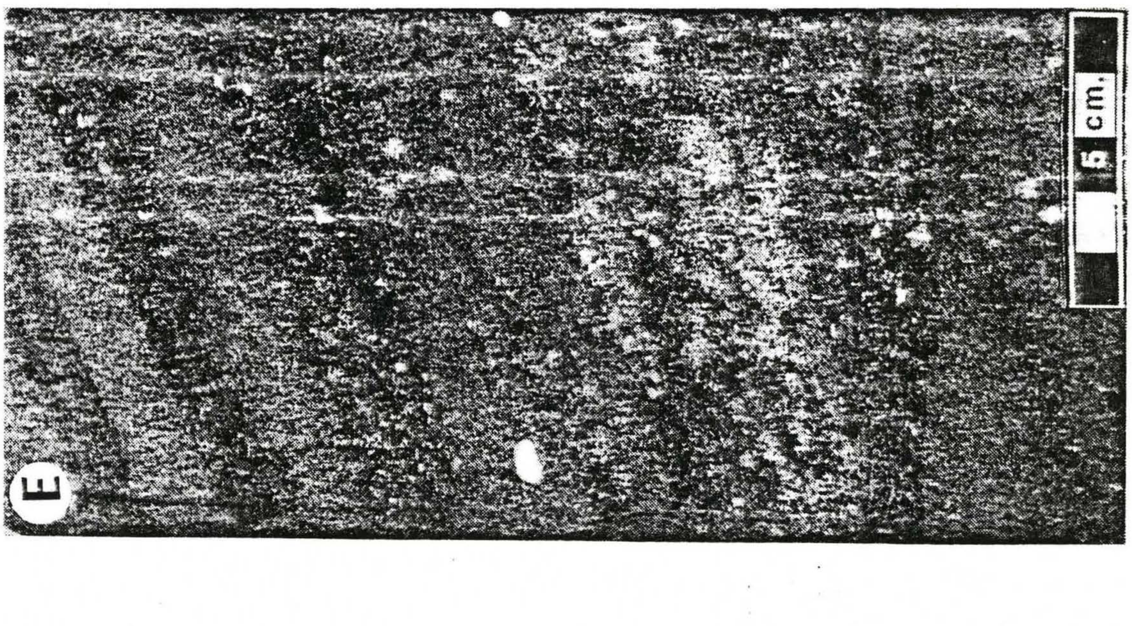
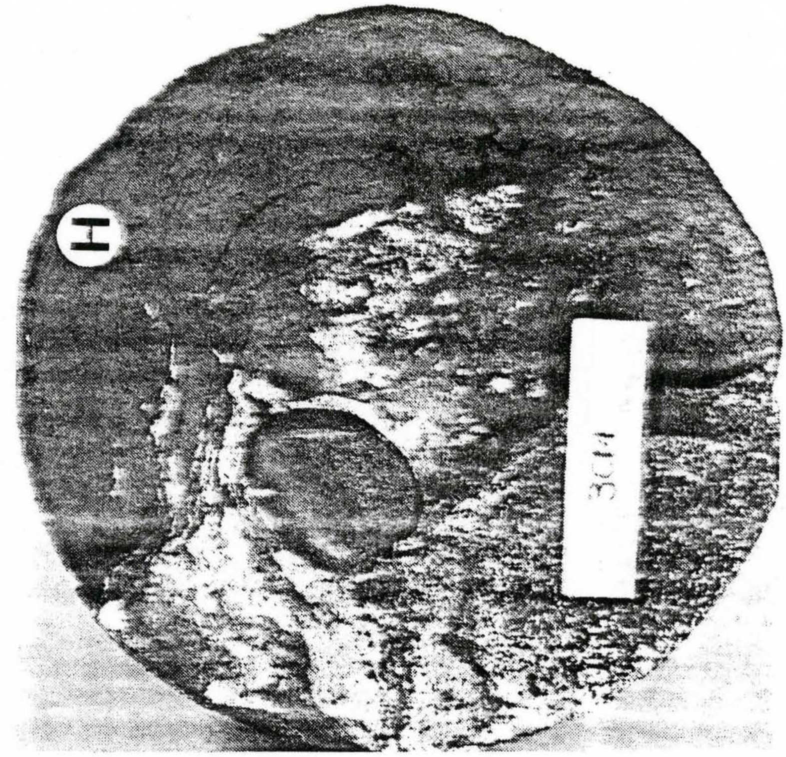
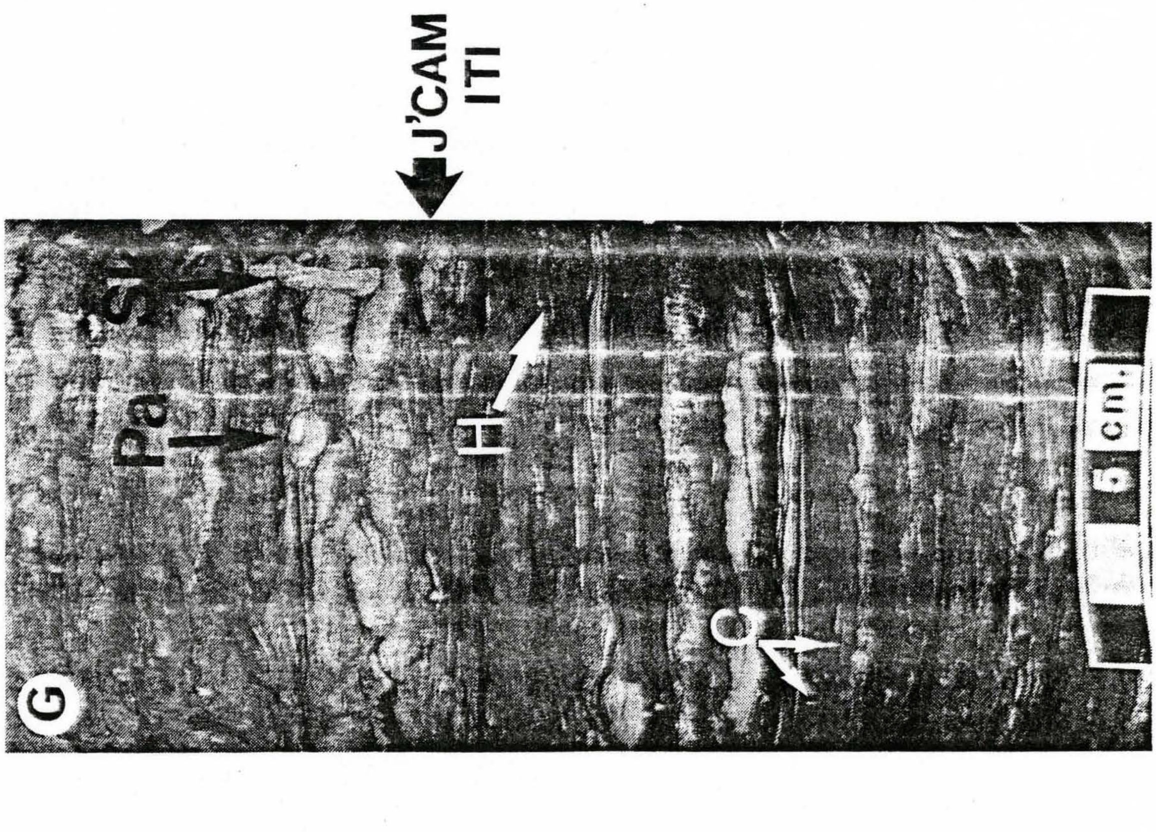

E
5 cm.

Figure 3.10 (cont'd) **Facies Association 2B**

G) Muddier sediments of regional succession 2/3 are overlain sharply (but subtlely) by relatively sandier facies at the base of FA 2B. The contact has no distinct trace fauna (ie. *Glossifungites*) associated with it and the change from below to above is marked by a slight change in the character of the ichnogenera. Note the *Palaeophycus (Pa)* and *Skolithos (Sk)* at the base of FA 2B and the *Chondrites (C)* and *Helminthopsis (H)* in the regional successions (FA. 1). Well 07-21-49-21W4; 995.0m; 3 inch whole core.

H) Rare black chert pebbles may mantle the basal contact of FA 2B with the underlying regional successions. In this case the chert pebble sits in black shale of FA 2B immediately above a low angle cross bedded sandstone at the top of regional succession 3. Well 10-32-48-21W4; 1016.7m; 3 inch whole core; scale bar 3cm.


H
3CM


G
Pa
Si
H
J'CAM
ITI
5 cm.

The top of the coarsening upward succession is likewise sharp and erosive and is typically overlain by a thin (1-25 cm thick) muddy conglomerate or conglomeratic sandstone bed. No distinct hardground trace fauna were observed at the upper or lower boundary contacts of this facies association.

Within the study area, there are possibly six localities where this facies succession occurs. Core from one of these locations (Joarcam) has been observed; the other five locations have been interpreted based upon well log signatures and correlations.

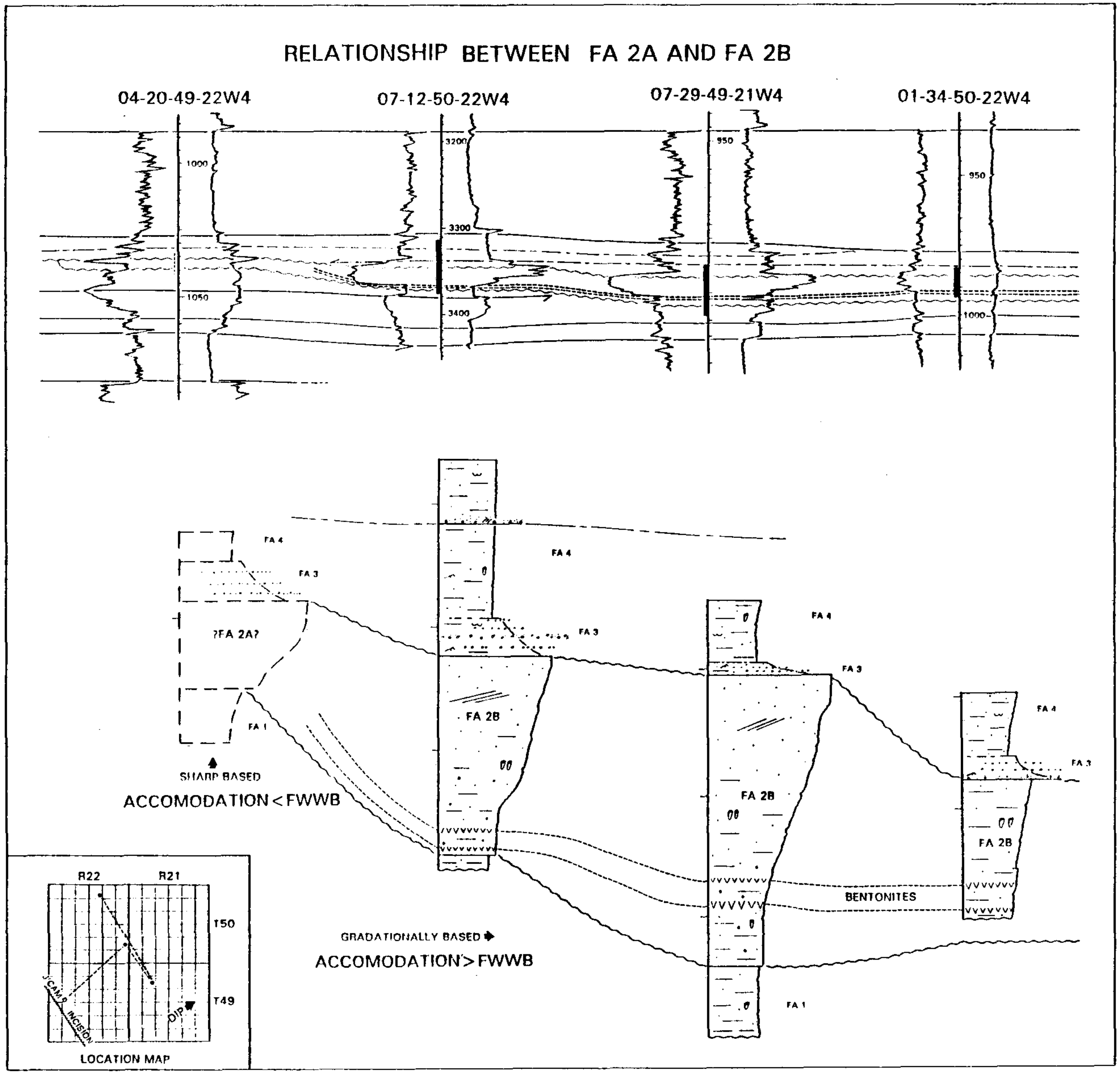
INTERPRETATION: The smooth gradation upwards from silty shales to muddy sandstones followed by sandstone suggests a prograding succession. Sedimentary structures and trace fauna also show a gradual progression upwards indicating decreased relative depth of sea level with time. In all, the package is interpreted as a regressive offshore marine to middle shoreface succession. The upper boundary is interpreted as a transgressive surface of erosion with associated lag overlying it. The interpretation of the erosion surface beneath the succession is almost entirel based upon truncation of the 'stacked' successions of FA 1 which is observed in well log cross sections (see chapter 5). The interpretation of an underlying erosional incision is similar in concept to that which was originally proposed by Downing and Walker (1988) at Joffre field. This facies succession tends to form in the distal portions of the incised shorefaces where the shoreface progrades into the basin to a depth sufficient to allow silty mudstones to accumulate before progradation and deposition of shoreface sandstone occurs. Within the Joarcam shoreface a facies association similar to FA 2A is interpreted to occur for the first 4-5 km east of the transgressive scour that the shoreface sits upon (as suggested by the relatively sharp basal contact of the shoreface in well logs) (figure 3.11). This facies succession (FA 2B) is prevalent basinwards of the inferred presence of FA 2A at Joarcam .

3.5 Facies Association 3: Fining Upward Interbedded, Conglomerate Mudstone and Sandstone Succession

Facies association 3 comprises moderately to poorly bioturbated, interbedded conglomerate, sandstones and silty mudstones that form a fining upward facies succession. The type well for this facies association is located at 2-19-48-20W4; a panel describing the SP and resistivity well log and core character of the type well is provided in figure 3.12. Figure 3.13 is a photomontage of the core from this well. Table 3.3 shows the descriptions of some past workers.

This association comprises matrix supported, muddy or sandy conglomerate or very coarse-grained sandstone at the base, followed by interbedded very coarse-grained muddy sandstones, fine-grained sandstones and silty mud in the middle, then by fine-grained sandstones and silty mud

Figure 3.11 Diagram illustrating the relationship between FA 2A and FA 2B. When accomodation space < FWWB a sharp based lower to middle shoreface succession (ie. FA 2A) will be formed directly above an erosion surface. When accomodation space > FWWB a gradational offshore to middle shoreface succession will develop (ie. FA 2B). Locations of the wells are illustrated in the inset map. Positions of the core are shown by vertical black bars on the well logs. The core interval indicated by the 'hatched' vertical column on the far left well corresponds to the interval represented by the inferred core log shown below which illustrates FA 2A.



RELATIONSHIP BETWEEN FA 2A AND FA 2B
04-20-49-22W4
07-12-50-22W4
07-29-49-21W4
01-34-50-22W4
SHARP BASED
ACCOMODATION < FWWB
GRADATIONALLY BASED
ACCOMODATION > FWWB
?FA 2A?
FA 2B
FA 4
FA 3
FA 1
BENTONITES
LOCATION MAP
R22
R21
T50
T49
DIP
CAMP INCISION

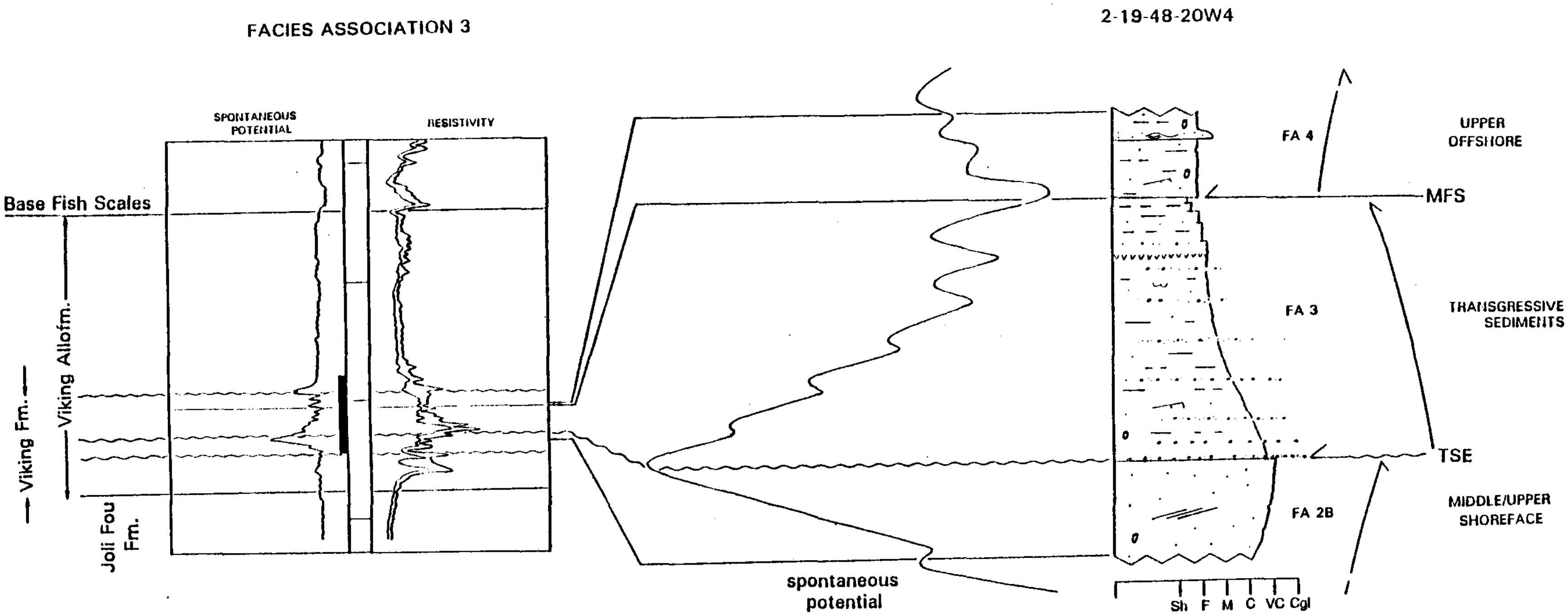
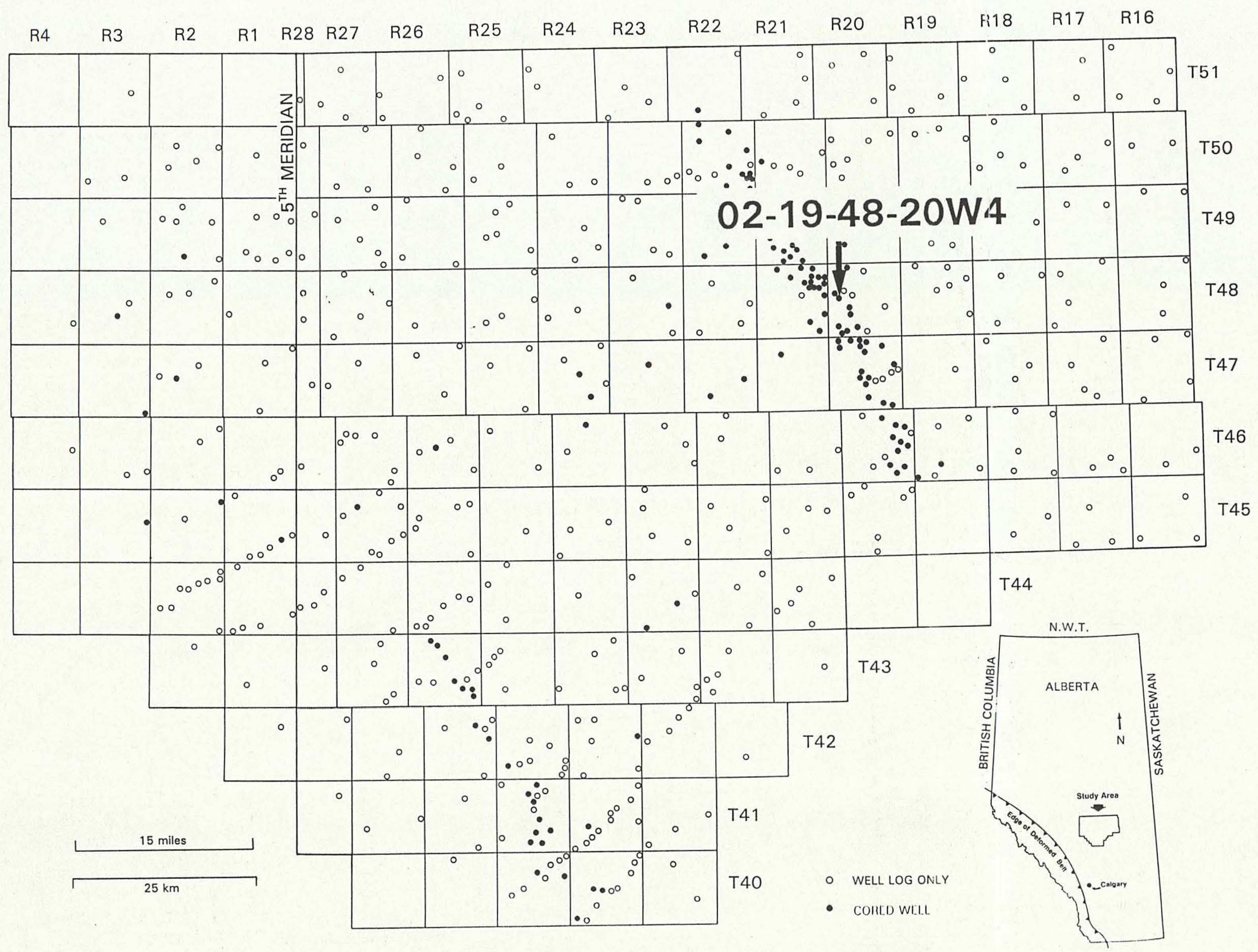


Figure 3.12 Type well for facies association 3 from 02-19-48-20W4 (984-973m) which illustrates a transgressive succession underlain by shoreface sediments of FA 2B and overlain by sediments of FA 4. The corresponding spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

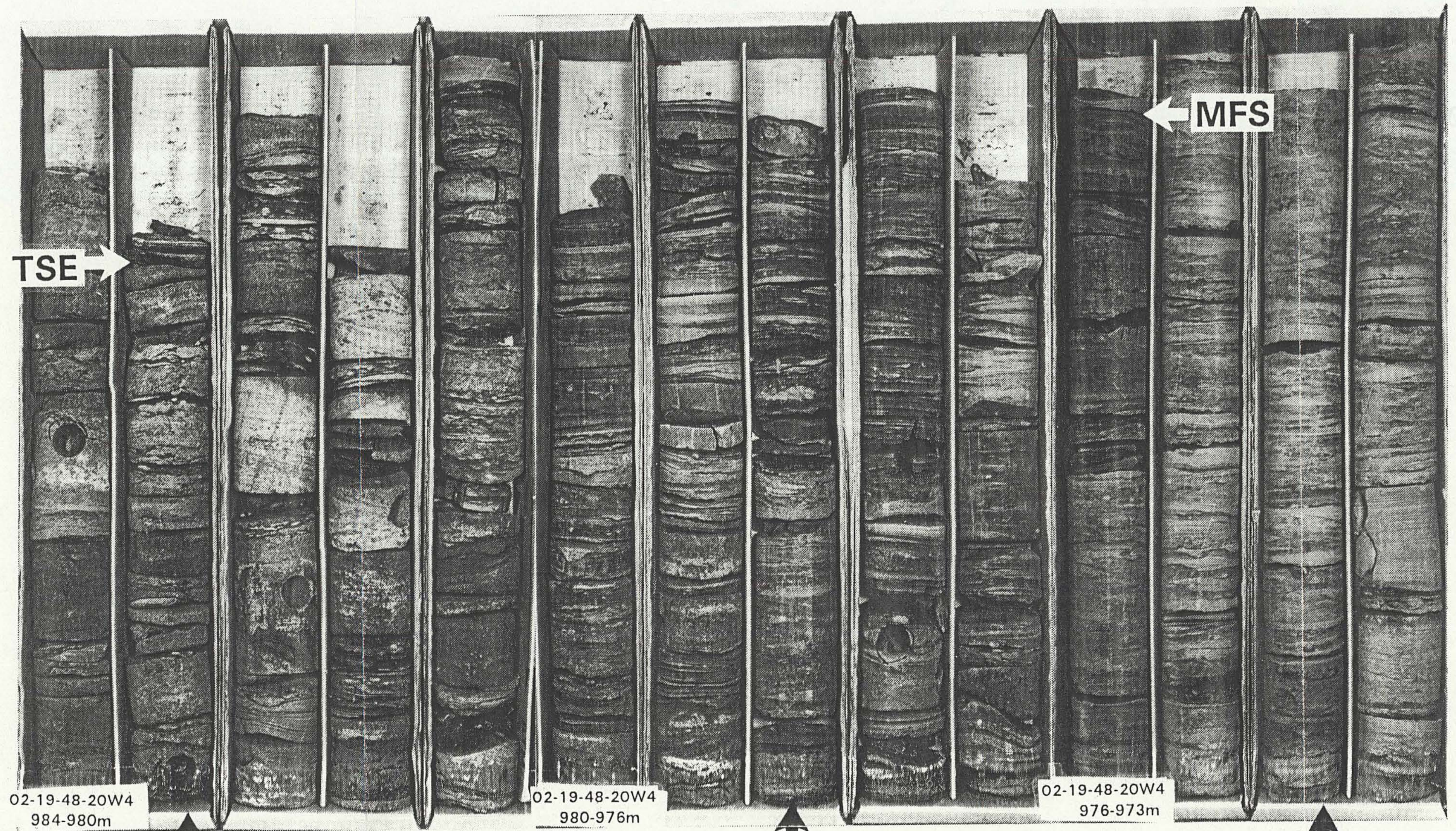
Figure 3.13 Core photographs of the type core for facies association 3 with bounding discontinuities indicated. Location of the core is provided on the map.



02-19-48-20W4
(3" Whole Core)

TYPE CORE: FACIES ASSOCIATION 3

TOP



BOTTOM

FA. 2B FA. 3 FA. 4

Table 3.3: Facies equivalents of past workers

FA 3: Fining-Upward Interbedded Conglomerate, Silty Mudstone & Sandstone Succession		
Reference	Field	Facies Designation (s)
Posamentier & Chamberlain (1991)	Joarcam	Member "C" - Fining Upward
Power (1988)	Joarcam	Member "C"
Pattison (1991)	Crystal, Cyn-Pem, Sundance-Edson	Facies Association 10: Interbedded Mudstone, Sandstone,
Reinson (1985)	Crystal	Upper Transgressive Facies
Boreen & Walker (1991)	Willesden Green	sediments directly above VE3
Raychaudhuri (1989)	Chigwell	Facies 6C
Downing & Walker (1988)	Joffre	Association 5: Interlaminated Sandstones and Mudstones
Raddysh (1988)	Gilby A and B	Facies I
Pozzobon & Walker (1990)	Eureka	Facies C (?)
Hadley (1992)	Harmattan East & Crossfield	Facies 6 (Conglomerate) and 7B (Coarse Grained Burrowed,
Davies (1990)	Caroline & Garrington	Facies 6 (Conglomerate)

with scattered chert granules at the top. The volume of conglomerate varies from 90% at the base to only 2-3% at the top, and the grain size decreases upwards from pebbles (3-7 mm in diameter) to granules (2-3 mm in diameter). The volume of sand varies from approximately 10% at the base, to 40 or 50% in the middle, to 15-25% at the top. The grain size decreases steadily upward from very coarse- to coarse-grained sand at the base to very fine- and fine-grained sand at the top. Bentonites (3-10 cm thick) and sideritic horizons (4-6 cm thick) are present. This succession reaches its fullest development east of the Joarcam field; elsewhere it has variable thickness and rarely shows full development.

Bioturbation within this succession is generally of low diversity and abundance. Typically, the trace fossil assemblage consists of *Thalassinoides* and *Diplocraterion habichi* burrows which are passively infilled and subtend vertically from coarser beds near the base and middle parts of the succession (figure 3.14A, B, C). Towards the middle and top of the package, *Chondrites, Teichichnus, Helminthopsis* and *Planolites* traces tend to dominate finer grained beds. Throughout the succession, fugichnia may occasionally be observed cross cutting beds of very fine- to fine-grained sandstone.

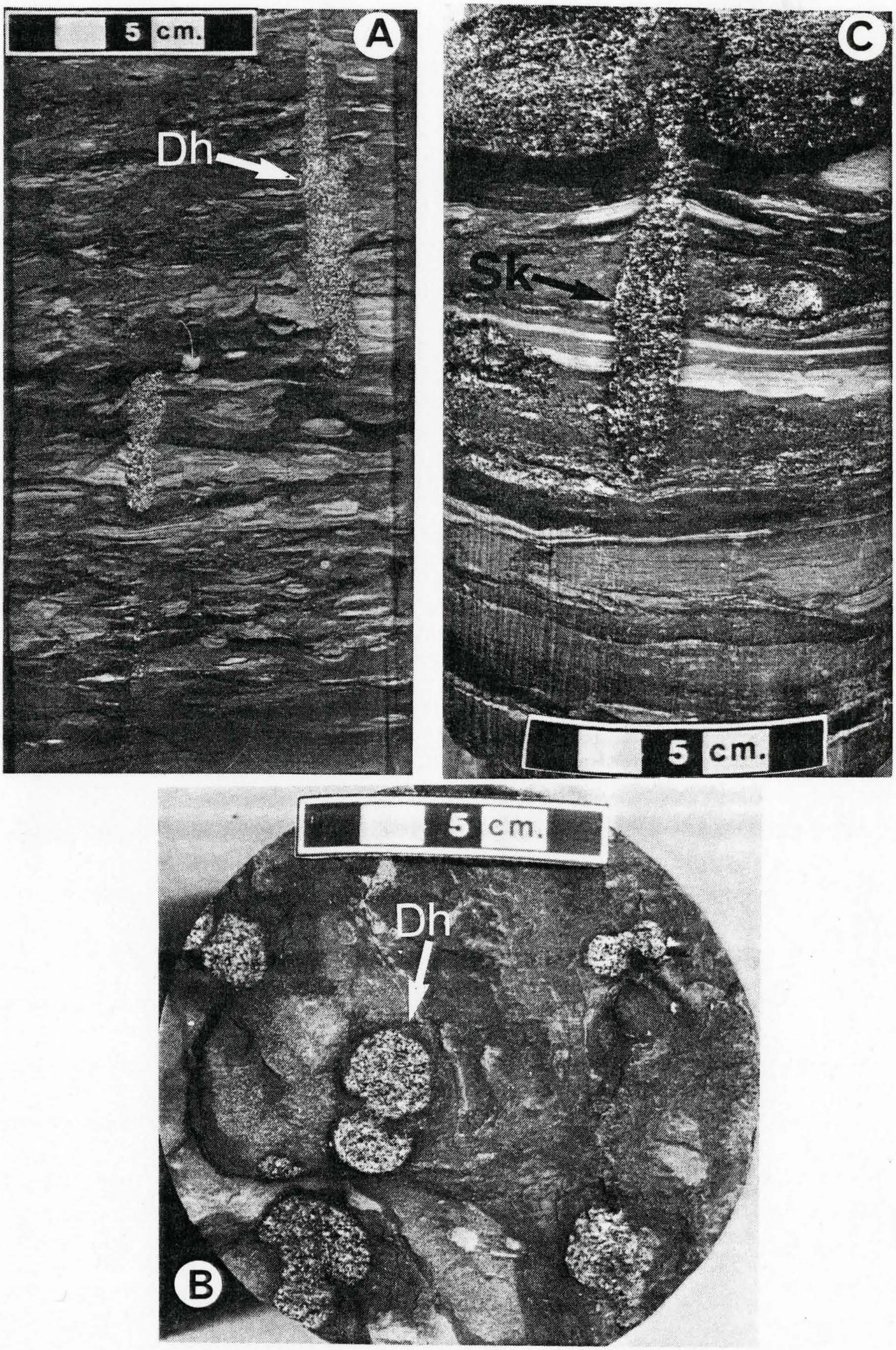
Sedimentary structures include planar cross bedding in pebbly sandstones and conglomerate occurring at the base of the succession; some

Figure 3.14 Facies Association 3

A) Passively infilled, vertical *Diplocraterion habichi (Dh)* burrows subtend from storm emplaced coarse sandstone layers. Well 03-19-49-21W4; 996.2m; 4 Inch slabbed core.

B) Typical plan view of *Diplocraterion habichi (Dh)* which are characterised by the close set or 'double barrel' vertical tubes. Coarse sandstone has passively infilled the vacated burrows during storm emplacement. Well 06-24-46-20W4; 982.0m; 4 inch whole core.

C) This *Skolithos (Sk)* burrow has been infilled with coarse sandstone from an overlying bed that represents a sharp based, storm emplaced layer. Well 10-06-48-20W4; 978.4m; 3 inch whole core.


5 cm.
A
Dh
C
Sk
5 cm.
5 cm.
Dh
B

of these beds are also massive (figure 3.14D). Wave/combined-flow ripples and wavy and parallel laminations occur in sandstone beds troughout the succession. Cross bedded/massive pebbly sandstones and conglomerates are generally 5-35 cm thick, becoming thinner and finer grained upward. They have sharp bases and relatively sharp tops. In places, several large granules occur at the base of these beds and they may show crude normal grading. Sandstone and conglomerate may contain some vaguely discernable cross bedding (figure 3.14E). Rippled and wavy or parallel laminated sandstone beds occur throughout the facies succession where they usually make up 3-8 cm thick beds that thin and fine upwards, with sharp bases and gradational upper contacts (figure 3.14F). These beds may also contain coarser grained sand present as a lag at their base, or disseminated throughout. These beds tend to grade normally upward to very fine sand, silts and shale.

This succession has a sharp, erosive base marked by a very coarse-grained sandstone or sandy/muddy conglomeratic lag (figure 3.14G, H). The contact may overlie incised shoreface deposits of FA 2A (ie. Chigwell) or FA 2B (ie. Joarcam), or may overlie 'regional' coarsening upward successions of FA 1. Although the entire facies succession is variably preserved, the coarse lag marking the base of the succession is almost always identifiable. The sharp increase in grain size from below to above the erosive contact,

Figure 3.14 (cont'd) Facies Association 3

D) Note the sharp and erosive base of the coarse gritty sandstone bed, mudstone and sandstone rip up clasts, contorted internal structure and crude draping of overlying sandy mudstone. Background sedimentation, deposited between storm events, is represented by the silty mudstone at the top of the photo. Well 16-12-48-21W4; 978.2m; 4 inch whole core.

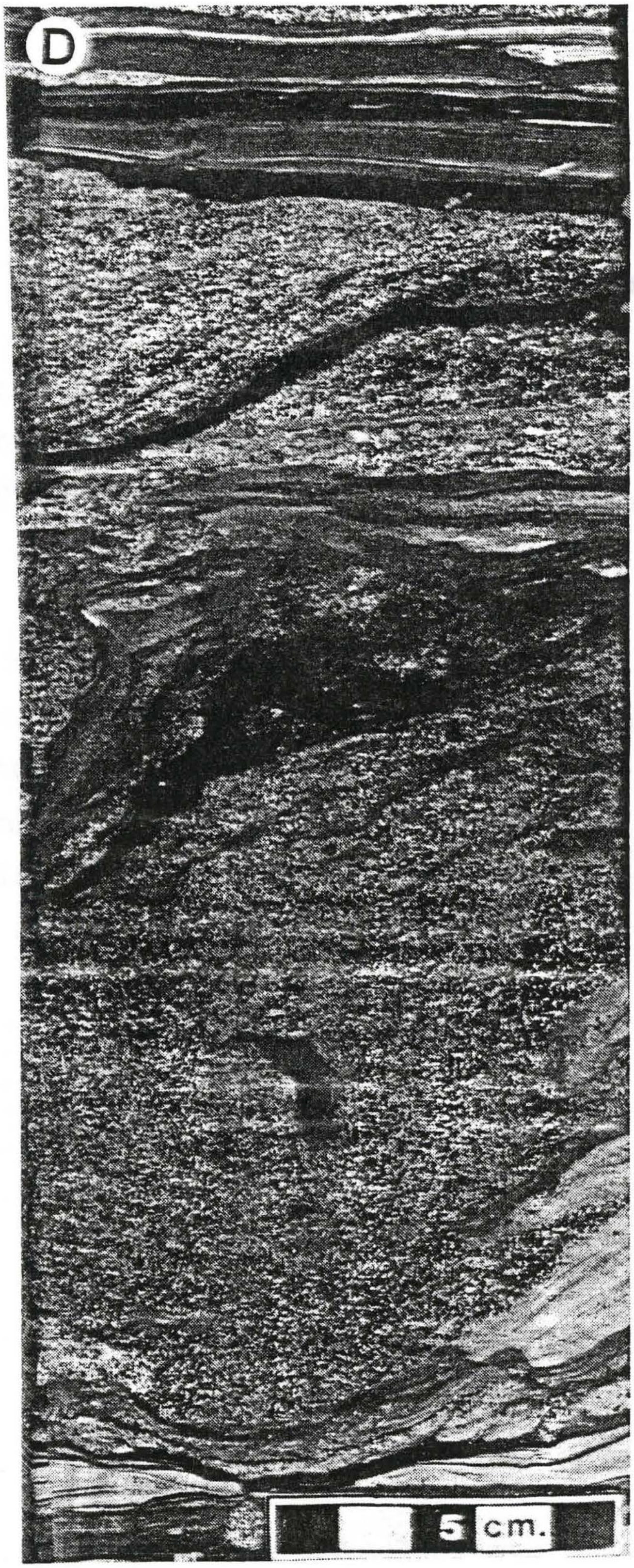
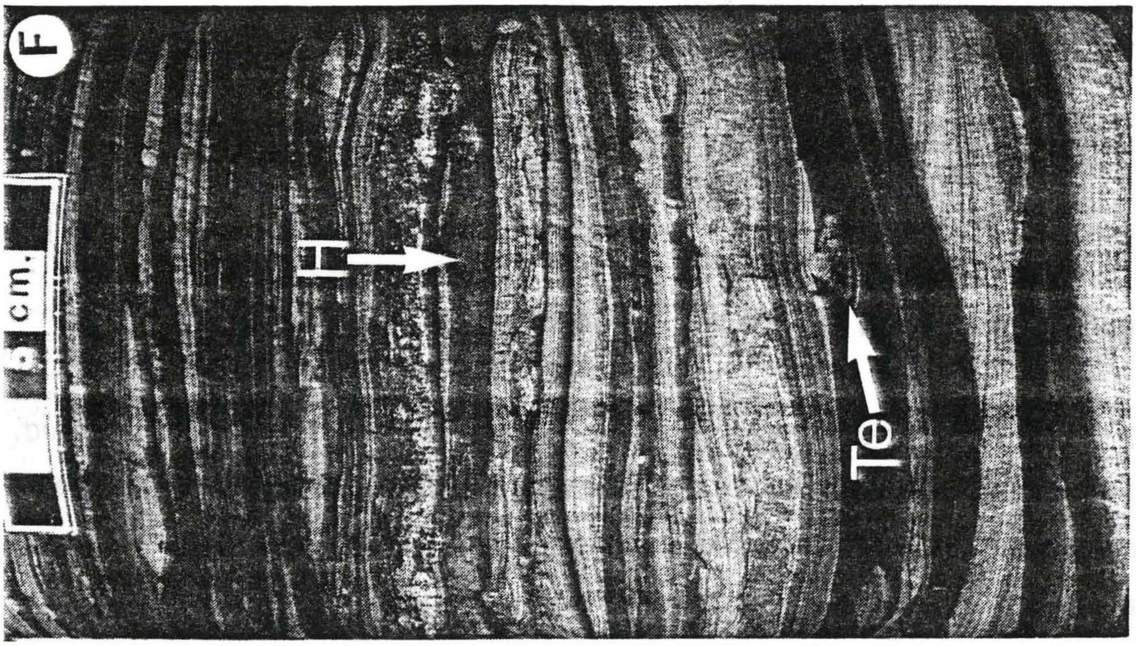

D
5 cm.

Figure 3.14 (cont'd) Facies Association 3

E) Cross bedding in the gritty sandstones is common. Note again the sharp and erosive nature of the base of the bed which has truncated bedding bioturbated by *Planolites (P)* burrows. Well 16-12-48-21W4; 978.8m; 4 inch whole core.

F) Towards the top of the succession, rippled and wavy or parallel laminated sandstones and silts are common and typically have sharp bases, fine upwards, and may have bioturbated tops. Gritty sandstones are present only as thin layers. Note also the *Teichichnus (Te)* and *Helminthopsis (H)* burrows in the muddier sediments. Well 14-25-45-2W5; 1618.3m; 4 inch whole core.


F
5 cm.
H
Te

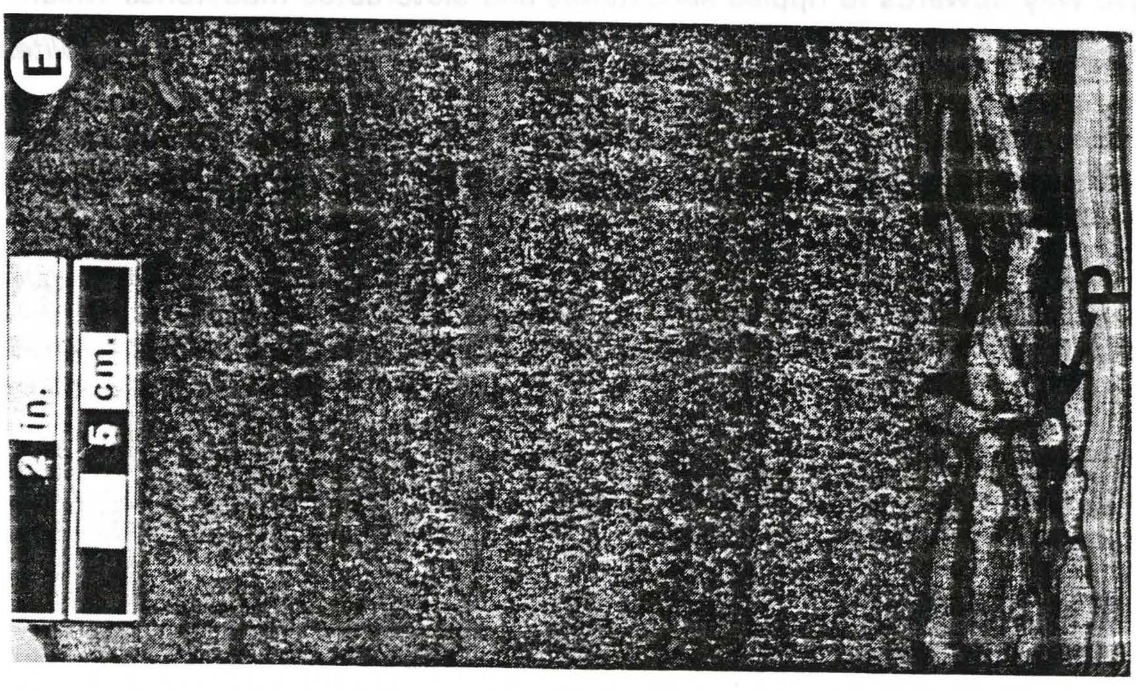
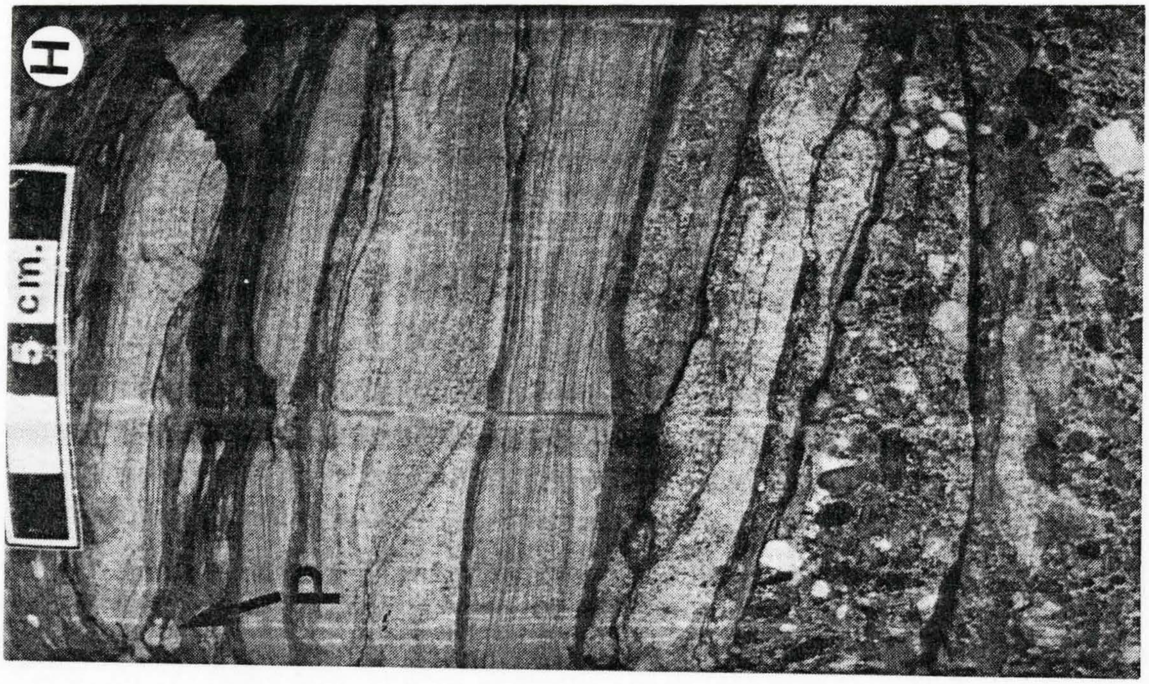
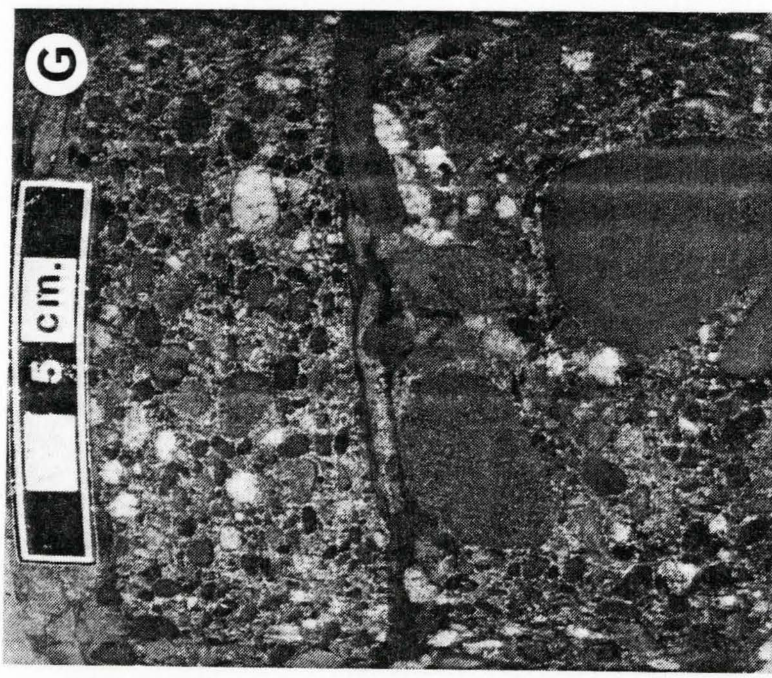

E
2 in.
5 cm.
P

Figure 3.14 (cont'd) Facies Association 3

G) The base of this succession is often characterised by a poorly sorted, polymictic conglomerate with abundant sideritised mudstone clasts. The base of the bed is sharp based and erosive and is interpreted as a transgressive surface of erosion overlain by conglomeratic lag. Well 06-11-43-26W4; 1418.5m; 4 inch whole core.

H) Conglomeratic lags may show very crude normal grading and often give way upwards to rippled sandstones and bioturbated mudstones which represent 'background' sedimentation. Bioturbation is resticted to *Planolites (P)* in this photo. Well 06-11-43-26W4; 1417.8m; 4 inch whole core.


H
5 cm.
p


G
5 cm.

the interstratified nature of the succession, and its fining upward character makes its identification reliable in core or well log. The upper contact of the succession is normally completely gradational, however, it may be locally sharp and erosive. Where gradational, the top of this association is picked at the point where the sediments cease to fine upward and begin to become sandier/coarser upward. This almost always corresponds to the last occurrence of chert granules or very coarse sand in the package. This is commonly the position of a dark shale bed which separates this succession from the overlying one. Where the top of the succession is sharp, it is erosively overlain (and thus variably preserved) by a matrix-supported conglomerate, sandy conglomerate or muddy coarse sandstone of facies association 6 (to be discussed). The sharp contact is interpreted to represent an erosion surface overlain by transgressive deposits. If the depth of erosion on this surface is great enough this association will only be partially preserved.

INTERPRETATION: The sedimentary structures and the progressive fining upward nature of the succession suggest deposition in a transgressive marine setting. Cross bedding in coarse sandstones and conglomerates passing upwards to rippled fine sandstones and shales suggests an evolution from shoreface to offshore depositional environments. The ichnofacies provide supporting evidence for increasingly deeper marine conditions through time. The sharp base of the succession is interpreted as a transgressive surface of erosion formed by wave action in the shoreface, which by landward translation through the process of erosive shoreface retreat, has 'cannibalized' the upper parts of the shoreface and beach and redepositing them "offshore" as conglomeratic lags (Posamentier and Chamberlain, 1989). As relative sea level rises, the succession becomes progressively finer grained and the coarse sandstones, interpreted as storm beds, become thinner as their deposition becomes more and more infrequent. The top of the succession is interpreted as a maximum flooding surface during which a condensed horizon (dark marine shale) was deposited.

This facies association occurs throughout the study area and appears to be thickest directly east of the Chigwell field and especially east of the Joarcam field. Essentially, this package blankets the tops of incised shorefaces, valley fills and regional successions, its variable preservation perhaps due to the infilling of underlying topographic irregularities in the erosion surface or by later erosive removal.

3.6 Facies Association 4: Coarsening Upward Interbedded Mudstone, Silty Mudstone and Sandstone Succession.

Facies association 4 consists of variably bioturbated, interbedded sandstone, siltstone, shales and minor conglomerate that form a series of crudely coarsening upward facies successions. The type well for this association is located at 7-5-48-20W4. The gamma, SP and resistivity well log character as well as the schematic core character of the type well is illustrated in figure 3.15. Figure 3.16 is a photomontage showing the core character of the type well. Table 3.4 shows the descriptions of past authors.

This association comprises poorly bioturbated, interbedded fine-grained sandstone, silty shale and shale at the base. Similar, albeit sandier and poorly to moderately bioturbated lithologies occur in the middle, followed by moderately bioturbated fine-grained sandstone, silt, shale and minor conglomerate granules at the top. The volume of sand varies from 30-40% at the base up to 70-80% at the top. Siltstone tends to make up 15-20% sediment volume at the base and only 5-15% at the top. Sandstone grain size increases from very fine- to fine-grained at the bottom up to fine-grained towards the top. Disseminated chert granules (2-3 mm in diameter) and very coarse sand may be found in the upper half of the successions (figure 3.17A). Commonly, 15-30 cm thick fine grained sand beds with hummocky cross stratification are present (figure 3.17B). The entire facies association may be present as vaguely 'stacked' successions which may be resolved with core but are not recognised from well logs. Bentonites (5-10 cm thick) and sideritic horizons (15-30 cm thick) are

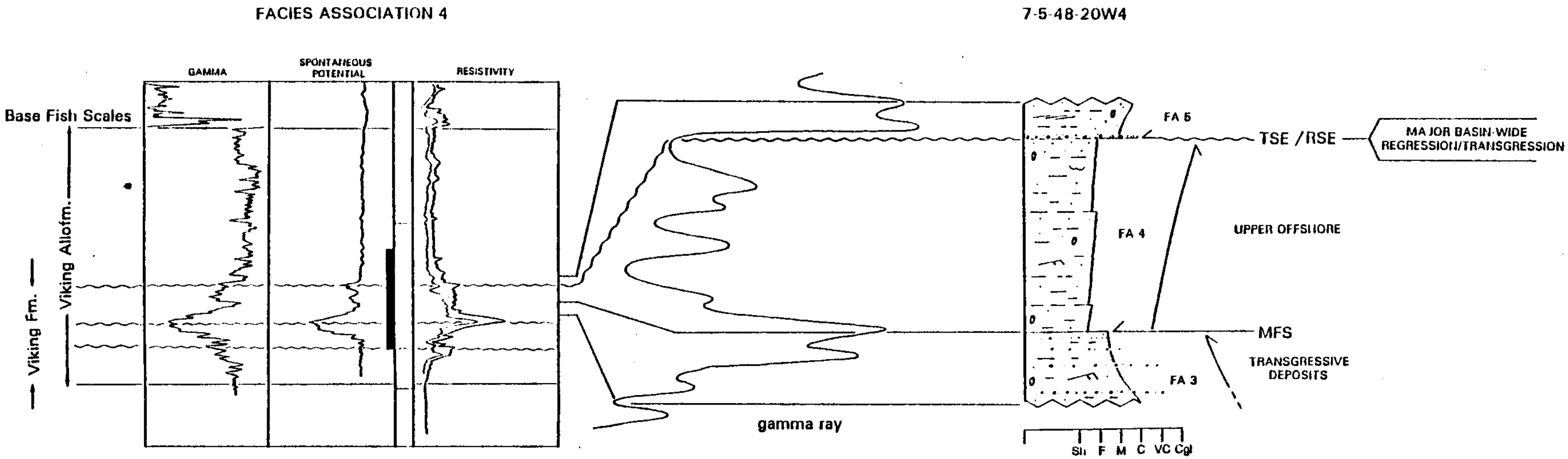
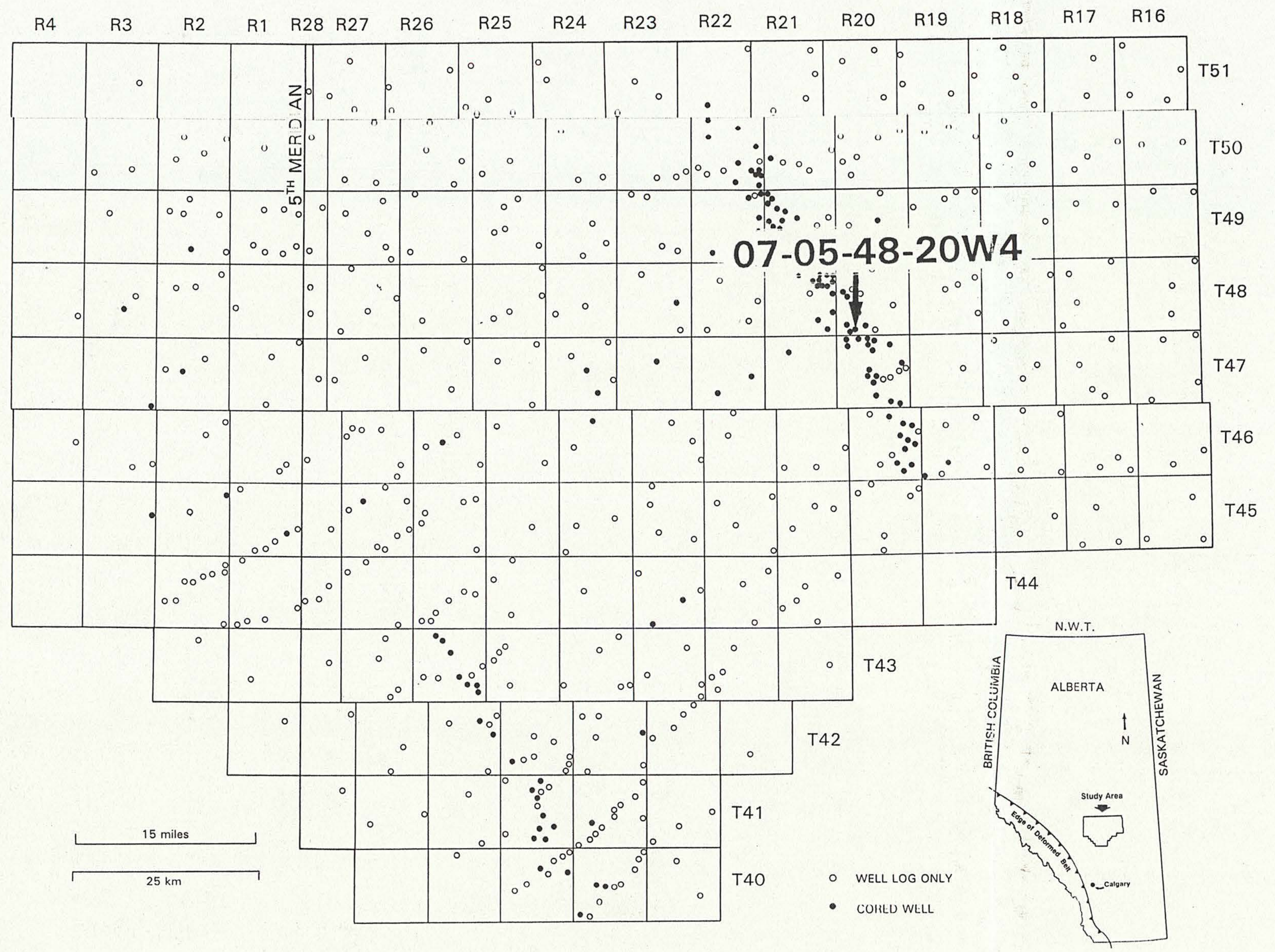


Figure 3.15 Type well for facies association 4 from 07-05-48-20W4 (969-959m) which illustrates a regressive succession (FA 4) underlain by transgressive sediments of FA 3 and sharply overlain by sediments of FA 5. The corresponding gamma ray, spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

Figure 3.16 Core photographs of the type core for facies association 4 with bounding discontinuities indicated. Location of the core is provided on the map.



07-05-48-20W4

(3.5" Slabbed Core)

TYPE CORE: FACIES ASSOCIATION 4

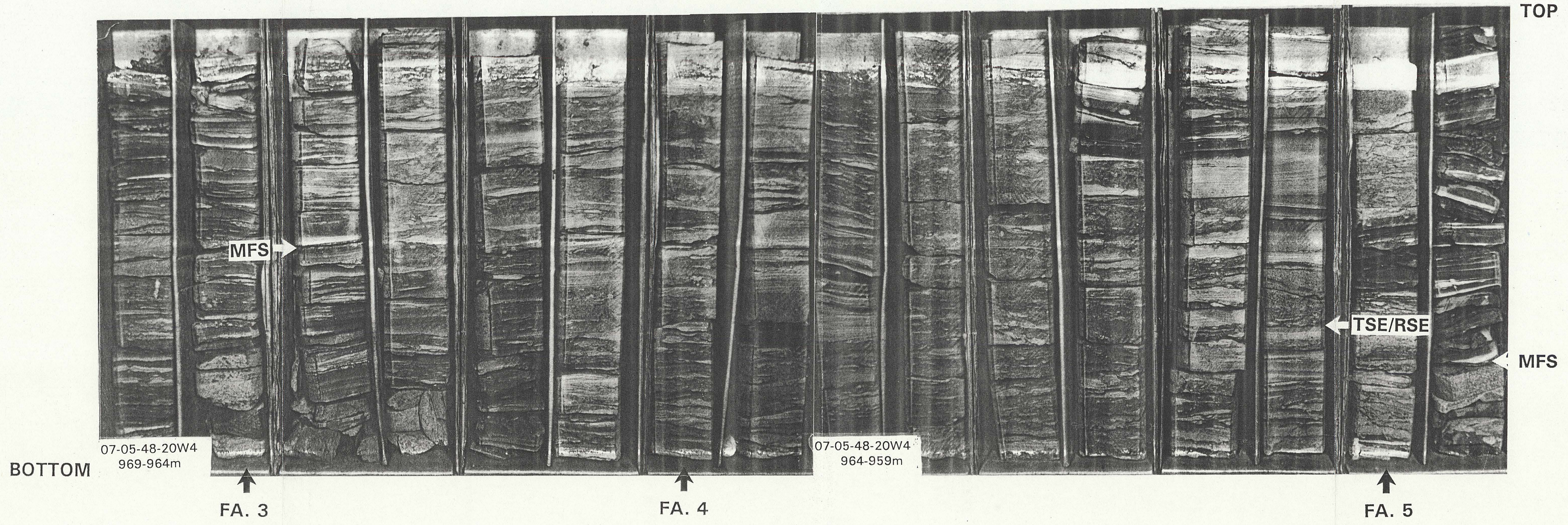


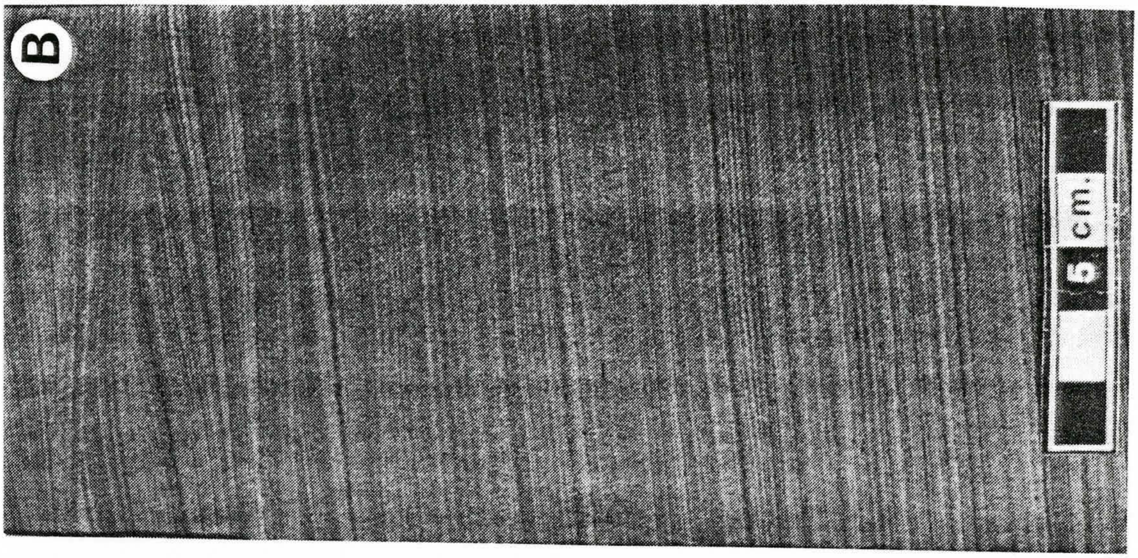
Table 3.4: Facies equivalents of past workers

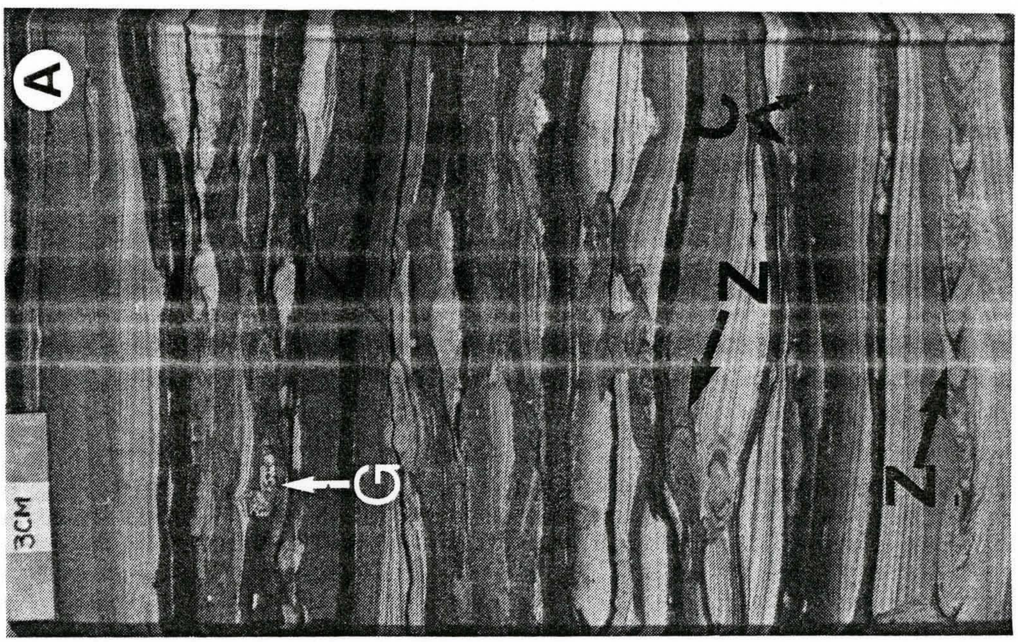
FA 4: Coarsening-Upward Interbedded Shale, Silty Shale and Sandstone Succession		
Reference	**Field**	**Facies Designation (s)**
Posamentier & Chamberlain (1989)	Joarcam	Member "C" - Coarsening Upward
Power (1988)	Joarcam	Member C
Pattison (1991)	Crystal, Cyn-Pem, Sundance-Edson	No Designation
Reinson (1985)	Crystal	No Designation
Boreen & Walker (1991)	Willesden Green	Facies Association 4: HCS Sandstone Association
Raychaudhuri (1989)	Chigwell	Facies 7A
Downing & Walker (1988)	Joffre	Association 5: Interlaminated Sandstones and Mudstones
Raddysh (1988)	Gilby A and B	No Designation
Pozzobon & Walker (1990)	Eureka	Facies E
Hadley (1992)	Harmattan East & Crossfield	Facies 7A (Fine Grained Burrowed Laminated Mudstone and
Davies (1990)	Caroline & Garrington	Facies 2 (Burrowed and Laminated

Figure 3.17 Facies Association 4

A) Typical 'striped' character of FA 4 sediments having an overall low ichnotaxonomic diversity comprising mainly *Zoophycos (Z)* and *Chonditres (C).* Note the small accumulation of very coarse-grained grit (G) towards the top of the core. Well 03-19-49-21W4; 998.0m; 4 inch slabbed core; scale bar is 3cm.

B) An example of hummocky cross stratification in fine grained sandstone which can reach a thickness of 30cm. Note the transition to wave rippled lamination toward the top. Well 14-08-48-20W4; 963.7m; 3 inch slabbed core.


B
5 cm.


A
C
Z
G
Z
3CM

present in places. The type well for this association shows three very crudely coarsening upward packages.

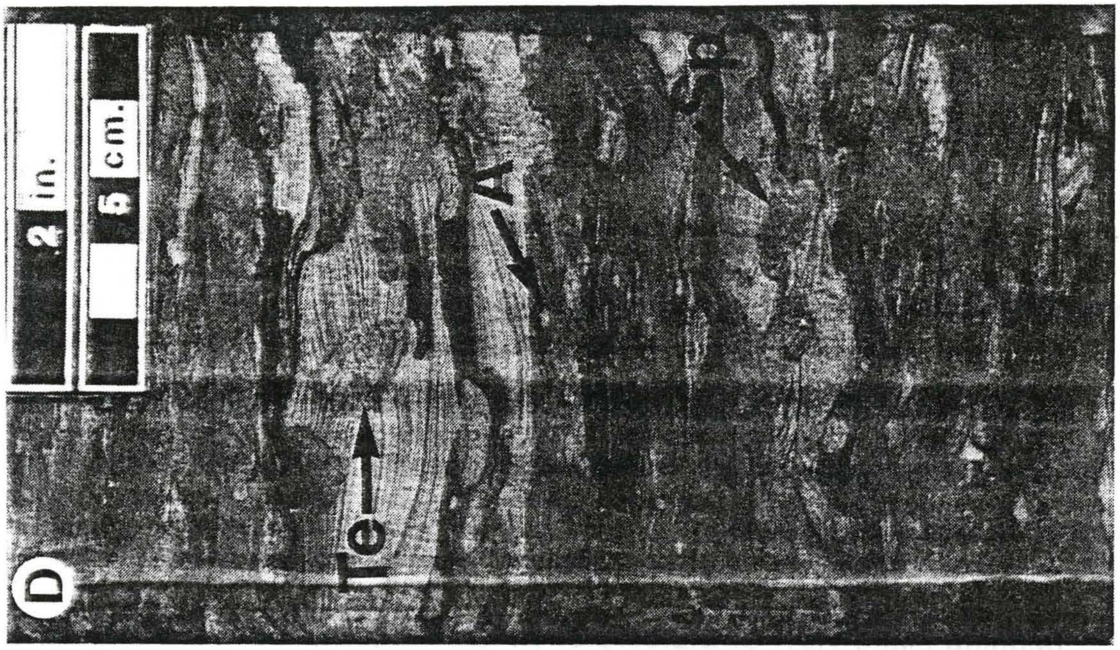
The degree of bioturbation and the diversity of trace fauna is considerable. Generally, the ichnofauna consists of *Asterosoma, Zoophycos, Subphylumchordate, Chondrites, Terebellina, Palaeophycus, Planolites, Teichichnus, Helminthopsis, Diplocraterion habichi, Ophiomorpha,* and *Skolithos* (figure 3.17C, D, E, F, G) which form part of the *Cruziana* and *Skolithos* ichnofacies (Frey and Pemberton, 1984). Although the diversity of bioturbators is relatively constant, the local degree of bioturbation may vary considerably. In places, the entire facies succession is churned and reworked to such an extent that no bed is unaffected and most beds exhibiting sedimentary structures are partially to completely obliterated. The facies in this case will lose some of its distinctive 'striped' character and will appear more homogeneous. In addition, individual coarsening upward cycles within the entire package will be obscured. More commonly, the facies association displays only moderate bioturbation and although the diversity of traces is no less, it retains its typical 'striped' character. In some instances the more bioturbated variety may be 'stacked' vertically with the less bioturbated variant. However, there is no apparent regularity to this arrangement.

Sedimentary structures present within this association comprise

Figure 3.17 (cont'd) Facies Association 4

C) Sideritised zone of FA 4 which has been burrowed by *Planolites (P), Siphonichnus (Si),* and *Palaeophycus (Pa).* Well 16-12-48-21W4; 972.1m; 4 inch slabbed core.

D) Slightly more bioturbated version of this association which does not have as pronounced 'striped' character. *Asterisoma (A), Teichichnus (Tc), Siphonichnus (Si)* make up a relatively low diversity ichnofaunal assemblage typical of this association. Well 07-05-48-21W4; 971.0m; 3.5 inch slabbed core.


D
2 in.
5 cm.
Te
A

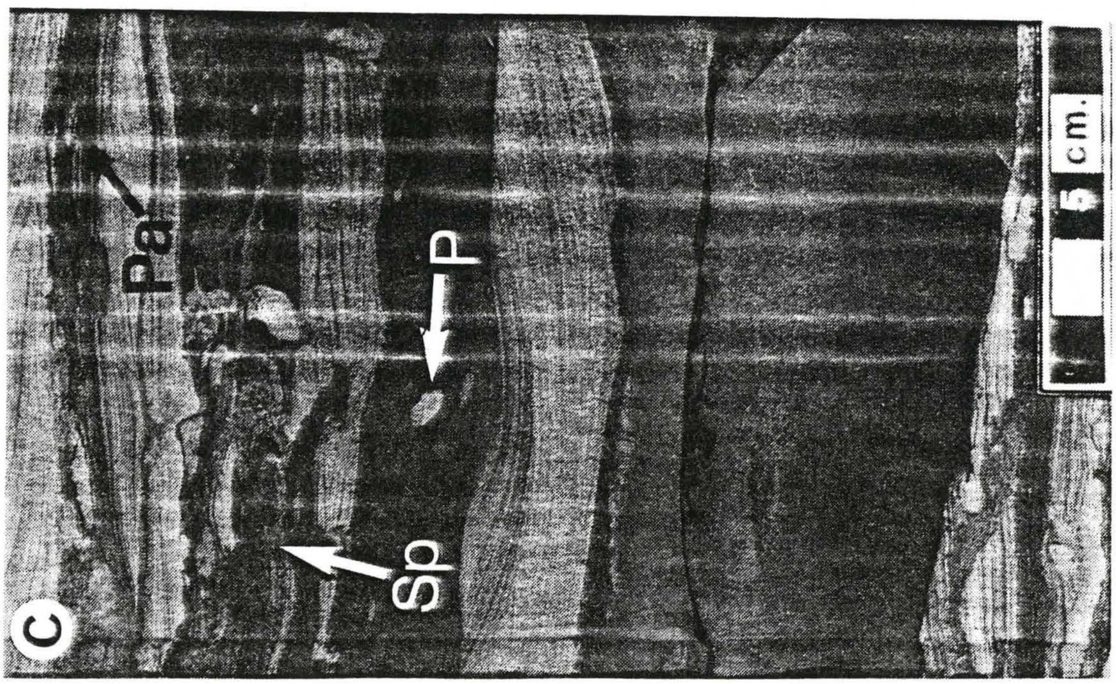
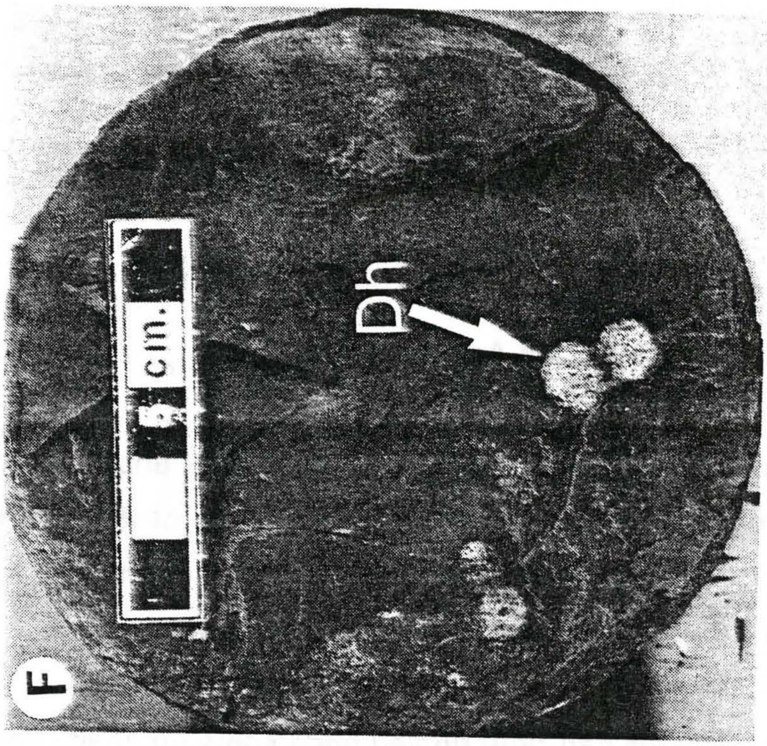

C
Pa
P
Sp
5 cm.

Figure 3.17 (cont'd) Facies Association 4

E) Profile view of an oblique trending *Opiomorpha? (O)* burrow in wave rippled fine grained sandstone. Well 07-21-49-21W4; 976.2m; 3 inch whole core; scale bar is 3cm.

F) Bedding plane view of *Diplocraterion habichi (Dh)* burrows which are passively infilled with fine grained sandstone. Well 06-11-43-26W4; 1416.2m; 4 inch whole core.


F
cm.
Dh

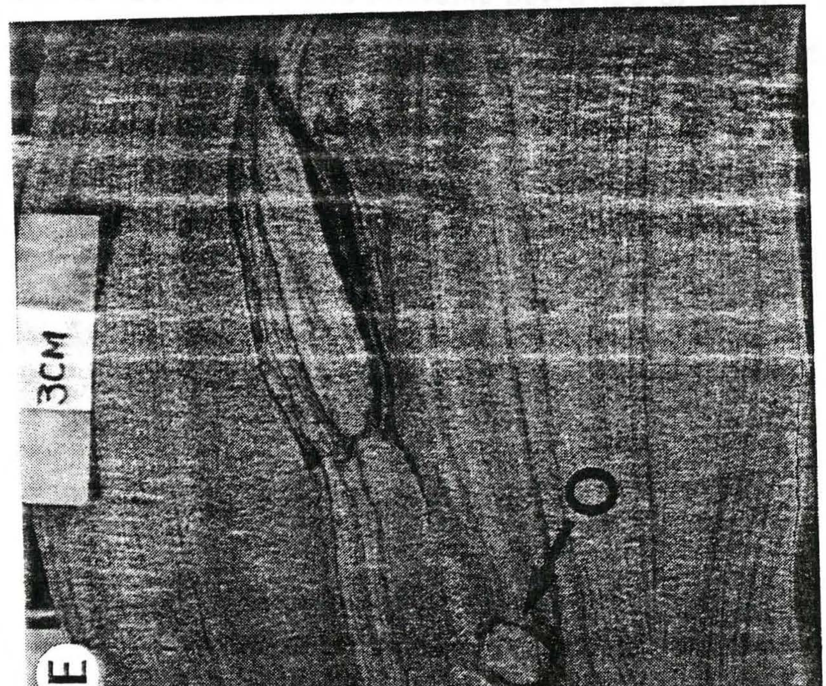
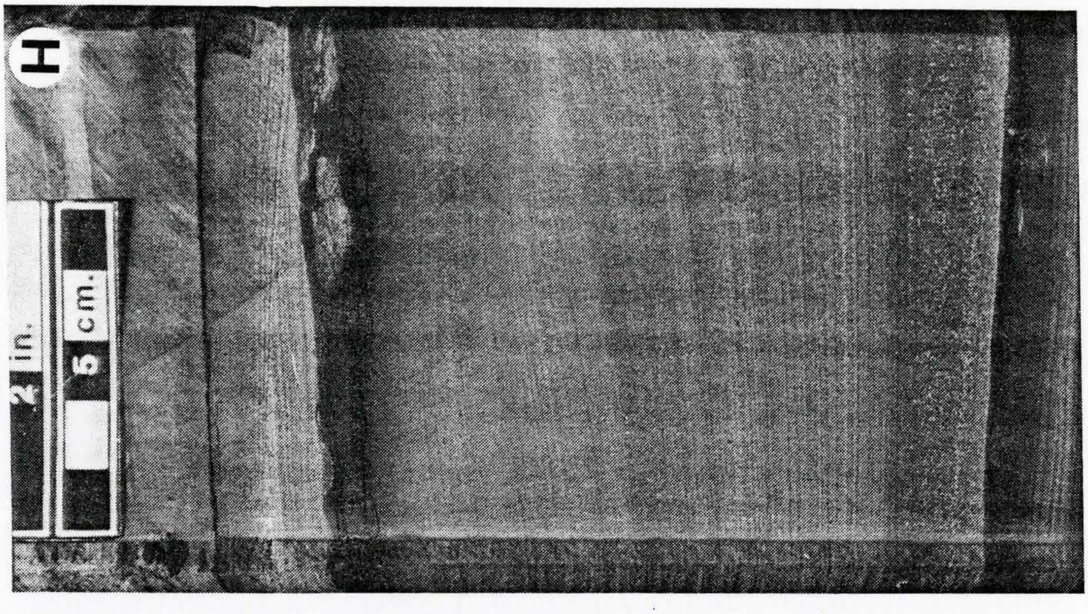
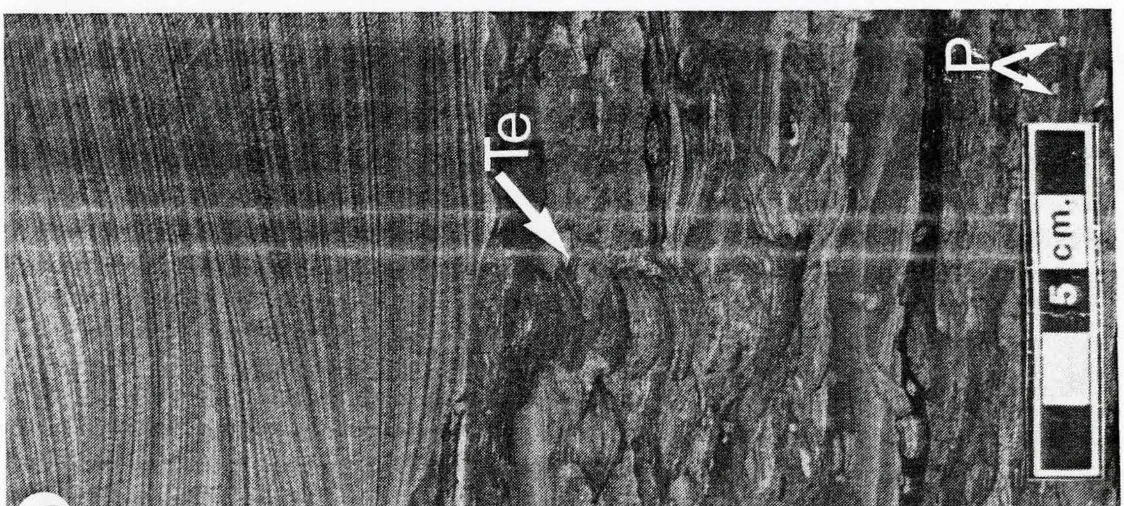

E
3CM
O

Figure 3.17 (cont'd) Facies Association 4

G) Sharp base wave rippled fine grained sandstone enplaced onto bioturbated sandy mudstones. Note the erosive base of the sandstone and the *Teichichnus (Te)* and small *Planolites (P)* burrows in the underlying facies. Well 14-08-48-20W4; 962.8m; 3 inch slabbed core.

H) Sharp based combined-flow rippled beds showing nicely developed normal grading. Note the sharp base and coarser nature of the sandstone which fines upward to burrowed siltstone and shale. Well 07-05-48-20W4; 968.5m; 3.5 inch slabbed core.


H
2 in.
5 cm.


G
Te
P
5 cm.

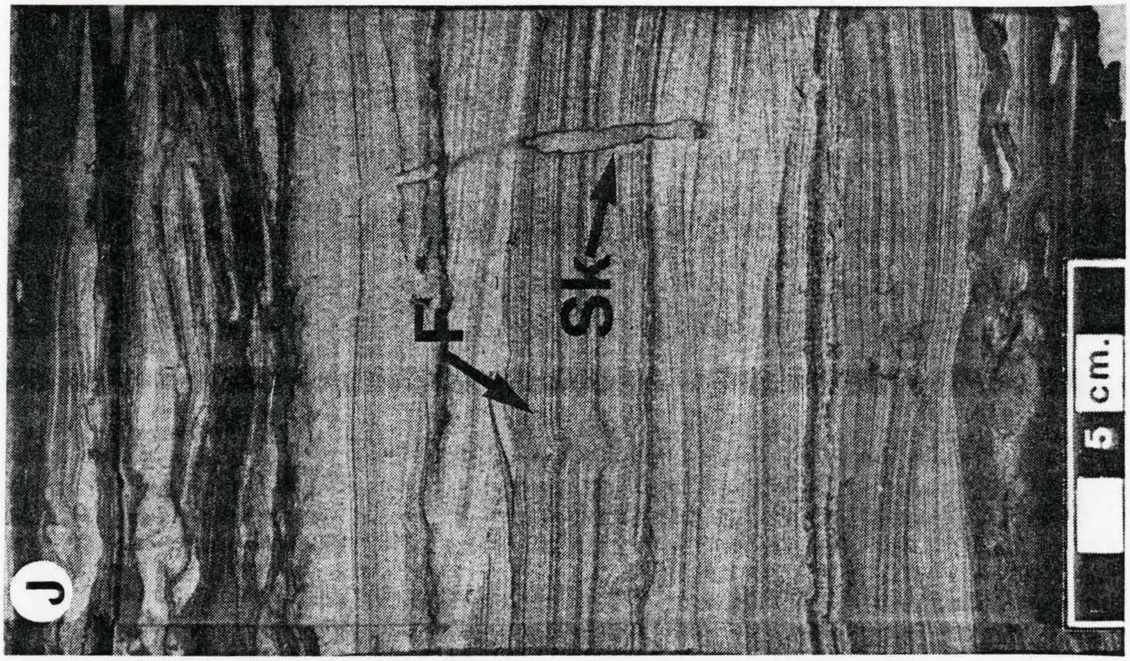
wave/combined-flow ripple, hummocky cross stratification and wavy/parallel (color) lamination in fine-grained sandstones which occur throughout the succession. Wave and combined-flow rippled sandstone beds are generally 2-10 cm thick, are sharp based and have gradational tops where they grade into silts and mudstones (figure 3.17G, H). Commonly, these beds are erosively amalgamated (figure 3.17I, J). Very coarse-grained sandstone may form a thin (few millimeters thick) lag at the base of these beds or occur disseminated throughout the lower portion of the bed. Hummocky cross stratified (HCS) sandstones are always sharp based on underlying muds, silts, or sands and have gradational tops with a progression upwards from HCS to wavy laminated sandstone to parallel (color) laminated silts and shales. The HCS beds are typically 10-40 cm thick and occur in the upper portions of the succession. Wavy and parallel laminated very fine sand and silt beds are 2-5 cm thick and may have sharp or gradational bases and gradational tops. Cross bedded sandstone occurs rarely near the top of the succession in sharp based beds 10-15 cm thick. These beds are made up of fine- to medium-grained sandstone and have sharp tops or less commonly may grade into very fine sandstone, siltstone and shale.

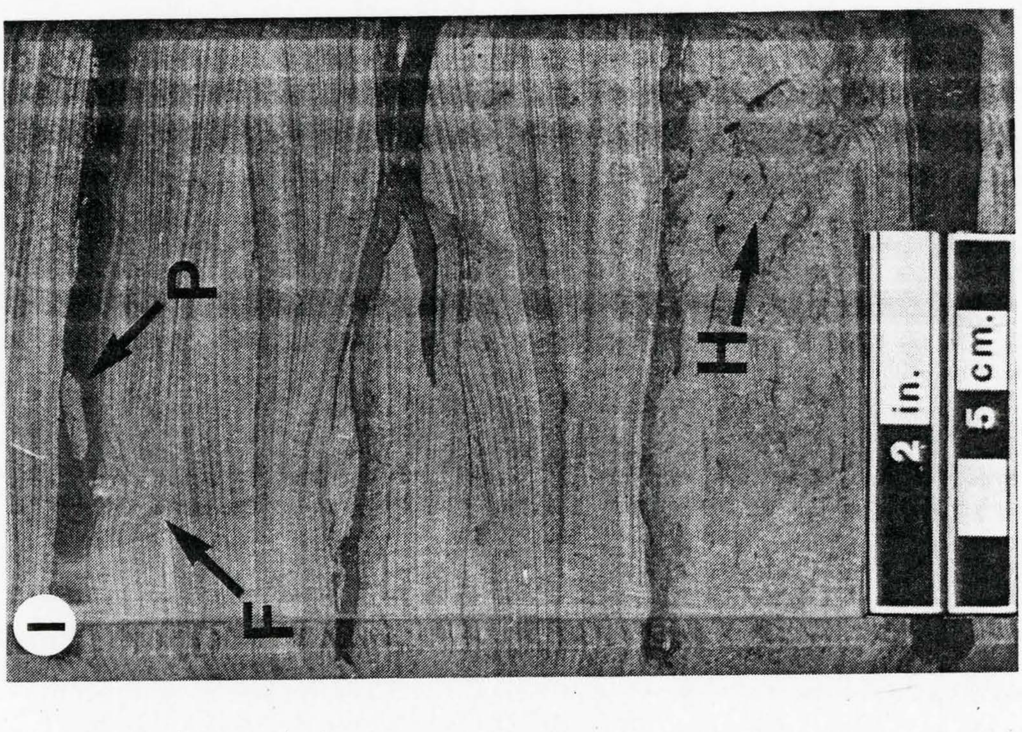
This succession has a gradational lower contact where it characteristically overlies a black mudstone, silty mudstone or gritty mudstone of FA 4. The base of the association is picked at the point on

Figure 3.17 (cont'd) Facies Association 4

I) Erosive amalgamation of rippled sandstones is common especially near the top of the association. In this case bioturbated rippled sandstones are separated by thin mudstone laminae at the top of each bed which is variably eroded by the base of the overlying bed. Bioturbation in the rippled sandstones include fugichnia (F), *Helminthopsis (H)* and *Planolites (P).* Well 07-05-48-20W4; 971.5m; 3.5 inch slabbed core.

J) Rippled sandstones amalgamated without intervening mudstone laminae. Note truncation of ripple laminae in underlying beds by overlying beds. These storm emplaced layers may have bioturbated tops or may be cross cut by vertical traces such as fugichnia (F) or sharp walled *Skolithos (S)* burrows. Well 16-12-48-21W4; 972.3m; 4 inch slabbed core.


J
F
Sk
5 cm.


I
F
P
H
2 in.
5 cm.

logs and core where the underlying sediment of FA 4 ceases to have a fining upward character and begins to coarsen upwards. There is a gradational increase in sandstone, grain size and bioturbation upwards through the succession. The top of the succession is sharp and erosive with a variety of sediments ranging from conglomerate, bioturbated muddy sandstone, gritty sandstone or sideritic gritty mudstone of FA 6. Trace fossils such as *Diplocraterion habichi, Skolithos, Planolites* and *Arenocolites* may be seen subtending from this erosional surface into the top of this succession. These traces are interpreted to belong to the *Glossifungites* ichnoassemblage of Frey and Pemberton (1984).

This facies association occurs in patches throughout the study area, being thickest in the Joarcam and Chigwell field areas and being thinnest (due to erosional removal) in the intervening areas.

INTERPRETATION: The progressively sandier upward nature of the succession and the suite of sedimentary structures suggests that this package was possibly deposited as a progradational succession mostly below storm wave base. Bioturbation suggests that fully marine conditions were present and that an active benthic community was established. This facies association is interpreted as having formed in an upper offshore environment. The gradational lower contact suggests gradual shallowing and associated progradation of the upper offshore basinwards. The lowermost sediments prograde out onto a maximum marine flooding surface capping FA 3. The upper sharp and apparently erosive contact is interpreted as a modified surface of erosion (RSE/TSE) associated with the VE4 transgression (to be discussed).

3.7 Facies Association 5: Variably Bedded Conglomerates, Sandstones and Shales

Facies association 5 comprises a heterogeneous mixture of conglomerate, pebbly sandstone, bioturbated muddy sandstones, sandy shales and shale that may form a coarsening to fining upward succession. The type well for this association is located at 12-17-49-21W4. Figure 3.18 illustrates SP and resistivity well log character as well as the schematic log character for the type well. Figure 3.19 is a core box photomontage of the type core. Table3.5 shows observations of past authors.

This association is composed of a succession of sediments that has great vertical variability such that it cannot be characterised as fining or coarsening upward - there is no "characteristic" facies succession. The basal portion is characterised by conglomerate, conglomeratic sandstone or muddy sandstone. The midsection can consist of a wide variety of lithologies including conglomerate, conglomeratic sandstone, muddy sandstone, siltstone, or silty mudstone. The top commonly is characterised

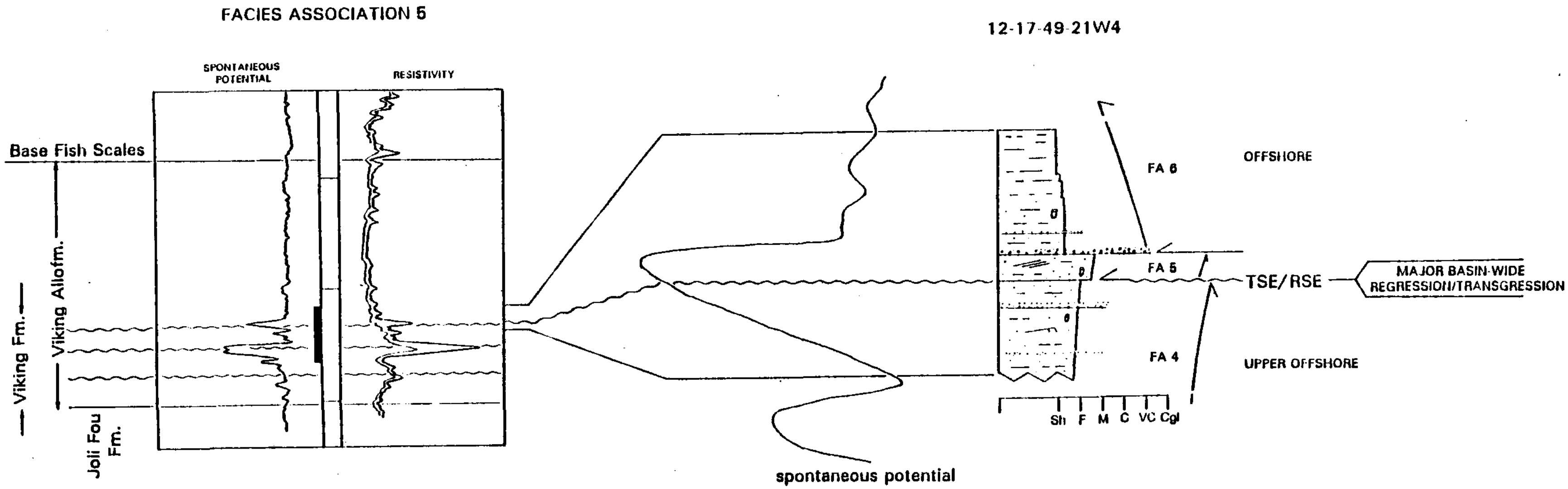
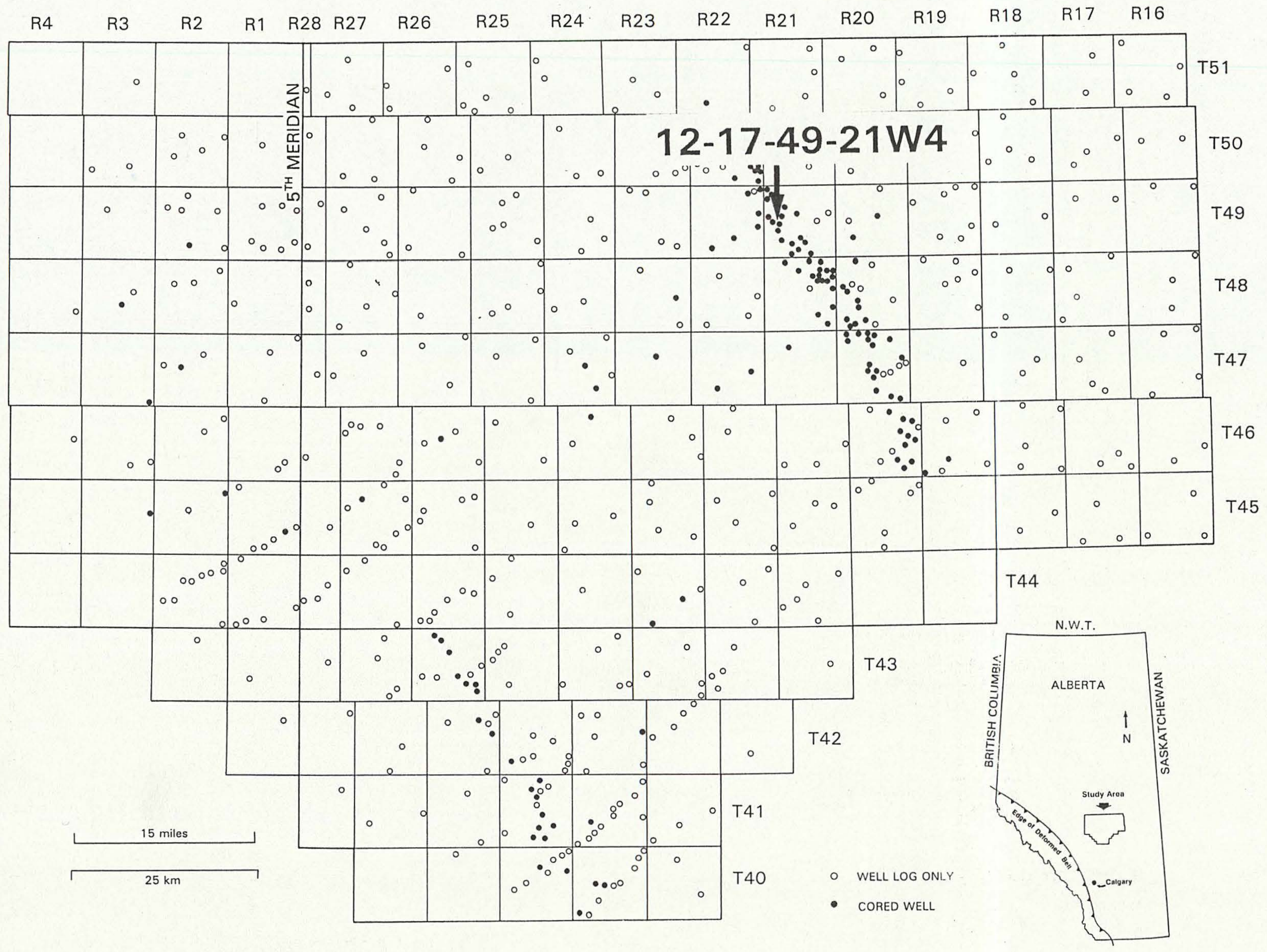


Figure 3.18 Type well for facies association 5 from 12-17-49-21W4 (982-974m) which illustrates a package of sediment above VE4 sharply overlying a sediment package comprising FA 4 it is in turn conformably overlain by sediments of FA 6. The corresponding spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

Figure 3.19 Core photographs of the type core for facies association 5 with bounding discontinuities indicated. Location of the core is provided on the map.



12-17-49-21W4

(3" Slabbed Core)

TYPE CORE: FACIES ASSOCIATION 5

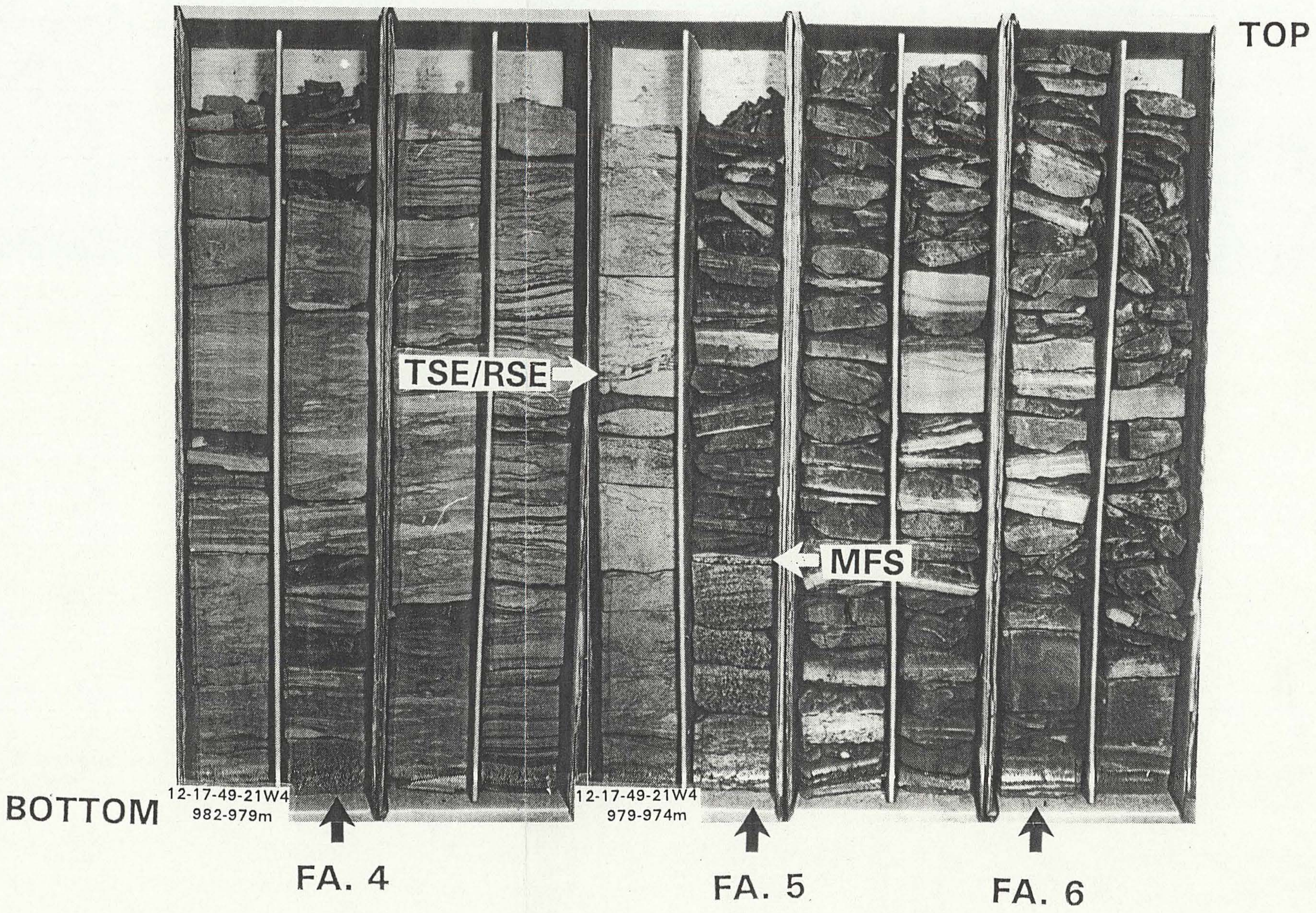


Table 3.5: Facies equivalents of past workers

FA 5: Variably Bedded Conglomerates, Sandstones, and Shale Succession		
Reference	Field	Facies Designation (s)
Posamentier & Chamberlain (1991)	Joarcam	No Designation
Power (1988)	Joarcam	Member "D"
Pattison (1991)	Crystal, Cyn-Pem, Sundance -Edson	Facies Association 10: Interbedded Mudstone, Sandstones
Reinson (1985)	Crystal	No Designation
Boreen & Walker (1991)	Willesden Green	Facies Association 5: Shale, Conglomerate, Cross Stratified
Raychaudhuri (1989)	Chigwell	Facies 7B:
Downing & Walker (1988)	Joffre	sediments directly above Bounding Surface E3
Raddysh (1988)	Gilby A and B	Facies J: Conglomerate
Pozzobon & Walker (1990)	Eureka	sediments directly above Bounding Surface E4
Hadley (1992)	Harmattan East & Crossfield	Facies 5A, 7B, 13, and 1B (above VE4)
Davies (1990)	Caroline & Garrington	Facies 7, 8, and 9

by a massive conglomerate or cross bedded sandstone or alternately by bioturbated muddy sandstone. Disseminated chert grains (3-20 mm in size), sideritic mud rip up clasts (10-60 cm in size), glauconite and bentonite layers (1-3 cm) occur in places throughout the succession. The entire facies succession is present in parts of the study area, but commonly a thin (5-15 mm) lag of conglomerate or very coarse-grained sandstone is all that is preserved. Preservation potential seems to have been highest in regions west of the Joarcam field in the study area.

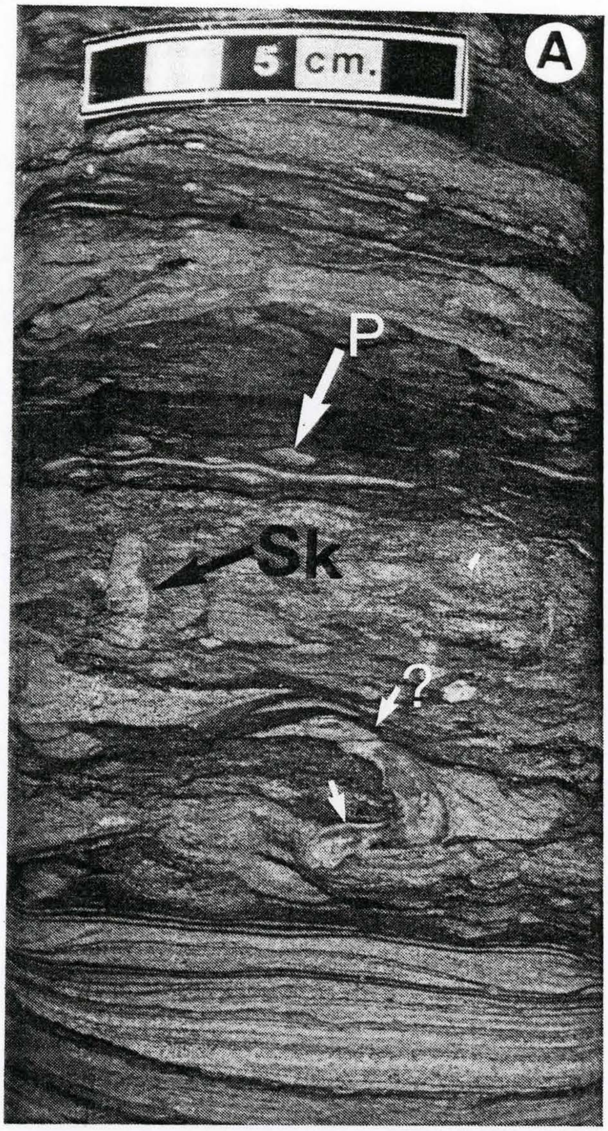
Trace fossils preserved within the succession include *Diplocraterion habichi, Teichichnus, Asterosoma, Skolithos, Planolites* and *Ophiomorpha* (figure 3.20A, B) The diversity of traces and the overall amount of bioturbation is generally relatively low. Due to the great variety of facies present in this package it is difficult to characterise any particular suite of bioturbators found in the succession. The only common ichnological aspect is the presence of a *Glossifungites* assemblage found at the base of the succession. This will be discussed later in this section.

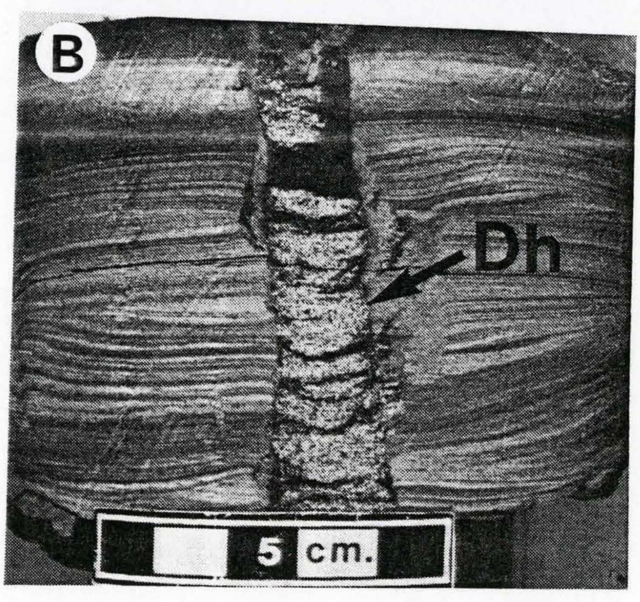
Sedimentary structures present within the association include cross bedding, wave/combined-flow ripples, low angle cross laminations, hummocky cross stratification, and wavy to parallel laminations in very fine- to fine-grained sandstones and siltstones. Cross bedded sandstone and massive conglomerate are always sharp based with evidence of erosion into

Figure 3.20 Facies Association 5

A) Photograph of one type of typical facies comprising FA 5; moderately bioturbated muddy fine to medium grained sandstones. *Skolithos (Sk)* and *Planolites (P)* are common. Note the unidentified clast in the lower center of the core. Well 16-21-43-26W4; 1410.4m; 3 inch whole core.

B) Rippled fine grained sandstone with normal grading cross cut by a *Diplocraterion habichi (Dh)* burrow which has been passively infilled by medium grained sandstone from above. Well 14-25-45-02W5; 1617.5m; 4 inch whole core.


5 cm.
A
P
Sk
?


B
Dh
5 cm.

underlying substrate including undulatory base, loading features and cross cutting of underlying sedimentary layers. These beds may be 5-20 cm thick and are made up of a substantial proportion of muddy or silty material. They generally comprise well sorted sands or very poorly sorted conglomeratic sandstone. Rippled, low angle laminated, HCS and wavy/parallel laminated sandstones and siltstones are generally sharp based with gradational tops. These may be 2-10 cm thick and are generally very fine- to fine-grained sandstone which may grade up over the last 1 cm of the bed to silt and shale. Rarely, contorted bedding is observed in which any of the above mentioned structures can be overturned and convoluted.

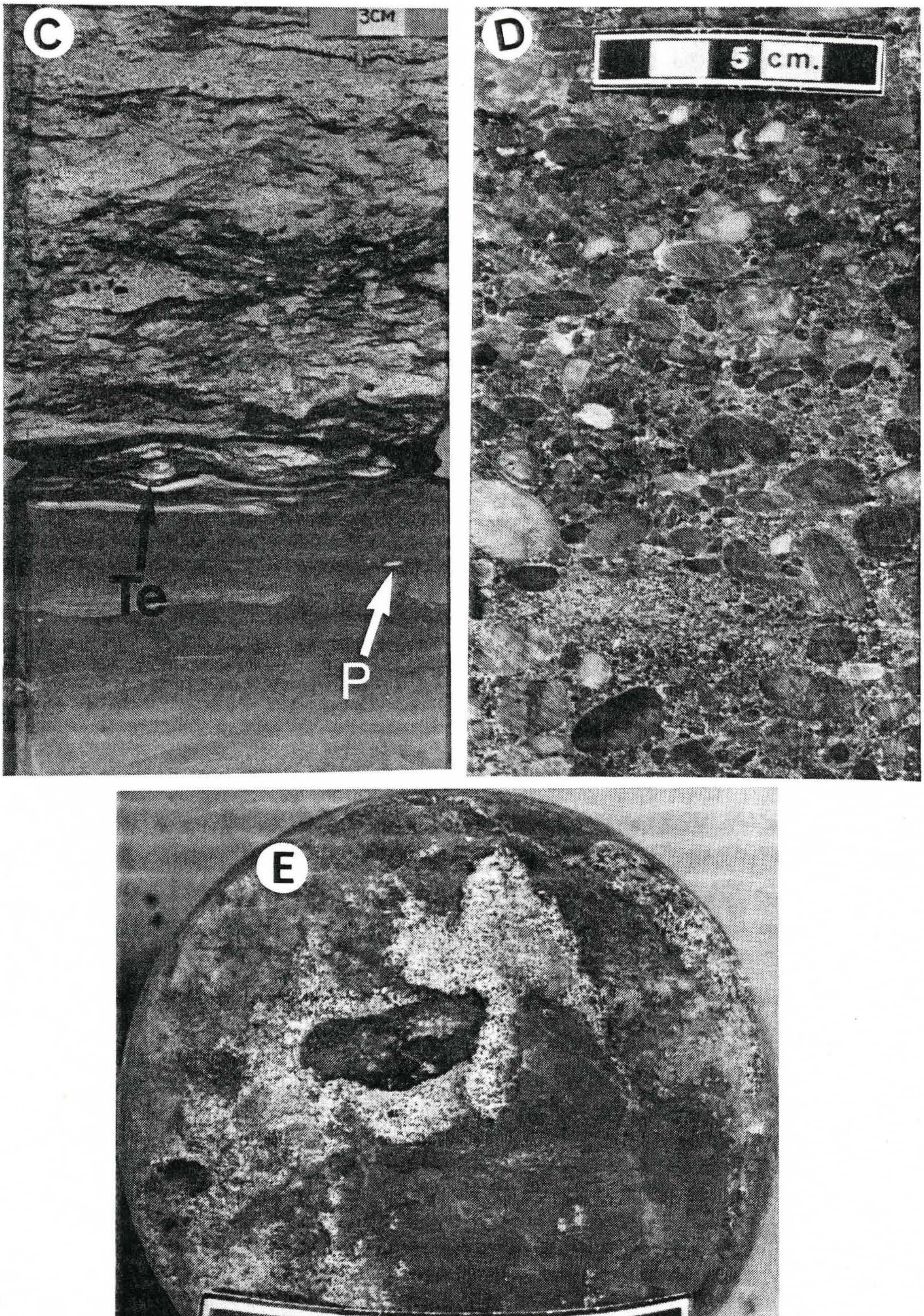
The succession always has a sharp lower contact. The base of the succession is marked by abundant bioturbation, erosive truncation of underlying bedding, sharp grain size increase and common development of a sideritic horizon (up to 25 cm thick) (figure 3.20 C, E). Commonly, a poorly sorted conglomerate, pebbly sandstone or muddy sandstone will occur at the base of the succession (figure 3.20D). Often, a well developed ichnofaunal assemblage subtends from the base and comprises sharp walled, passively infilled, robust vertical burrows that may be 10-30 cm long. These are interpreted as *Thalassinoides, Diplocraterion habichi* or *Skolithos* which form a firmground *Glossifungites* ichnofacies. The top of this facies association is almost always sharp but can also be relatively gradational.

Figure 3.20 (cont'd)   Facies Association 6

C) Heavily bioturbated, muddy medium grained sandstone with abundant disseminated granule sized black chert grains. The lower contact is sharp and erosive with sideritised black mudstone of FA. 4 Note the general absence of bioturbation in the underlying facies except for a few minor *Planolites (P); Teichichnus (Te)* is identifiable at the base of the overlying facies. Well 05-20-49-21W4; 988.1m; 4 inch slabbed core; bar scale 3cm.

D) Poorly sorted, polymictic conglomerate comprising black and white chert, sideritised mudstone and lithic clasts in a medium to very coarse-grained sandstone matrix. This facies is typical in the western portion of the study area and represents a transgressive lag. Well 06-20-47-02W5; 1544.2m; 3 inch slabbed core.

E) A single large black chert pebble which occurs at the base of FA 5 in the Joarcam area marks a rapid change in facies from rippled fine-grained sandstones (FA 4) below to bioturbated muddy sandstones with disseminated grit (FA 5) above. Well 04-35-47-20W4; 961.6m; 2 inch whole core.


C
3CM
Te
P
D
5 cm.
E
5 cm.

Where sharp it is marked by an abrupt change in grain size, with fine- to coarse-grained sandstones or conglomerate below, and silts and shales above, in the overlying succession. A few granules of chert may be found in the basal few tens of centimeters of the overlying facies. Gradational contacts at the top of this succession occur less frequently and are characterised by a rapid yet gradual decrease in grain size (from fine- to coarse-grained sand to shale) and sand volume (from 60% to 5%) over a 15 to 30 cm 'transition' zone.

This facies association occurs throughout the study area and is best preserved east of the Joarcam field. However, variable preservation and facies character make the association difficult to distinguish from other sandy or conglomeratic zones within the upper Viking Formation. Usually, this facies is best recognised as the last such conglomeratic or sandy zone before the base of the Westgate Formation.

INTERPRETATION: The sedimentary structures and ichnology suggest deposition in a marine environment. The sharp based nature of the succession with associated *Glossifungites* ichnofacies suggests an erosive and rapid emplacement of the sediments. The sharp based conglomerate present at the base of FA 5, partially composed of large pebbles or granules and sideritised mudstone clasts, is interpreted as a transgressive, erosional lag. In all, the facies may be interpreted to represent a transgressive package, variably preserved and emplaced in an lower shoreface to offshore environment during rise in relative sea level. The overlying facies (FA 6; to be discussed) comprises muds and silts supporting an overall rise in sea level during and after deposition of this package.

3.8 Facies Association 6: Aggradational Black Mudstone

Facies association 6 consists of black mudstone with minor silty laminae and rare muddy sandstone and chert layers forming an aggradational package of sediment. This facies occurs both below and above the Viking Formation, as the Joli Fou Formation and the Westgate Formation, respectively. However, for the purposes of this study I will concentrate only on the Westgate Formation because they form part of the Viking Alloformation as defined by Boreen and Walker (1991). The type well for this association is located at 6-24-45-3W5 the SP and resistivity log character as well as a schematic core log of this type well are shown in figure 3.21. Figure 3.22 illustrates the core character in a photomontage. Table 3.6 shows descriptions of some past workers.

The association comprises black mudstone, minor siltstone laminae, fine- grained sandstone and rare fine- to medium-grained sandy mudstones. The character of the association is generally consistent throughout. The percentage of siltstone and sandstone at the base is 5-10% but decreases upward through the basal 2 meters of the succession until it is generally less

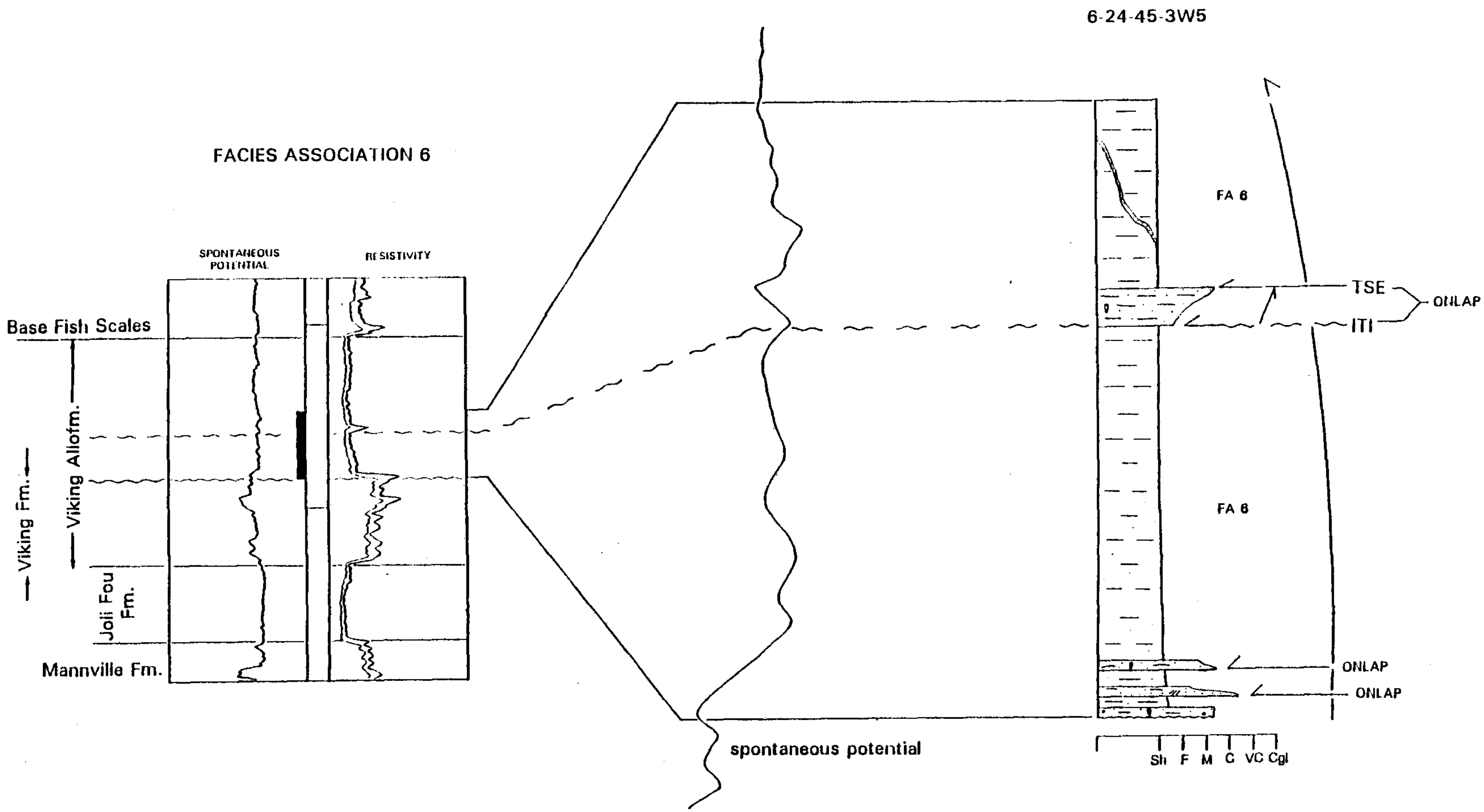


Figure 3.21 Type well for facies association 6 from 06-24-45-03W5 (1687-1673m) which illustrates a transgressive succession comprising black mudstones with silty storm beds and an onlapping marker. The corresponding spontaneous potential and resistivity well logs are shown as is the position of the core by the vertical black bar. Interpretations are made to the right of the core.

Figure 3.22 Core photographs of the type core for facies association 6 with bounding discontinuities indicated. Location of the core is provided on the map.

06-24-45-03W5
(4" Whole Core)

TYPE CORE: FACIES ASSOCIATION 6

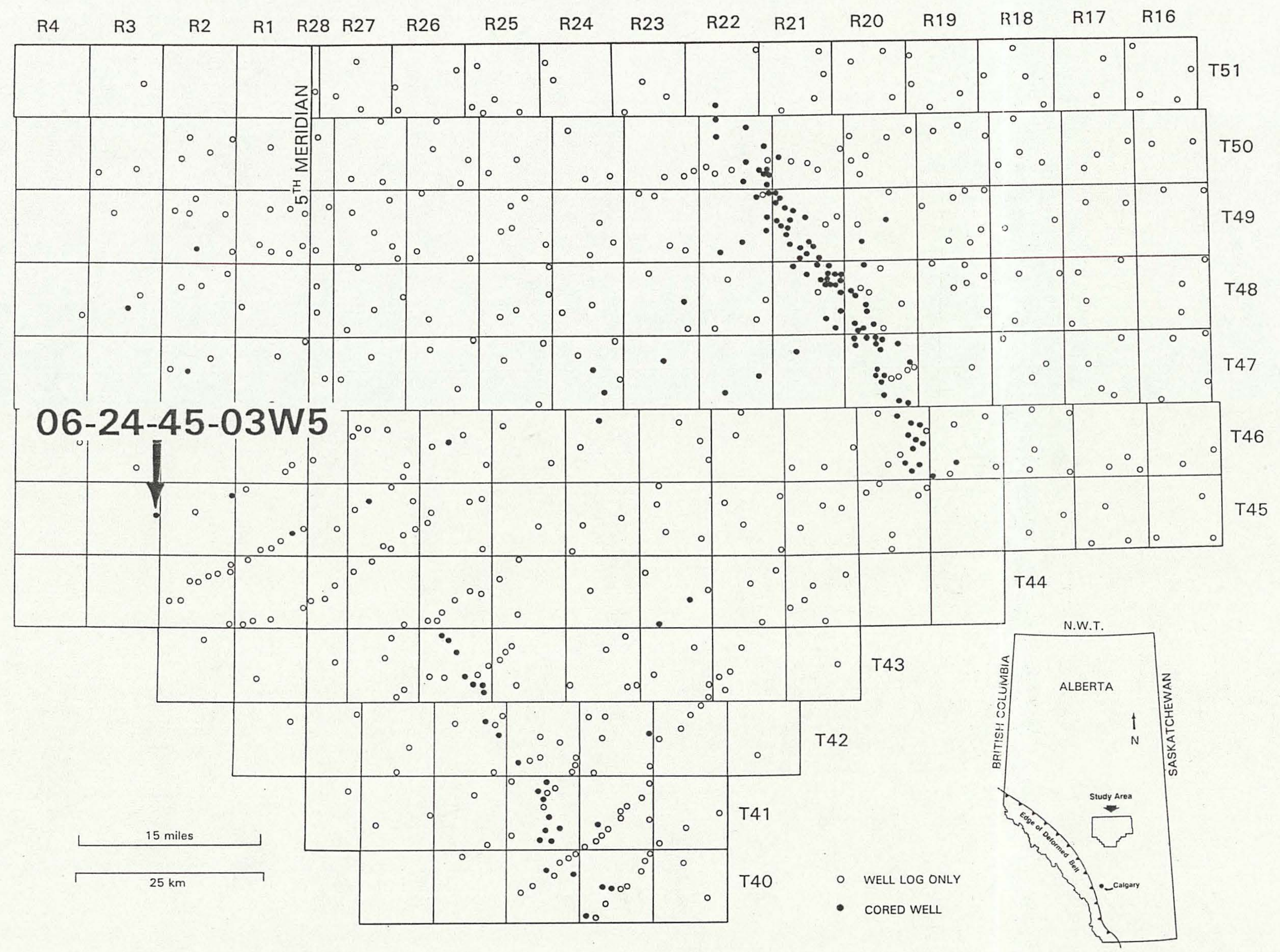


Table 3.6: Facies equivalents of past workers

FA 6: Aggradational Black Shale Succession		
Reference	Field	Facies Designation (s)
Posamentier & Chamberlain (1991)	Joarcam	No Designation
Power (1988)	Joarcam	No designation
Pattison (1991)	Crystal, Cyn-Pem, Sundance -Edson	No Designation
Reinson (1985)	Crystal	No Designation
Boreen & Walker (1991)	Willesden Green	Shale Facies of Facies Association 5
Raychaudhuri (1989)	Chigwell	Association 6: Black Mudstones
Downing & Walker (1988)	Joffre	Facies K: Black Mudstone
Raddysh (1988)	Gilby A and B	Facies A: Silty Bentonitic Mudstones
Pozzobon & Walker (1990)	Eureka	
Hadley (1992)	Harmattan East & Crossfield	Facies 1: Dark Mudstone
Davies (1990)	Caroline & Garrington	Facies 9: Black Mudstone

than 3% by volume. Silt makes up the greatest component of the thin laminae present, however, very fine sand is also common. Rare granules (2-3 mm in diameter) are commonly disseminated throughout the basal (10-20 cm) portion of the succession. Fine-grained sandstone beds (10-30 cm thick) occur in the lower 5-7 m of the succession. These are sharp based and grade upward to siltstones and shales representing 'background' sedimentation. Even rarer are fine- to medium-grained sandy mudstones that may occur anywhere throughout the succession (but was observed in core only once). These beds are sharp based, bioturbated and may coarsen upwards. The one example (approximately 1.3 m thick) observed occurred approximately 20 cm above a sideritic horizon in black mudstones had a sharp base and top and had a 'mottled' texture (figure 3.23A). Bentonites (2-5 cm thick) and sideritic layers (5-20 cm thick) are commonly intercalated with the black shale. A rare fine-grained sandstone dike (110 cm long, 2 cm wide) subtending from a 5 cm sideritic horizon was also observed in one core.

Bioturbation in this facies association is poor to non-existent. The only occurence of trace fauna occurs in association with thin siltstone and very fine sandstone beds. In these beds small *Planolites, Helminthopsis, Anconichnus,* and *Lochia?* may be observed. These traces appear to represent the *Cruziana* ichnofacies of Frey and Pemberton (1984).

Figure 3.23 Facies Association 6

A) Close up core photograph of the onlapping marker (E1) of Davies and Walker (1993). Note the bentonite and the sideritic alteration of the mudstone directly below the base of the marker. In this area the onlapping marker comprises sharp based, bioturbated sandy mudstone. Well 06-24-45-03W5; 1693.5 - 1692.0m, 4 inch whole core; core sleeves 60cm, base of core to bottom left.


A
1674.5m
06-24-45-03W5
1673.0-1675.2m

Sedimentary structures are restricted to parallel (color)/wavy laminations and ripples in siltstones and very fine-grained sandstones and hummocky cross stratification in fine-grained sandstones (figure 3.23B, C). Parallel and wavy laminated as well as rippled silts and sands occur in thin (<2 cm thick), sharp based beds. 'Sediment-starved' combined-flow ripples are typically 10-15 cm thick and are most common in the lower 5 m of the unit. The beds are sharp based, usually nonbioturbated, and grade upwards to parallel and wavy laminated very fine sands, silts and shales. Thin conglomeratic horizons (generally <5 cm) are usually massive and have sharp bases and tops (figure 3.23D).

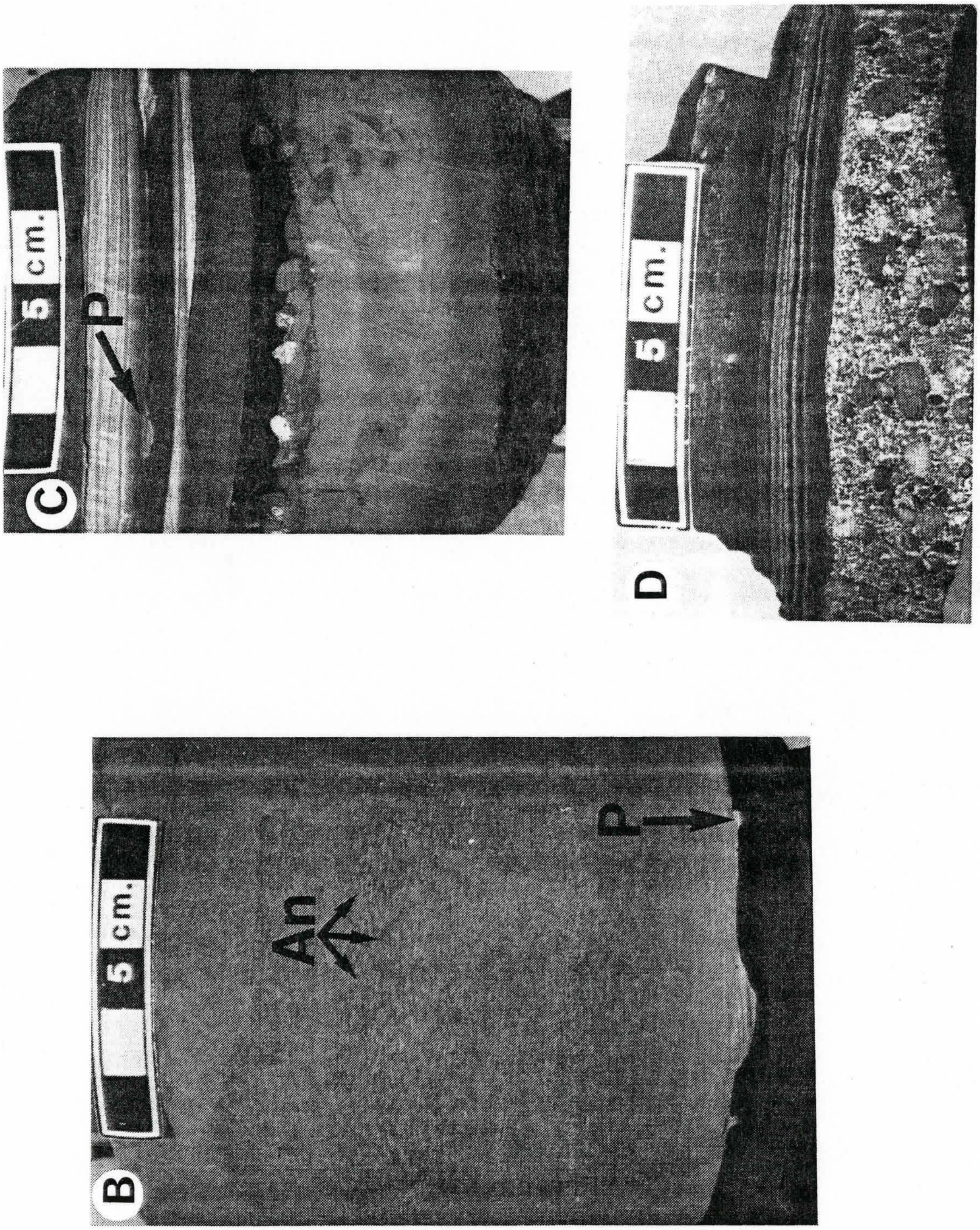
The base of the association is sharp where it overlies the top of sediments deposited over the VE4 erosion surface (ie. FA 5). It is marked by a pronounced decrease in grain size from medium-grained sandstone to conglomerate of FA 6 below to muds, silts and very fine-grained sandstones of this facies succession above. The basal portion of the succession may be marked by up to 20% very fine sand and silt but this quickly dies out over the first 3-5 m until sand and silt together make up less than 5% by volume of the total succession. The top of the succession is marked by a sharp contact that is the base of the Fish Scales Formation (BFS). This zone has not been observed in core, but is easily recognised on well logs as a 'hot' or radioactive pick on the gamma log. This zone represents a datum for all well

Figure 3.23 Facies Association 6

B) Heavily *Helminthopsis (H)* and *Anconichnus (An)* burrowed fine grained sandstone with sharp base and gradational top (not shown). Note the possible *Planolites (P)* at the base of the bed. Well 05-09-46-19W4; 948.5m; 3 inch whole core.

C) Thin layer of granule chert grains overlying sideritised mudstone (S) at the base of FA. 6. Note the 'starved ripples' in thin fine-grained sandstone and siltstone beds above with a possible *Planolites (P)* burrow at the base. Well 06-24-47-20W4; 951.5m; 3 inch whole core.

D) Sharp based poorly sorted conglomeratic sandstone bed at the base of the association south of the Chigwell area. The sharp top gives way upwards to finely laminated siltstone and shale. Well 06-06-40-24W4; 1409.2m;4 inch whole core.


C
5 cm.
P
D
5 cm.
B
5 cm.
An
P

log cross sections used in the study.

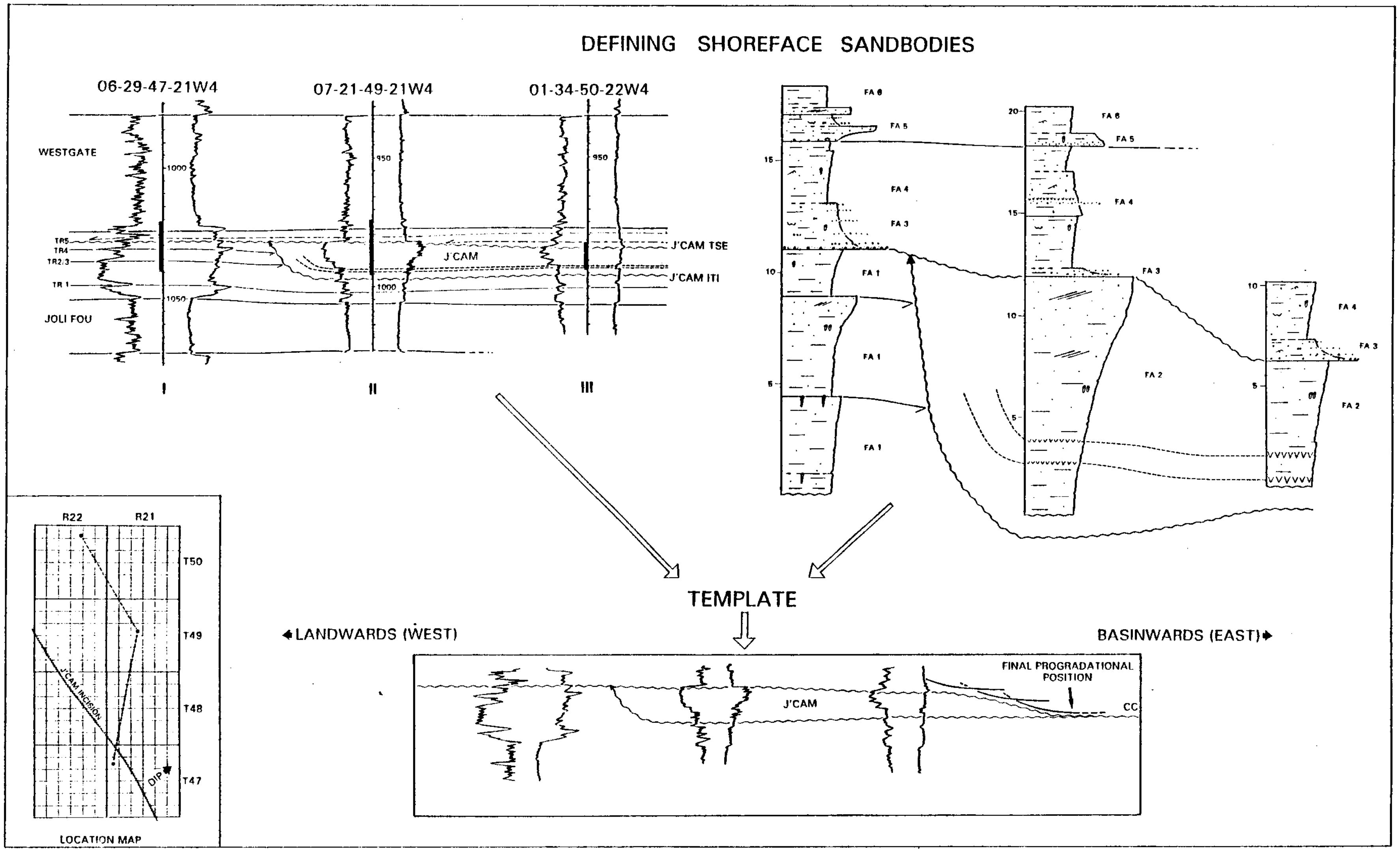
INTERPRETATION: The overall fine grain size (ie. muds), the paucity of thick sandstone beds and the relatively few sedimentary structures in the thin sands and silts present in this succession suggest deposition in a distal environment. Bioturbation seems to suggest a depositional environment which was increasingly unsuitable for habitation by benthic marine fauna. The sharp nature of the base of the succession and the fining upward character displayed in the lower 5 m suggest deposition during transgression. The sharp top of the succession is interpreted as a maximum flooding surface (ie. a condensed section). The rare sandy mudstone layers may represent storm emplaced sediment, sourced at distant prograding shorefaces which may have been fed into the basin during progradational events associated with stillstands on an overall transgressive movement of sea level (see Davies and Walker, 1993).

CHAPTER 4: A TEMPLATE FOR REGIONAL CORRELATION

4.1 Introduction

A 'correlation template' has been defined in the Joarcam area, where abundant core and well control enable a detailed analysis of facies, lateral and vertical facies relationships and bounding discontinuities. The concept of correlation by template was introduced by Bergman and Walker (in prep) in a sequence stratigraphic analysis of multiple incised shorefaces within the Shannon Sandstone of Wyoming. The construction and application of the template is based upon the premise that in areas where stratigraphic relationships are well defined by abundant core data the evidence for interpretation of the facies and bounding discontinuities can be assembled into a 'model' that is then applied to areas where insufficient core control exists. The template presented here (figure 4.1) is similar to that proposed by Bergman and Walker (in prep) in that four basic elements have been recognised: a) a coarsening- and sandier-upward succession interpreted as a shoreface sandbody; b) an underlying asymmetrical erosion surface; c) a transgressive surface of erosion above the shoreface sandbody; and d) extensions of the erosion surfaces beyond the immediate area of the shoreface incision. A second template illustrating the relationships between

Figure 4.1 Diagram illustrating a correlation template for incised shorefaces developed at Joarcam. Well log correlations (on the left) are supported by core data (on the right) and are assimilated into the correlation template (bottom). Inset map shows the location of wells used.


DEFINING SHOREFACE SANDBODIES
06-29-47-21W4
07-21-49-21W4
01-34-50-22W4
WESTGATE
JOLI FOU
J'CAM
J'CAM TSE
J'CAM ITI
I
II
III
FA 1
FA 2
FA 3
FA 4
FA 5
FA 6
TEMPLATE
◂LANDWARDS (WEST)
BASINWARDS (EAST)▸
FINAL PROGRADATIONAL POSITION
CC
R22
R21
T50
T49
T48
T47
J'CAM INCISION
DIP
LOCATION MAP

two incised shorefaces has also been constructed from well logs in the Lindbrook - Joarcam area.

4.2 Defining Shoreface Incisions

The 12 and 6 m thick funnel shaped gamma ray and resistivity well log patterns which occur above the top of TR1 in wells II and III (figure 4.1), respectively, correspond to coarsening- and sandier-upward bioturbated successions. In well II the succession comprises fine-grained sandy mudstones at the base to coarse-grained cross bedded sandstones at the top. In well III the succession is composed of fine-grained sandy mudstones to muddy sandstones. Each succession of sediments makes up FA 2B and the reader is directed to chapter 3 for a more comprehensive analysis of the sedimentary character of these deposits. Since the sandstones at the top of this succession in well II make up the reservoir at Joarcam field it has here been termed J'CAM.

The base of the J'CAM succession (ITI) in wells II and III is abrupt. In core this contact is marked by a rapid decrease in sandstone grain size and the occurrence of large chert pebbles (as described in chapter 2, FA 2B). This surface is traced basinwards (well III) where it tends to flatten or dip slightly to the east. Landwards this surface is more difficult to trace and several potential correlations can be envisaged.

The succession of funnel shaped gamma and resistivity well log patterns in well I corresponds in core to a series of stacked coarsening- and sandier-upward successions of FA 1 (described in detail in chapter 3). Between wells I and II markers TR5, TR4 and TR2/3 are truncated and in well II they are replaced by the sharp based 12 m thick funnel shaped succession of FA 2B (J'CAM on figure 4.1). The possible relationship of ITI in between these two wells includes the correlations: a) ITI to TR 2/3; b) ITI to TR 4; c) ITI to TR5 or d) no correlative of ITI in well I. Core control in well I indicates that each of the successions within the stack comprise much finer grained sandstone with a higher percentage of mudstone at the tops of each of the successions as compared with the J'CAM sandbody. Thus, over a dip-projected distance of 13 km several stacked successions of relatively fine grained muddy sandstone (in well I) are replaced basinwards (in well 2) by a single coarsening- and sandier-upward succession comprising much coarser and cleaner sandstones. The relatively coarse grained nature of the J'CAM deposits compared to the successions in well I and the apparent truncation of markers TR 4 and TR2/3 suggests that the first two possible correlations are probably incorrect. The third possibility appears to be invalid because of the striking difference in the character of the facies which overlie ITI as compared with those overlying TR5. Deposits above TR5 comprise a distinctive assemblage of fining- and muddier-upward interbedded very coarse sandstone, siltstone and shale of FA 3 (see chapter 3 for a discussion) as compared to the coarsening- and sandier-upward succession that comprises J'CAM. For this correlation to be made one must assume that an integral change in the character of the sediments above ITI has occurred over the distance between the wells. This is probably not warranted. The final correlation presented and the one preferred is that ITI has no correlative in well I and has been erosively removed by the TSE surface between these wells. This correlation suggests that the ITI surface tends to form an asymmetrical shoreface incision which is truncated between wells I and II by the TSE surface; the ITI surface is steepest in the west where it has eroded into successions 1 through 5 and open to the east where it flattens out basinwards. Evidence presented in chapter 5 suggests that this surface may form an initial transgressive incision during stillstand on an overall transgression.

4.3 Defining Shoreface Truncation

The funnel shaped well log pattern in wells II and III end abruptly at the TSE log marker. In core, this contact is marked by a change from coarse- to very coarse grained sandstone below TSE (FA 2B, chapter 3) to interbedded conglomerate, mudstone and sandstone (FA 3, chapter 3) above. Therefore the top of the J'CAM sandbody is interpreted as an erosive contact (TSE) associated with transgressive ravinement by wave action in the shoreface as renewed transgression moved the shoreface landward. The deposits overlying the J'CAM shoreface have been suggested by Posamentier and Chamberlain (1989, 1991) to represent cannibalised upper shoreface, beach and non-marine deposits which were eroded and transported seaward of the zone of coastal erosion. These deposits form a succession which progressively onlaps the TSE landward of the preserved J'CAM sandbody.

The TSE that truncates J'CAM can be traced landwards to well I where it overlies succession 5. Transgressive deposits overlie this erosive contact in well I. They formed during the same phase of transgression responsible for deposition of those above Joarcam. Basinwards, the TSE surface gradually passes into a correlative conformity below the position of fairweather wave base at the furthest extent of J'CAM progradation. The correlative conformity at its basinward extent will overlie thin distal (muddy lower shoreface to offshore) deposits which represent correlatives to the J'CAM shoreface deposits occurring landwards.

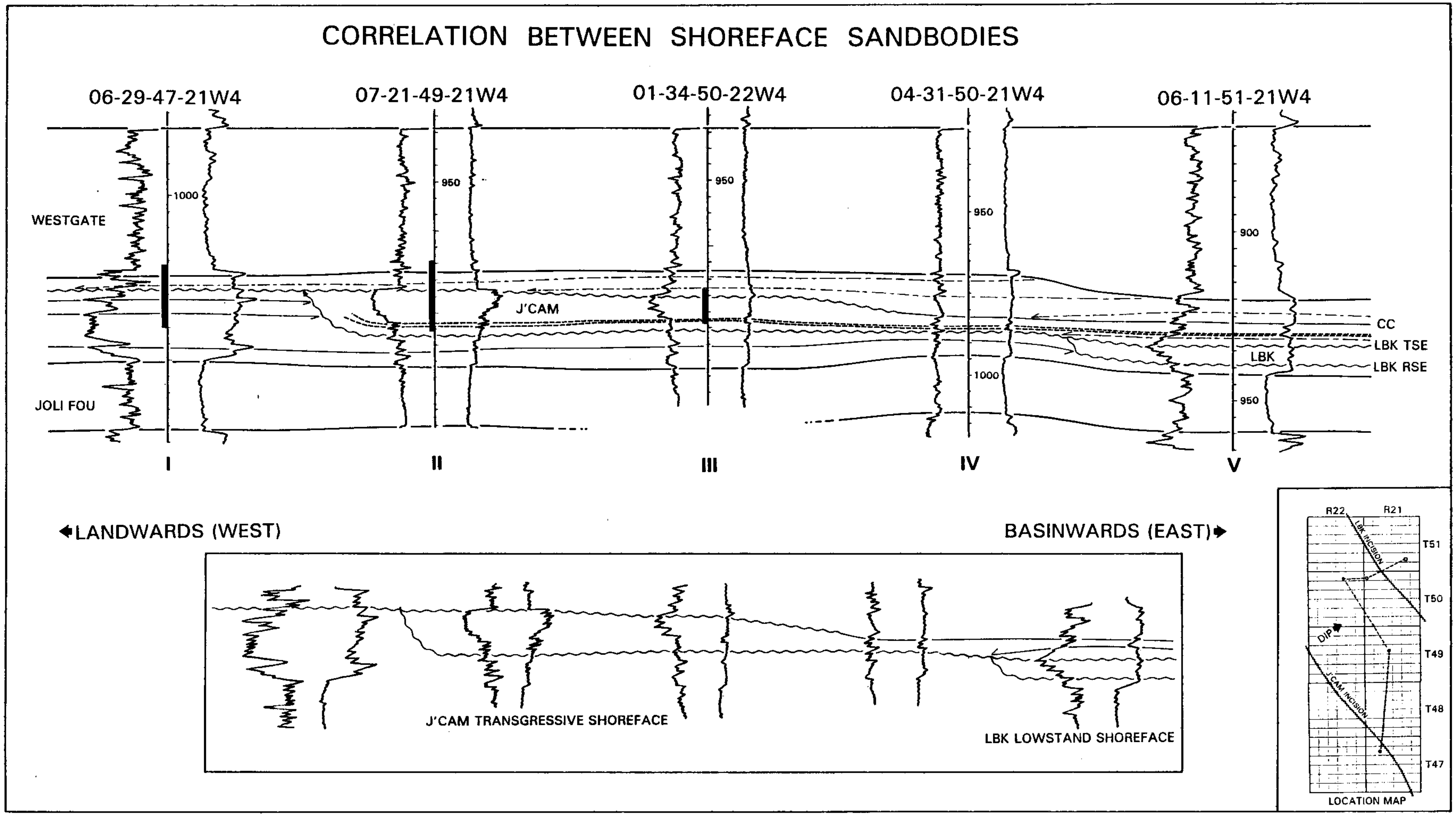
Extensions of the bounding discontinuities to other areas of apparently sharp based sandbody development is the mechanism by which each incised sandbody (shoreface or valley) is placed in relative stratigraphic context. An example of this is provided in the next section.

4.4 Correlation of Bounding Discontinuities Between Shoreface Incisions

The correlation template constructed at J'CAM can be applied to other shoreface deposits which may or may not have as good core control. The sandbody at Lindbrook (LBK) has been interpreted as a lowstand incised shoreface which is older than that preserved at J'CAM (Walker and Wiseman, in press). This section will explain in detail the application of the incised shoreface template (developed at J'CAM) to the LBK sandbody and how bounding discontinuities have been extended from LBK to J'CAM to place each in relative stratigraphic position. The relationship between these two sandbodies, determined in this way, forms the basic premise and working theory used to define all sandbodies and their stratigraphic context in the study area.

Figure 4.2 shows a short well log section between J'CAM and LBK below which is an extended version of the incised shoreface template. The 6 and 4 m thick funnel shaped well log patterns which occur at the top of TR1 in wells IV and V, respectively, are interpreted to represent a coarsening- and sandier-upward shoreface succession (Walker and Wiseman, in press). No cores penetrate the LBK sandbody, but correlations of its bounding discontinuities can be made with confidence through use of the correlation template. The lower boundary of the LBK sandbody (RSE) is not considered correlative with the ITI surface at J'CAM for three reasons: a)

Figure 4.2 Diagram illustrating the correlation of bounding discontinuities beyond field boundaries to establish relative stratigraphic positions of incised shorefaces. The TSE at the LBK shoreface is traced westward where it underlies the J'CAM shoreface. Bentonites (dashed lines on well log cross section) help define the distal J'CAM sediments above LBK. Location of the wells is shown on the inset map.


CORRELATION BETWEEN SHOREFACE SANDBODIES
06-29-47-21W4
07-21-49-21W4
01-34-50-22W4
04-31-50-21W4
06-11-51-21W4
WESTGATE
JOLI FOU
1000
950
950
950
1000
900
950
J'CAM
CC
LBK TSE
LBK
LBK RSE
I
II
III
IV
V
◆LANDWARDS (WEST)
BASINWARDS (EAST)◆
J'CAM TRANSGRESSIVE SHOREFACE
LBK LOWSTAND SHOREFACE
R22
R21
LBK INCISION
T51
T50
DIP
T49
J'CAM INCISION
T48
T47
LOCATION MAP

the well logs suggest that the distal J'CAM sediments are significantly finer grained than the sandstones implied by the logs at LBK; b) LBK appears to be at a stratigraphically lower position then J'CAM and; c) bentonitic marker beds (VVV in figure 4.2) which form effective 'time lines' within the J'CAM shoreface can be traced basinwards where they overlie LBK sediments. Since there are no other potential correlations it can be assumed that the RSE surface is an asymmetric scour (shoreface incision) which is present in well IV but not in well III. Similarly, the apparent rapid truncation of the top of the funnel shaped well logs (along TSE) appears to suggest the presence of a J'CAM-like TSE. This surface occurs at the same stratigraphic horizon as the ITI surface beneath J'CAM and has been correlated as such, barring any other suitable candidate.

4.5 Application of the Template

Through the application of the correlation template, the sandbody at Lindbrook appears to meet all of the criteria of an incised shoreface. The landward truncation of the asymmetical scour upon which the sandbody rests occurs between wells III and IV while basinwards this surface is presumed to grade into a correlative conformity. The upper bounding discontinuity to the shoreface is also assumed to grade basinwards into a correlative conformity but landwards it is traced underneath the Joarcam sandbody where it forms the asymmetrical scour described in the construction of the template. The upper boundary to the sandbody at LBK appears to be a TSE (based upon application of the template) and can be traced landwards where it becomes an ITI underlying the Joarcam incised shoreface, thus establishing the relative stratigraphic positions of the sandbodies.

Since the template has been constructed using sedimentary successions interpreted as incised shorefaces, its only proper application is to other sandbodies that are most likely shorefaces (Bergman and Walker, 1994). All sandbodies in the study area have previously been interpreted as incised shoreface deposits (see review of overlapping studies, chapter 1) and therefore are reasonable candidates for its application.

CHAPTER 5: LATERAL FACIES ASSOCIATIONS, BOUNDING DISCONTINUITIES AND INTERPRETATIONS

5.1 INTRODUCTION

Nineteen regional depositional dip and strike cross sections (figure 5.1), using data from over 500 well locations, were used to determine stratigraphic relationships within the Viking Formation in the study area. Nine cross sections constructed using SP, resistivity or gamma ray curves are presented in this chapter (figure 5.2). The datum for all sections is the base of the Fish Scales Formation. Cored intervals are indicated and commonly represent an adjusted cored interval calibrated to the well logs. Scale distances between wells on the sections have not been attempted for the sake of illustrating statigraphic relationships at the expense of geometry.

The cross sections show the lateral relationships between lowstand incised shorefaces, transgressive incised shorefaces, and incised valley fills that comprise two full stratigraphic sequences.

5.2 BOUNDING DISCONTINUITIES

Each of the facies associations are defined by bounding discontinuities which separate conformable and 'genetically related' packages of strata. Within this chapter, interpretations of the bounding discontinuities are based

Figure 5.1 Base map illustrating the locations of regional well log cross sections used to determine stratigraphic relationships within the Viking Formation. Nineteen cross sections (15 depositional dip, 4 depositional strike) were constructed using gamma, resistivity or SP well logs and core (where available).

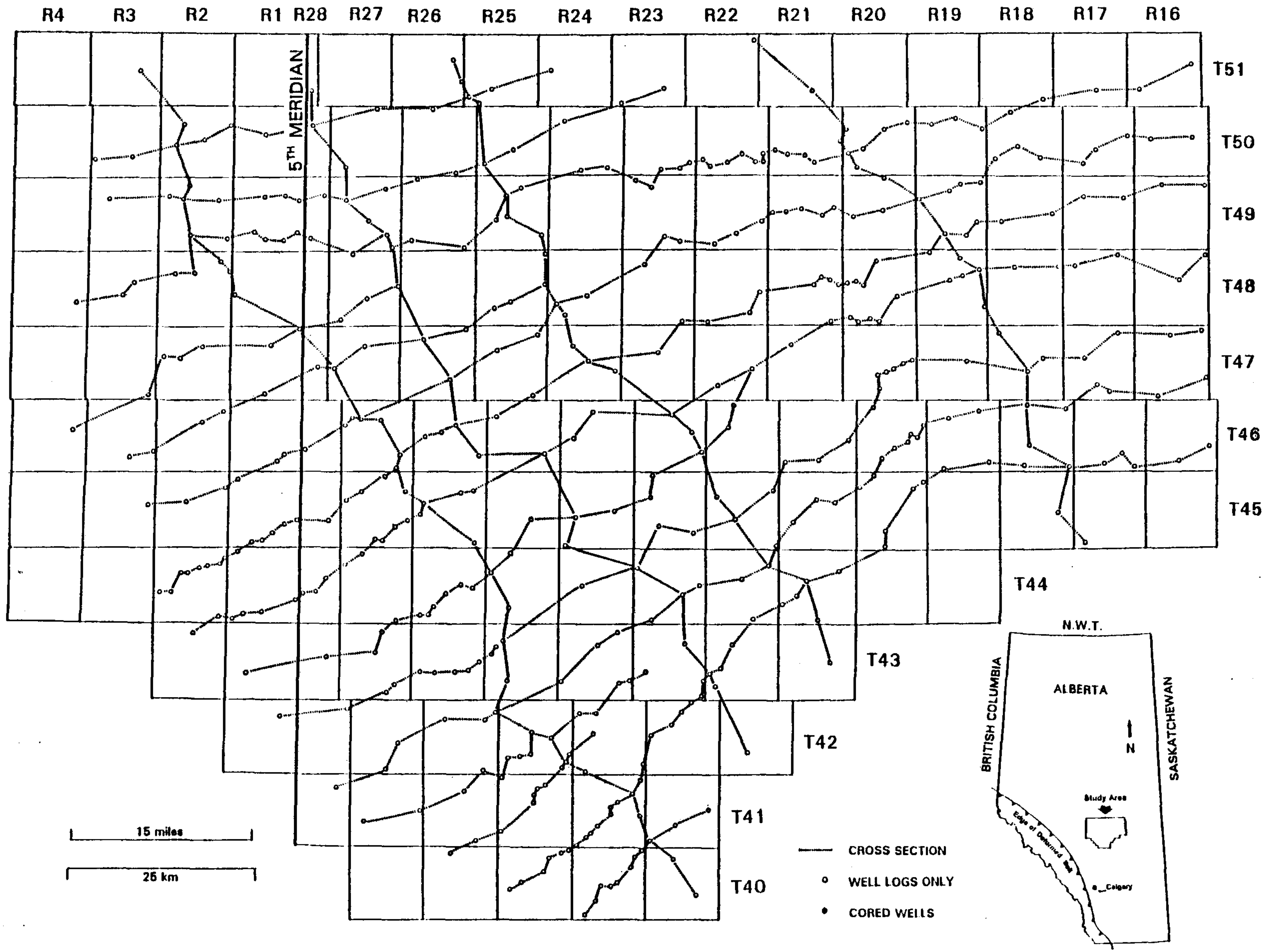
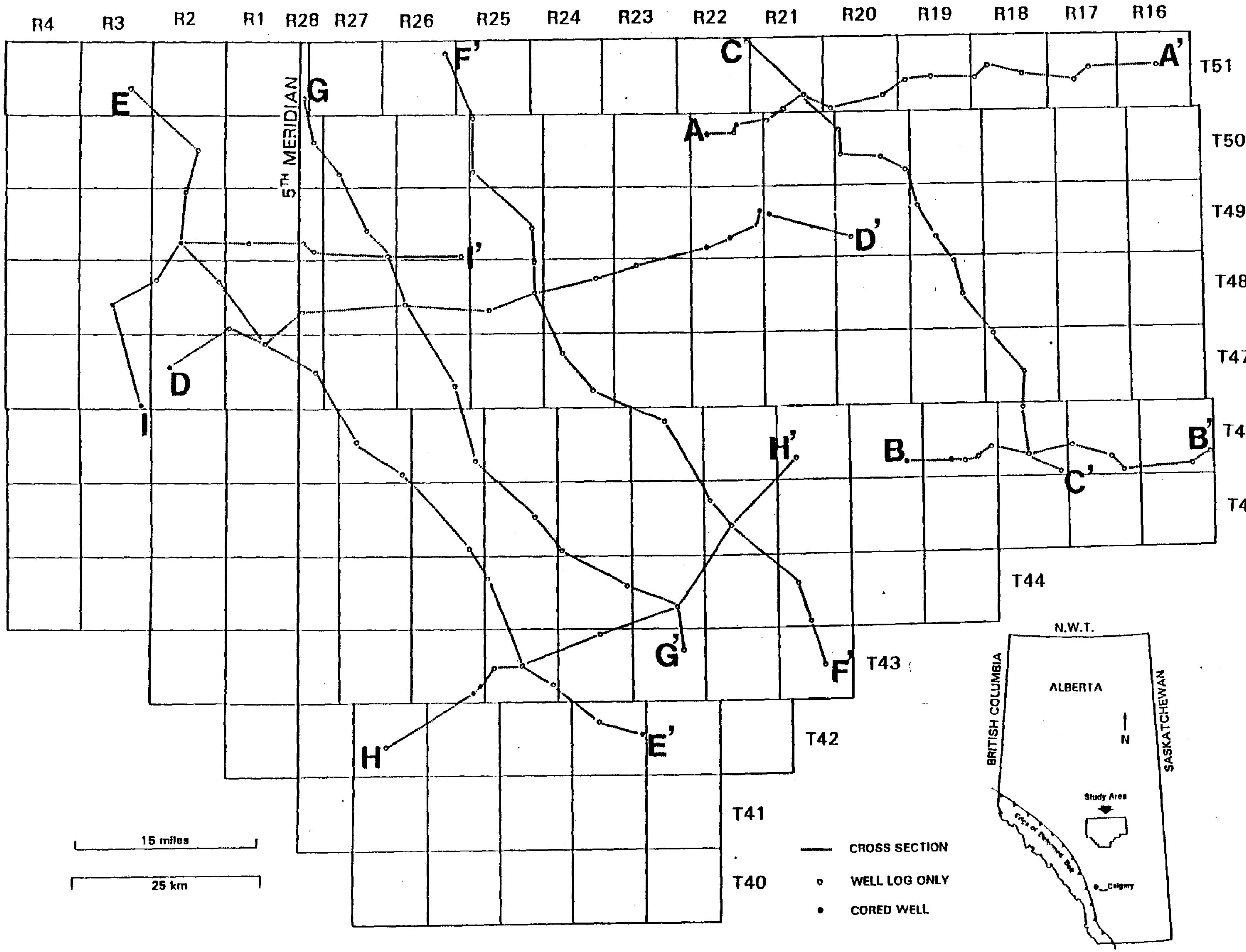

R4
R3
R2
R1
R28
R27
R26
R25
R24
R23
R22
R21
R20
R19
R18
R17
R16
5TH MERIDIAN
T51
T50
T49
T48
T47
T46
T45
T44
T43
T42
T41
T40
15 miles
25 km
CROSS SECTION
WELL LOGS ONLY
CORED WELLS
N.W.T.
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
N
Study Area
Edge of Deformed Belt
Calgary

Figure 5.2 Base map showing the locations of cross sections shown in this thesis. Nine cross sections (5 depositional dip, 4 depositional strike) illustrate the relationship between six incised shorefaces and two valley fills.


R4
R3
R2
R1
R28
R27
R26
R25
R24
R23
R22
R21
R20
R19
R18
R17
R16
T51
T50
T49
T48
T47
T46
T45
T44
T43
T42
T41
T40
5TH MERIDIAN
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
I
I'
15 miles
25 km
CROSS SECTION
WELL LOG ONLY
CORED WELL
N.W.T.
ALBERTA
BRITISH COLUMBIA
SASKATCHEWAN
N
Study Area
Calgary

upon the observed lateral relationships between the various facies associations.

Four main types of bounding discontinuities have been identified; 1) regressive surfaces of erosion (RSEs), 2) transgressive surfaces of erosion (TSEs), 3) initial transgressive incisions (ITIs), and 4) marine flooding surfaces (MFSs or Mx.FSs). RSEs are formed during conditions of falling relative sea level either when fluvial channels incise into exposed marine sediments or through wave action in the shoreface when erosional scours are cut. Within the Viking Formation, RSEs have cut into regional marine successions where they underlie incised valleys and lowstand incised shorefaces. TSEs are formed through erosive action in the shoreface during rise in relative sea level. They form the upper boundary to all incised shorefaces and incised valley fills. ITIs are also formed by erosion within the shoreface during relative rise in sea level. The ITI surfaces underlie all transgressive shorefaces and incised valley fills (where they may be coplanar with an RSE) and form during a minor stillstand in the overall transgression. They may be traced basinwards to TSE surfaces that truncate a previous lowstand/ transgressive incised shoreface or incised valley fill (discussed in chapter 7). Lastly, MFSs form during continued rise or at the point of maximum highstand of relative sea level. Within the Viking Formation, they are characterised by deposition of fully marine mudstones which may form a condensed horizon (i.e. Mx.FS). The flooding surfaces have not been indicated on the cross sections in order to avoid cluttering the diagrams. These surfaces are significant for the separation of different facies associations and are utilized more fully in the next chapter.

5.3 APPLYING THE CORRELATION TEMPLATE TO SHARP BASED SANDBODIES

Each of the sandbodies presented in this section have been interpreted as being incised shorefaces (ie. LBL, BHL, J'CAM, SBK 'A', SBK 'B' and CHIG) or incised valleys and fill (ie. Crystal). The valley fills have been interpreted by Pattison and Walker (1994) and are incorporated here to illustrate relationships with incised shorefaces. The other sandbodies are interpreted as incised shorefaces based upon application of the correlation template presented in the previous chapter. Criteria used to define the template at J'CAM have been applied to all the other sandbodies and a similar working theory that was used to describe LBK - J'CAM stratigraphy has also been applied. Sandbodies that meet the criteria for interpretation as shoreface (by application of the template) are simply referred to as shoreface in the following description of the cross sections.

5.4 WELL LOG AND CORE CROSS SECTIONS

The stratigraphic cross sections are presented in this chapter as groupings which illustrate lowstand incised shorefaces, transgressively incised shorefaces, and incised valley fills and the relationships these elements have with regional coarsening upward successions and transgressive deposits. The stratigraphic relationship between each element on the cross section is discussed and interpretations are made based upon presented evidence.

5.4.1 Lowstand Incised Shorefaces

Three cross sections (two depositional dip and one depositional strike) make up this portion of the chapter. The relationships between the LBK, J'CAM, and BHL incised shorefaces are illustrated.

Cross Section A-A'

Cross section A-A' (figure 5.3) is oriented west to east along depositional dip and illustrates the relationship between the LBK, J'CAM, and BHL shorefaces.

In section A-A', the base of the Viking Formation is defined as the first 'significant' deflection to the right on the resistivity curve overlying the Joli Fou Formation. In this part of the study area, the transition appears relatively sharp. Several regional coarsening upward successions of allomembers A and B overlie the base of the Viking Formation (Boreen and Walker, 1991). In the west, successions 1, 2/3, and 4 are visible, whereas towards the east only succession 1 is preserved, the others being removed

Figure 5.3 Cross section A-A'. Section is composed of SP and resistivity well logs, vertical scales and locations as indicated.

Figure 5.4 Cross section B-B'. Section is composed of SP and resistivity well logs, vertical scales and locations as indicated.

A
WEST
(C-C')
EAST
A'
6-29-50-22W4
8-27-50-22W4
1-34-50-22W4
4-31-50-21W4
7-4-51-21W4
6-11-51-21W4
2-6-51-20W4
8-11-51-20W4
10-18-51-19W4
16-16-51-19W4
11-18-51-18W4
11-20-51-18W4
13-14-51-18W4
7-16-51-17W4
2-22-51-17W4
6-22-51-16W4
BASE FISH SCALES
DATUM
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
WESTGATE FORMATION
JOLI FOU FM.
BHL TSE
BHL RSE
LBK TSE
LBK RSE
J'CAM ITI
0
25
50m
JOARCAM
(TRANSGRESSIVE SHOREFACE)
LINDBROOK
(LOWSTAND SHOREFACE)
BEAVERHILL LAKE
(LOWSTAND SHOREFACE)
B
WEST
(C-C')
EAST
B'
10-16-47-20W4
7-23-47-20W4
6-24-47-20W4
10-20-47-19W4
6-23-47-19W4
4-19-47-18W4
5-15-47-18W4
6-23-47-18W4
10-20-47-17W4
8-26-47-17W4
1-24-47-16W4
BASE FISH SCALES
DATUM
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
WESTGATE FORMATION
JOLI FOU FM.
BHL TSE
BHL RSE
J'CAM ITI
0
25
50m
JOARCAM
(TRANSGRESSIVE SHOREFACE)
BEAVERHILL LAKE
(LOWSTAND SHOREFACE)
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
REGIONAL SUCCESSIONS
INCISED SHOREFACE
'TRANSGRESSIVE' SUCCESSIONS

by erosion associated with development of the LBK shoreface.

The stratigraphically lowest shoreface sand body on this section is LBK. This is not a known producing field and appears to be 'water wet' from its resistivity log character. It is everywhere defined by the LBK RSE surface at its base, and either the LBK TSE or BHL RSE at its top. This shoreface cuts into the very lowermost Viking Formation sediments comprising the regional coarsening upward successions lying above the Joli Fou Shales. The shoreface itself is defined by a sharp SP deflection to the left and a corresponding resistivity deflection to the right. This sandbody is suggested to be an incised shoreface due to the sudden occurrence of the deflection down dip from wells showing primarily muddy sediments of the regional successions (ie. 4-21-50-21W4). The sandbody first occurs at 7-4-51-21W4 and erosional remnants have been traced basinwards for over 30 kilometers where it is ultimately removed by erosion associated with the incision of BHL. This erosional removal occurs on the cross section between wells 13-14-51-18W4 and 7-16-51-17W4. The surface defining the upper limit of the sandbody at LBK (LBK TSE) is interpreted as having formed by the process of transgressive ravinement during rise in relative sea level. This surface can be traced toward the west where it passes into the incision underlying J'CAM (J'CAM ITI). The correlation of the LBK TSE with the surface of initial transgressive incision at J'CAM (J'CAM ITI) indicates that

J'CAM is the stratigraphic younger of the two sandbodies.

The J'CAM ITI surface can be seen to cut out all or portions of regional successions 1,2/3, and 4. Core data from intervals shown on the logs provide an important tool in the interpretation of the stratigraphy, especially in areas just east of the field boundaries. The upper bounding discontinuity at J'CAM (BHL TSE) is interpreted as a transgressive ravinement surface associated with rising sea level after deposition of the BHL shoreface (to be discussed). Cores throughout the J'CAM field show a rapid change from FA 2B to FA 3 across this surface and as such its interpretation as a transgresssive ravinement surface.

The third shoreface sandbody, BHL, is the youngest of the three present. It first appears in well 2-6-51-20W4 and may be traced extensively downdip where it progressively thins and presumably becomes muddier for a distance of over 45 kilometers to the end of (and presumably beyond) the study area. The shoreface is defined by the BHL RSE below and the BHL TSE surface above. The RSE upon which the BHL shoreface rests cuts into the older LBK deposits (ie. 16-16-51-19W4). With increasing depth of incision (to the east) it rests directly on top of the stacked regional successions (ie. well 7-16-51-17W4). The first occurrence of this shoreface coincides with the last occurrence of the pair of bentonites present in the J'CAM sandbody. The disappearance of the bentonites is interpreted as being due to erosion by the BHL shoreface as it incised into the pre-existing LBK and distal J'CAM shoreface sediments. Thus, these bentonites provide excellent markers from which the relative stratigraphic positions of the various sandbodies in the J'CAM area may be determined (to be discussed in section 5.5). The bounding discontinuity overlying this shoreface (BHL TSE) can be traced along the top of the J'CAM shoreface where it is presumably coincident with the J'CAM TSE surface. It is therefore termed the BHL TSE over BHL as well as over J'CAM. Several markers onlap this surface and comprise relatively coarse grained pulses of sediment that appear to represent storm layers which were deposited with progressively waning frequency and strength through time (Posamentier and Chamberlain, 1989, 1991).

The uppermost erosion surface recognised within the section is associated with a major sea level fall and rise (VE4) which ended Viking deposition. Overlying this surface are transgressive sediments of FA 5 and FA 6 representing Westgate Formation deposition.

Cross Section B-B'

This section (figure 5.4) is oriented west to east along depositional dip and illustrates the stratigraphic relationship between the J'CAM and BHL shorefaces.

The J'CAM sandbody, defined by the J'CAM ITI and BHL TSE surfaces below and above, respectively, occurs in the western portion of the study area. The distal J'CAM sediments are erosively truncated by incision underlying the BHL shoreface (BHL RSE) between wells 5-15-47-18W4 and 6-23-47-18W4. The BHL shoreface rests directly above an erosively thinned, regional coarsening upward succession 1. In well 8-26-47-17W4 it is difficult to distinguish a regional coarsening up succession (such as 2/3) from some other type of sandbody such as an incised shoreface. Both show a fairly sharp SP and resistivity response underlying the sands of the BHL shoreface. Without core control it is difficult to distinguish whether the deposits are erosively thinned LBK deposits or erosively thinned regional succession 2/3. It is quite possible that these deposits represent a small remnant of the LBK shoreface. Walker and Wiseman (in prep.) suggest that this stratigraphy could represent deposition during lowering of relative sea level from a LBKa shoreface position to a LBKb position which has incised further basinwards in response to small scale forced regression (their figure 6). The true stratigraphic significance of the deposit is obscured in this part of the basin due to multiple erosional incisions which have severely dissected the stratigraphy. Whatever their nature, it is apparent that the base of the BHL shoreface moves slightly upwards stratigraphically with respect to the base of the Viking Formation in this area.

The surface truncating BHL (BHL TSE) can be traced westward where it overlies the J'CAM shoreface because the nature of the surface (ie. TSE) does not change, for clarity it retains its nomenclature (ie. BHL TSE).

Cross Section C-C'

This section (figure 5.5) is oriented along depositional strike and was constructed to illustrate the relationship of the J'CAM transgressive shoreface, and the LBK and BHL lowstand shorefaces. Points on this cross section that tie in with the previously described sections are indicated.

In the northern part of the section (wells 16-36-51-22W4 through 7-18-50-20W4) the LBK shoreface is overlain by distal (muddy) J'CAM shoreface sediments. The bounding discontinuity below LBK is LBK RSE. The J'CAM ITI separates LBK and J'CAM, and above J'CAM is the BHL TSE. The relationship between these sandbodies is clearly defined with LBK being the older. An enlargement of the resistivity well log in 6-11-51-21W4 shows in more detail the LBK shoreface overlying regional succession 1 and 2/3. It is in turn overlain by the J'CAM shoreface with its conspicuous paired bentonitic layers as described in section A-A'.

Due to the orientation of the section (west of the BHL incision in the north) the BHL shoreface is first seen in well 7-15-50-20W4 where it is interpreted to erosively truncate the distal (muddy) J'CAM sediments and

Figure 5.5 Cross section C-C′. Section is composed of gamma ray and resistivity well logs, vertical scales and locations as indicated.


C
NORTH
16-36-51-22W4
(A-A')
6-11-51-21W4
6-30-50-20W4
7-18-50-20W4
7-15-50-20W4
7-12-50-20W4
1-30-49-19W4
12-9-49-19W4
10-34-48-19W4
13-14-48-19W4
10-31-47-18W4
(B-B')
5-15-47-18W4
12-33-46-18W4
10-9-46-18W4
6-1-46-18W4
SOUTH
C'
DATUM
0
25
50m
BASE FISH SCALES
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
WESTGATE FORMATION
JOLI FOU FM.
BHL TSE
J'CAM ITI
LBK RSE
BHL RSE
JOARCAM
(TRANSGRESSIVE SHOREFACE)
BEAVERHILL LAKE
(LOWSTAND SHOREFACE)
LINDBROOK
(LOWSTAND SHOREFACE)
BENTONITE
BENTONITE
BHL TSE
J'CAM ITI
LBK RSE
DISTAL (MUDDY)
JOARCAM SHOREFACE
LINDBROOK SHOREFACE
2/3
1
BHL TSE
BHL RSE
LBK RSE
BEAVERHILL LAKE SHOREFACE
LINDBROOK SHOREFACE
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
BENTONITE
INCISED SHOREFACE
REGIONAL SUCCESSIONS
'TRANSGRESSIVE' SUCCESSIONS

enclosed bentonites, and cut into the top of the LBK shoreface. An enlargement of the resistivity log signature in well 7-12-50-20W4 shows the interpreted stratigraphy more clearly, with the LBK shoreface resting on top of regional succession 2/3 and in turn overlain erosively by the BHL shoreface which has removed any evidence of J'CAM deposition (ie. bentonites and muddy coarsening up succession) observed to the north. Along strike the BHL shoreface continues to downcut through the LBK shoreface and ultimately begins to incise regional succession 1 (ie. well 13-14-48-19W4). This alongstrike variation in the depth of incision, which may result in the sometimes ambiguous relationship between BHL and J'CAM, is clearly illustrated.

5.4.2 Transgressively Incised Shorefaces

Five stratigraphic cross sections (two depositional dip, three depositional strike) have been drawn to show the stratigraphic relationships between the J'CAM, Sunnybrook 'A' (SBK 'A'), Sunnybrook 'B' (SBK 'B'), and Chigwell (CHIG) transgressive incised shorefaces.

Cross Section D-D'

This cross section (figure 5.6) is oriented west to east. The stratigraphic relationships between the SBK 'A' and 'B' and J'CAM shorefaces are shown. Below the well log cross section is a core section

Figure 5.6 Cross section D-D′. Well log section composed of gamma ray and resistivity well logs, vertical scales and locations as indicated. Corresponding core log is also illustrated with correlations.

D
D'
WEST
EAST
6-20-47-2W5
14-6-48-1W5
(E-E')
5-34-47-1W5
14-11-48-28W4
(G-G')
8-18-48-27W4
15-8 48-25W4
(F-F')
6-24-48-25W4
6-26-48-24W4
7-32-48-23W4
14-5-49-22W4
11-10-49-22W4
10-13-49-22W4
10-24-49-22W4
3-19-49-21W4
11-8-49-20W4
BASE FISH SCALES
DATUM
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
TRANSGRESSIVE DEPOSITS?
WESTGATE FORMATION
JOLI FOU FM.
SUNNYBROOK 'A' (TRANSGRESSIVE SHOREFACE)
SUNNYBROOK 'B' (TRANSGRESSIVE SHOREFACE)
JOARCAM (TRANSGRESSIVE SHOREFACE)
SBK 'A' TSE
SBK 'A' ITI
SBK 'B' TSE
SBK 'B' ITI
BHL TSE
J'CAM ITI
0
25
50m
5
10m
Sh F M C VC Cgl
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
INCISED SHOREFACE
REGIONAL SUCCESSIONS
'TRANSGRESSIVE' SUCCESSIONS

whose datum is also the base of the Fish Scales Formation.

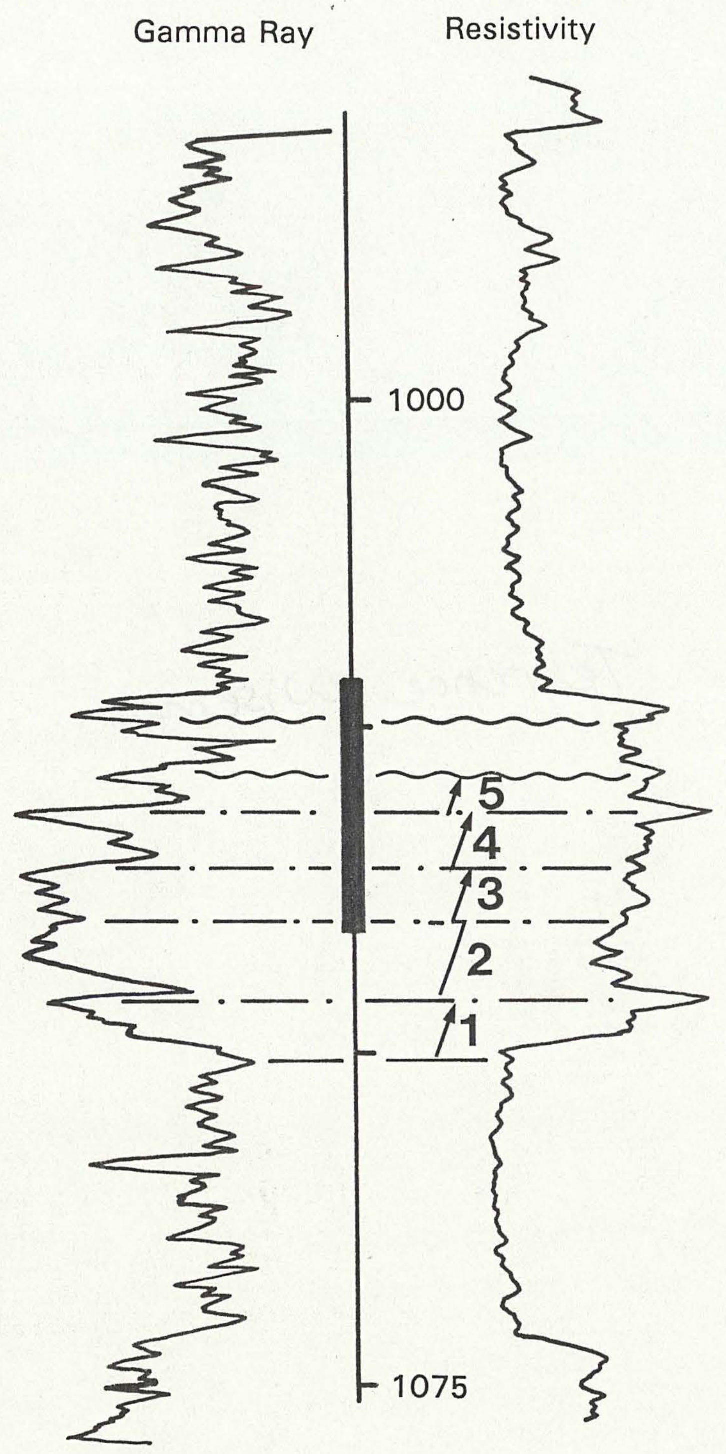
The easternmost portion of the cross section shows the position of the J'CAM which has incised into all or portions of regional successions 5, 4, and 2/3. The depth of incision increases to the east. The core in well 11-10-49-22W4 has just penetrated the top of J'CAM and occurs in the very western part of the sandbody. The succession cored in this well represents some of the very coarsest sediment from this sandbody observed in more then 70 cores in the J'CAM field. The base of the shoreface here is interpreted as being fairly sharply incised, with lower/middle shoreface sandstone resting directly on top of regional succession 4 sediments. The core section illustrates how the shoreface has an increasingly gradational appearance eastward as more offshore-lower shoreface sediments are preserved overlying the transgressive incision (J'CAM ITI). The upper boundary of the J'CAM shoreface is the BHL TSE, formed during resumed transgression initially after J'CAM deposition, then modified during lowstand and subsequent transgression associated with the BHL shoreface. Overlying this surface are packages of sediment comprising FA 3, FA 4, FA 5, and FA 6 which were deposited after both shorefaces at J'CAM and BHL had formed. Several prominent conglomerate or muddy, conglomeratic sandstone markers occur throughout this succession and onlap the BHL TSE surface.

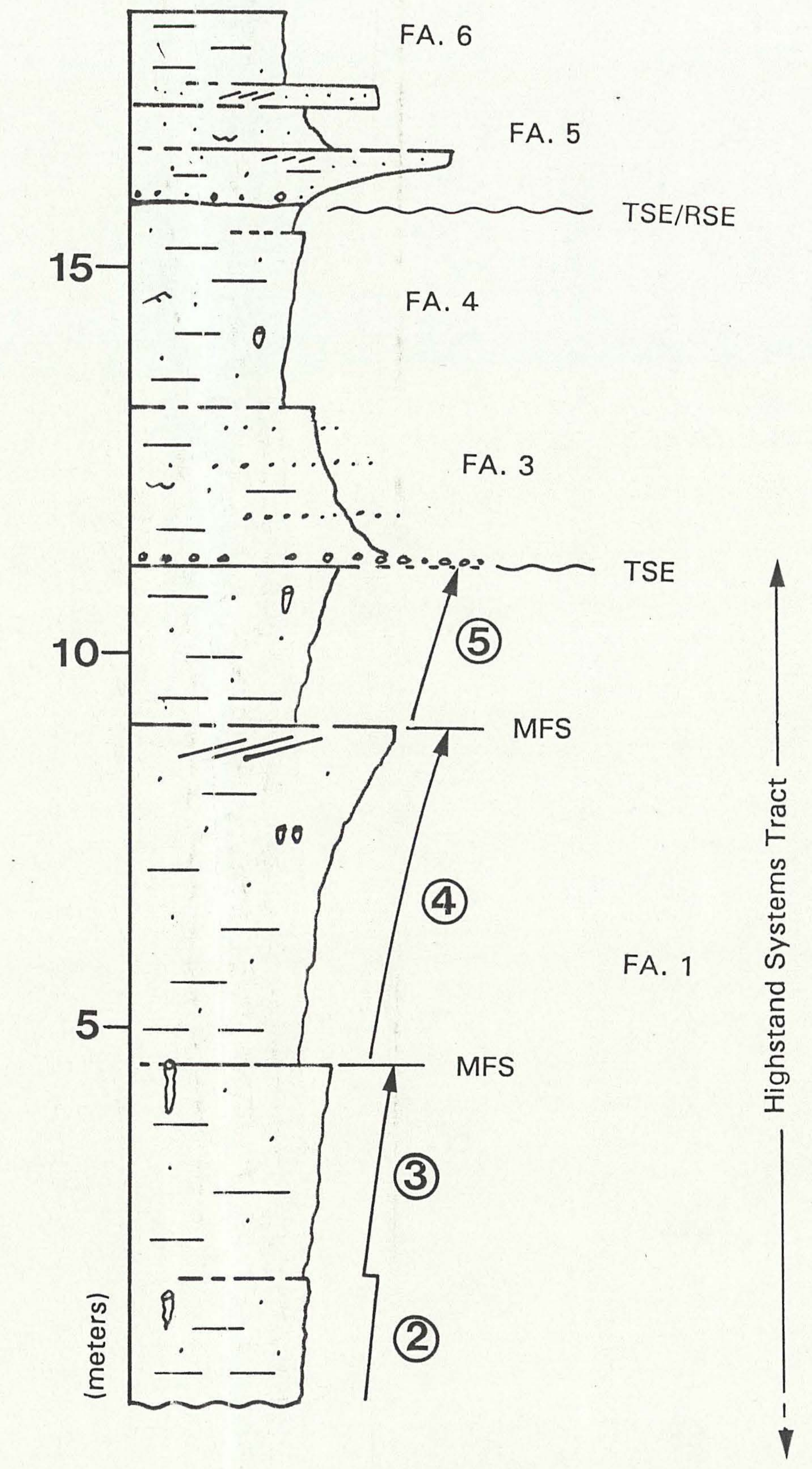
Westward, the stratigraphic relationships between the SBK 'A' and 'B' shorefaces are illustrated. No cores penetrate these two sandbodies on this cross section. Correlation of well logs in this area shows that SBK 'A' incises into regional successions 4 and 5, removing all or portions of these sediment packages. On this cross section SBK 'A' is present between 6-20-47-2W5 and 14-6-48-1W5 in the western part of the study area. The shoreface thins progressively eastward due to erosion by the younger SBK 'B' shoreface and disappears eastward between 15-8-48-25W4 and 6-24-48-25W4.

The SBK 'B' shoreface is also interpreted to incise into transgressive deposits overlying SBK 'A' as well as the upper portions of the SBK 'A' shoreface itself between wells 14-11-48-28W4 and 8-18-48-26W4. Ultimately, the lower bounding discontinuity of the shoreface (SBK 'B' ITI) cuts into regional successions 4 and 5 east of well 15-8-48-25W4. The well log correlations illustrate the progressive thinning of the SBK 'B' shoreface eastward as the basal discontinuity (SBK 'B' ITI) rises upwards through the stratigraphy. This results in an apparently westward dipping basal erosion surface. Eastward of the last preserved remnants of the SBK 'B' shoreface (ie. well 7-32-48-23W4) an erosional remnant of regional succession 5 is preserved underneath the SBK 'B' shoreface, this succession has been completely removed. This preserved portions of this succession form an 'outlier' (figure 6.4) as described in chapter 6. This interpretation is based upon well logs and evidence from cores in wells 14-5-49-22W4 and 6-29-47-21W4 which penetrate the stratigraphy west of the J'CAM field. Unfortunately, the entire core from well 14-5-48-22W4 is not available, probably due to loss during retrieval of the core. The missing section occurs at the upper contact between regional succession 5 and the overlying transgressive deposits (FA 3 and FA 4). Core from 6-29-47-21W4 provides important supporting evidence for the interpretation presented in cross section D-D'. A core photo, well log and interpretations are presented in figure 5.7. This core shows the uppermost two regional successions (succession 4 and 5) preserved between the J'CAM incised shoreface to the east (Posamentier, pers. comm., 1991) and the SBK 'B' incised shoreface to the west. Overlying the stack of successions is an erosional discontinuity overlain by sediments comprising FA 3, FA 4, FA 5, and FA 6. The discontinuity is interpreted as a transgressive surface of erosion. Well log correlations (figure 5.1) indicate that this surface is at the same stratigraphic level as the BHL TSE. This surface has been traced westward where it underlies the SBK 'B' shoreface, having a slight westward grade of 0.0005 (dip angle 0.003°). Thus, the SBK 'B' shoreface is younger than J'CAM because the discontinuity which truncates the top of the J'CAM shoreface (BHL TSE) becomes the surface underlying SBK 'B' (SBK 'B' ITI).

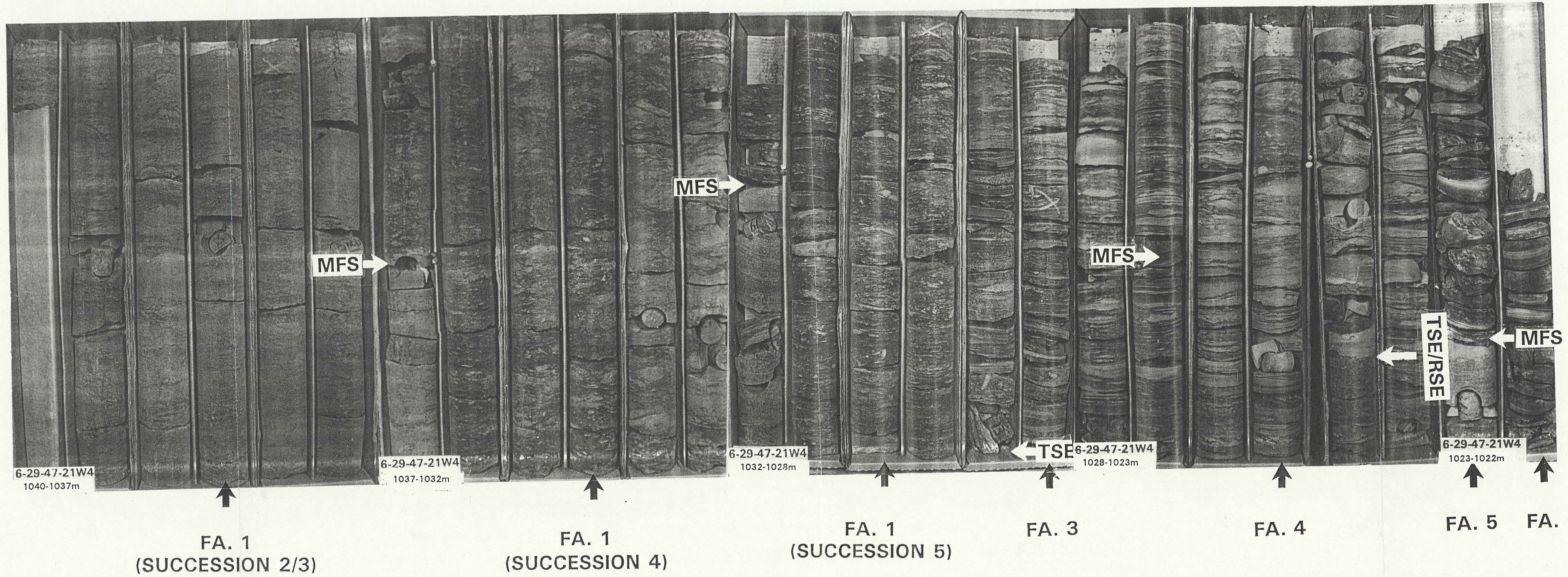
Figure 5.7 Well log, core photos and stratigraphic interpretation of well 06-29-47-21W4.

06-29-47-21W4





06-29-47-21W4
(3" Whole Core)



Cross Section E-E'

This depositional strike section (figure 5.8) illustrates the areal extent of the SBK 'A' and distal CHIG shorefaces. Two cores penetrate the Viking Formation on this line, one through the SBK 'A' shoreface (6-9-49-2W5) and another through the distal CHIG deposits (8-24-42-24W4).

The SBK 'A' shoreface is widespread through the study area and is thickest in township 47 (up to 14 m). The shoreface on this section reaches a maximum thickness east of one of the main arms of the Crystal valley, and is 13m thick in well 5-34-47-1W5 (figure 6.9). The base of the shoreface is defined by the SBK 'A' ITI surface which incises into regional successions 4 and 5. The top of the shoreface is defined as the SBK 'A' TSE or the surface that defines the top of the Viking Formation (VE4). The shoreface thins towards the south and east and reaches a thickness of just over 2m at its southernmost extent in this cross section. In well 4-22-43-25W4, the thinned SBK 'A' shoreface becomes difficult to distinguish from the underlying regional sediments. However, the gamma log indicates the presence of some sand at the top of the Viking (which is not present in wells penetrating only the regional succession in this area), interpreted as the shoreface deposits. Sediments overlying the SBK 'A' TSE surface are interpreted to represent either transgressive deposits eroded from the top of SBK 'A' during resumed transgression (ie. FA 3) and/or (younger) distal

Figure 5.8 Cross section E-E'. Well log section composed of gamma ray and resistivity well logs, vertical scales and locations as indicated. Corresponding core log and correlations are illustrated below.

E
NORTH
4-14-51-3W5
2-22-50-2W5
16-33-49-2W5
(I-I')
6-9-49-2W5
6-25-48-2W5
(D-D')
5-34-47-1W5
1-13-47-28W4
10-21-46-27W4
13-1-46-27W4
10-2-45-26W4
4-30-44-25W4
4-22-43-25W4
(H-H')
10-12-43-25W4
12-28-42-24W4
8-24-42-24W4
SOUTH
E'
DATUM
BASE FISH SCALES
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
SBK 'A' TSE
SBK 'A' ITI
WESTGATE FORMATION
JOLI FOU FM.
CHIG TSE
CHIG ITI
0
25
50m
SUNNYBROOK 'A'
(TRANSGRESSIVE SHOREFACE)
CHIGWELL
(TRANSGRESSIVE SHOREFACE)
SBK 'A' TSE
SBK 'A' ITI
CHIG TSE
CHIG ITI
0
5
10m
INCISED SHOREFACE
REGIONAL SUCCESSIONS
'TRANSGRESSIVE' SUCCESSIONS
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
DOWNLAPPING(?) MARKER
Sh F M C VC Cgl

CHIG shoreface deposits.

Distal CHIG deposits have been interpreted from core information in 8-24-42-24W4. The deposits are defined below by the CHIG ITI and the CHIG TSE above. In this well the actual thickness of the shoreface-equivalent sediments is less (<1m) than the overlying transgressive deposits (approximately 1m) eroded from the top of the shoreface further west. The erosional surface that defines the top of the Viking Formation (VE4) was also observed in this well. The position of the CHIG shoreface on this cross section is due to the fact that the SBK 'A' shoreface swings eastward in the southern part of the area where the section is drawn.

Cross Section F-F'

This depositional strike section (figure 5.10) illustrates the extent of the SBK 'B' shoreface. The base of the shoreface is defined as the SBK 'B' ITI surface which is incised into the fourth regional succession. The surface undulates slightly, with more or less of regional succession 4 being preserved. To the north, approximately 8 m of succession 4 is preserved in well 14-25-51-26W4, while in well 5-11-47-24W4 about 12 m of this succession remains. Several possible downlapping markers within the fourth succession have been suggested by the correlation lines. They form shingling markers that thin/downlap onto the top of regional succession 3.

Figure 5.9 Cross section F-F′. Well log section composed of gamma ray and resistivity well logs, vertical scales and locations as indicated.

Figure 5.10 Cross section G-G′. Well log section composed of gamma ray and resistivity well logs, vertical scales and locations as indicated.

F
NORTH
14-25-51-26W4
12-31-50-25W4
6-7-50-25W4
12-13-49-25W4
13-36-48-25W4
(D-D')
6-24-48-25W4
7-29-47-24W4
5-11-47-24W4
9-28-46-23W4
3-30-45-22W4
(H-H')
5-16-45-22W4
8-20-44-21W4
1-4-44-21W4
16-15-43-21W4
SOUTH
F'
BASE FISH SCALES
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
VIKING ALLOFM.
DATUM
WESTGATE FORMATION
JOLI FOU FM.
SBK 'B' TSE
SBK 'B' ITI
0
25
50m
SUNNYBROOK 'B'
(TRANSGRESSIVE SHOREFACE)
G
NORTH
8-12-51-28W4
13-24-50-28W4
3-8-50-27W4
7-15-49-27W4
(I-I')
3-1-49-27W4
(D-D')
8-18-48-27W4
15-11-47-26W4
11-12-46-26W4
4-23-45-25W4
6-6-45-24W4
7-25-44-24W4
(H-H')
10-10-44-23W4
4-26-43-23W4
SOUTH
G'
BASE FISH SCALES
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
VIKING ALLOFM.
DATUM
WESTGATE FORMATION
JOLI FOU FM.
SBK 'A' ITI
SBK 'B' ITI
SBK 'B' TSE
0
25
50m
SUNNYBROOK 'A' & 'B'
(TRANSGRESSIVE SHOREFACES)
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
REGIONAL SUCCESSIONS
INCISED SHOREFACE
'TRANSGRESSIVE' SUCCESSIONS

These markers are identified by small gamma and/or resistivity picks that are present in the logs in regional succession 4. Depending on the depth of incision by the overlying transgressive incised shorefaces, three to four of these markers can be distinguished.

The one core that penetrates the Viking Formation on this cross section at 5-11-47-24W4 has just penetrated the surface that defines the top of the Viking (VE4). Other than helping the interpretation of the position of this surface, it had limited value and thus was not included as part of a core section.

Cross Section G-G'

This depositional strike cross section (figure 5.11), oriented north to south shows the spatial distribution of the SBK 'A' and 'B' shorefaces. No cores penetrated this interval close to the cross section and all interpretations are made on the basis of well logs.

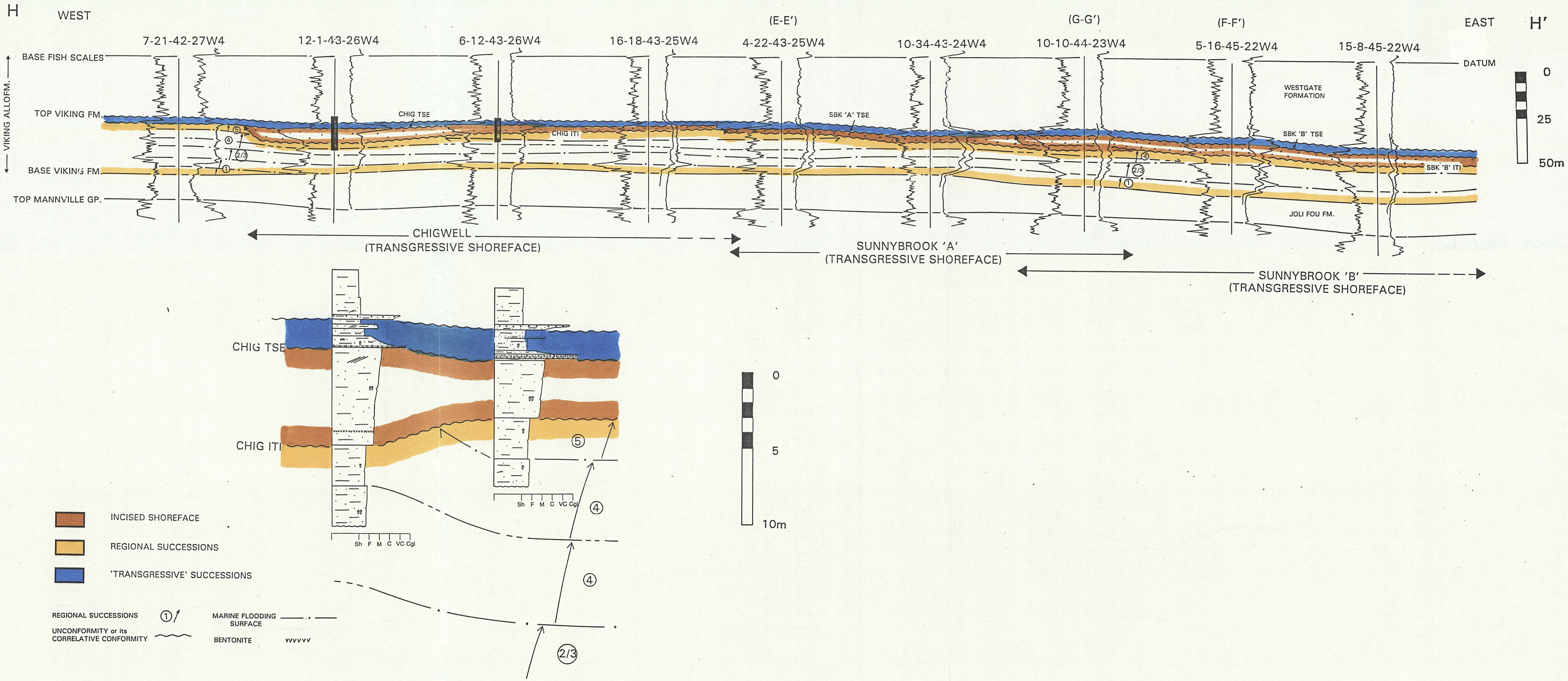
SBK 'A' is defined below by the SBK 'A' ITI and above by the SBK 'B' ITI surface. In the northern portion of the cross section, SBK 'A' incises through regional succession 4 and 5 and into the top of succession 2/3 (ie. well 8-12-51-28W4). Further south (well 14-31-48-26W4) this shoreface rests on top of the erosional remnants of regional succession 4. This shoreface thins depositionally and/or by erosion southward. Downlapping markers, present in F-F' are not reliably distinguishable on this cross section, possibly due to the depth of incision by the overlying shorefaces which have removed much more of regional succession 4.

The SBK 'B' shoreface incises into the older SBK 'A' shoreface throughout this section. It is defined below by the SBK 'B' ITI and above by the SBK 'B' TSE or by the top of the Viking Formation (VE4) (ie. 15-11-47-26W4). This shoreface also thins southward due to either depositional and/or erosional attenuation. Overlying this shoreface are deposits interpreted as being transgressive (ie. FA 3 or FA 4) associated with erosive ravinement of the SBK 'B' shoreface during relative rise of sea level.

Cross Section H-H'

This depositional dip cross section (figure 5.12) exhibits well and core correlations in order to illustrate the stratigraphic relationship between SBK 'A' and 'B' and CHIG shorefaces.

The SBK 'A' shoreface is the lowest of the three shorefaces illustrated on the section. It is defined below by the SBK 'A' ITI surface which incises into regional successions 4 and 5. The top of SBK 'A' is defined as the SBK 'A' TSE or the SBK 'B' ITI, following the convention established in the previous sections. The westward termination of this sandbody occurs in well 4-22-43-25W4 where the shoreface rests upon the steep side of an


H
WEST
EAST
H'
7-21-42-27W4
12-1-43-26W4
6-12-43-26W4
16-18-43-25W4
(E-E')
4-22-43-25W4
10-34-43-24W4
(G-G')
10-10-44-23W4
(F-F')
5-16-45-22W4
15-8-45-22W4
BASE FISH SCALES
DATUM
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
CHIG TSE
CHIG ITI
SBK 'A' TSE
SBK 'B' TSE
SBK 'B' ITI
WESTGATE FORMATION
JOLI FOU FM.
0
25
50m
CHIGWELL
(TRANSGRESSIVE SHOREFACE)
SUNNYBROOK 'A'
(TRANSGRESSIVE SHOREFACE)
SUNNYBROOK 'B'
(TRANSGRESSIVE SHOREFACE)
CHIG TSE
CHIG ITI
5
4
4
2/3
Sh F M C VC Cgl
0
5
10m
INCISED SHOREFACE
REGIONAL SUCCESSIONS
'TRANSGRESSIVE' SUCCESSIONS
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
BENTONITE

asymmetric scour. The shoreface in this well has a very subdued log response suggesting that little sandstone is present. This may be a function of erosional truncation by the SBK 'A' TSE which has resulted in muddy sandstones of the lower shoreface being the only preserved deposits in this area. Alternatively, the SBK "A' shoreface might not have reached as full a development in this area as it did farther north.

The SBK 'B' shoreface incises into the older deposits of SBK 'A' in the eastern part of the cross section (wells 10-10-44-23W4). The base of the shoreface is the SBK 'B' ITI or the SBK 'B' ITI, while the upper bounding discontinuity is called SBK 'B' TSE. This shoreface thickens eastward through the section.

The CHIG shoreface incises into regional sediments between wells 7-21-42-27W4 and 12-1-43-26W4 and may be correlated as an eastward thinning (muddier?) package of sediment until it dies out between wells 16-18-43-25W4 and 4-22-43-25W4. The CHIG shoreface is defined below by the CHIG ITI surface where it incises into regional deposits. The top of the shoreface is the CHIG TSE surface. Above this surface, transgressive deposits eroded from the top of the CHIG shoreface were deposited along with a distal coarsening upward package of sediment characteristic of FA 4. This cross section shows quite well the nature of the erosional scour that defines this particular shoreface (and incised shorefaces in general). The incision is deepest in the west, where it also has its steepest margin, and erosionally truncates all of regional succession 5 and part of succession 4. To the east the incision rises through the stratigraphy until it overlies the fifth regional succession in well 16-18-43-25W4. This is an excellent example of the nature of the asymmetric incisions onto which incised shorefaces prograde. Although there is no well in which distal CHIG deposits rest directly upon SBK 'A' or 'B' deposits, the higher stratigraphic position of of the sandbody to the most proximal of the two SBK sandbodies (ie. SBK 'A') indicates that it is probably a younger shoreface than SBK 'A'. Pattison (1991) reports that distal sediments of the Wolf Creek - Gilby 'A' - Joffre trend lie stratigraphically above the CHIG deposits; this constrains the age of CHIG to be younger then Sunnybrook 'A' but older than SBK 'B' (see chapter 7).

5.4.3 Incised Valley Fills

The lone cross section presented here illustrates the stratigraphic relationship between the two Crystal incised valley fills (Pattison and Walker, 1994) and the 'genetically related' transgressively incised shorefaces at SBK 'A' and 'B'.

Cross Section I-I'

This depositional dip cross section (figure 5.13) illustrates the

Figure 5.12 Cross section I-I'. Well log section composed of gamma ray and resistivity well logs, vertical scales and locations as indicated. Corresponding core section and correlations is also illustrated below.


I
WEST
4-1-47-3W5
8-16-48-3W5
6-30-48-2W5
(E-E')
6-9-49-2W5
9-8-49-1W5
6-11-49-28W4
11-1-49-28W4
(G-G')
3-1-49-27W4
3-1-49-26W4
EAST
I'
DATUM
BASE FISH SCALES
VIKING ALLOFM.
TOP VIKING FM.
BASE VIKING FM.
TOP MANNVILLE GP.
CRYSTAL INCISION 2
CRYSTAL INCISION 1
FACIES TRANSITION
SBK 'A' TSE
SBK 'A' ITI
SBK 'B' ITI
SBK 'B' TSE
WESTGATE FORMATION
JOLI FOU FM.
0
25
50m
CRYSTAL (VALLEY FILL #2)
CRYSTAL (VALLEY FILL #1)
SUNNYBROOK 'A'
(TRANSGRESSIVE SHOREFACE)
SUNNYBROOK 'B'
(TRANSGRESSIVE SHOREFACE)
CRYSTAL FILL #2 TSE
CRYSTAL FILL #2 ITI
CRYSTAL FILL #1 ITI
CRYSTAL FILL #1 TSE
SBK 'A' TSE
SBK 'A' ITI
Sh F M C VC Cgl
0
5
10m
INCISED SHOREFACE
REGIONAL SUCCESSIONS
'TRANSGRESSIVE' SUCCESSIONS
INCISED VALLEYS
REGIONAL SUCCESSIONS
UNCONFORMITY or its CORRELATIVE CONFORMITY
MARINE FLOODING SURFACE
FACIES CHANGE

relationship between the Crystal valley fills (#1 and #2) and the SBK 'A' and 'B' shorefaces.

The oldest shoreface, SBK 'A', is cored in well 6-9-49-2W5 and is inferred to have a genetic relationship with the Crystal Valley fill #1 (Pattison and Walker, 1994). The fully marine shoreface cored in 6-9-49-2W5 is inferred to be the time equivalent to the brackish marine facies of fill #1 cored in well 8-16-48-3W5 and 4-1-47-3W5. The lower boundary of SBK 'A' (SBK 'A' ITI) is the same surface as that underlying Crystal valley fill #1 (Crystal incision 1). Regional successions 2,3, and 4 are either partially or wholly removed beneath the time equivalent shoreface and valley fill. A facies change is inferred to occur between wells 6-30-48-3W5 and 6-9-49-2W5 where there is a distinctive change in log character from a "coarsening upward" trend in the cored well at 6-9 (interpreted as shoreface) to a subdued "fining- to coarsening-upward" trend (especially on the gamma log) interpreted as estuarine/brackish water deposits by Pattison (1991).

The physical connection between SBK 'A' and Crystal valley fill #1 is relatively easy to establish. However, no physical connection can be **clearly** shown to exist between SBK 'B' and valley fill # 2. Sunnybrook 'B' is incised into SBK 'A' deposits in well 9-8-49-1W5 and all wells to the east. Crystal incision 2 is preserved in well 4-1-47-3W5 where the basal disconformity (Crystal incision 2) cuts into valley fill #1. The top of both the

SBK 'B' shoreface and Crystal valley fill # 2 is the top of the Viking Formation. Presumably, any connection between the two depositional systems has been removed by erosion at the top of the Viking Formation or is unrecognised in well logs. The lack of core control in the entire area also precludes any definite identification of transitional facies between SBK 'B' and Crystal valley fill # 2.

5.5 PAST CORRELATIONS IN THE STUDY AREA

Several studies have been undertaken in this study area which were focussed on both local and regional correlation of Viking sandbodies (Amajor, 1988; Beaumont, 1984; Slatt, 1985; Ryer, 1987; Power, 1988; Posamentier and Chamberlain, 1989, 1991; Pattison, 1991; and Posamentier et al., 1992, 1993). Descriptions of the pre-1988 studies may be found in Power (1988). The most recent and detailed studies of Power (1988), Posamentier and Chamberlain (1989, 1991), Pattison (1991) and Posamentier et al (1992) have applied the concept of sequence stratigraphy or allostratigraphy to the Viking Formation with various resulting interpretations. The results presented here differ somewhat from these past studies and as such are discussed below.

Power (1988) correlated the thick coarsening-upward facies succession (member "B") of Joarcam southwestward with regionally extensive coarsening upward successions occurring toward Joffre field. As a result he suggested that Joarcam represented an attached strandplain which prograded from Joffre eastwards across the shelf, thus explaining the gradational nature of the succession observed in core.

Posamentier and Chamberlain (1989, 1991) showed that Power's (1988) interpretations were flawed when they recognised that the shoreface succession at Joarcam rests in an elongate asymmetric scour which was incised into - rather than correlated with - the stacked coarsening upward successions to the west. They interpreted the Joarcam sandbody as a lowstand shoreface formed during a large fall in RSL. In addition to subdividing the Viking Formation at Joarcam into various systems tracts, they recognised and correlated two thick (several tens of centimeters) bentonite beds (identified in core) which are present at the base of the prograding J'CAM shoreface. They recognised that the bentonites formed suitable time lines within the prograding shoreface and determined an original paleoslope of the shoreface to have been approximately 0.10°.

Later, Posamentier et al. (1992) proposed an elaborate series of relative sea level rises and falls to account for the complicated stratigraphy comprising sharp based sandbodies (interpreted from well logs) basinwards of J'CAM. Three 'lowstand' shorelines (termed I, IIa and IIb) were interpreted to have formed during "a number of high frequency relative sea level falls (fourth order?) superimposed an the rising limb of a lower frequency relative sea level cycle (third order?)" (Posamentier et al., 1992). The stratigraphic positions of each of these sandbodies was based on a single cross section showing the apparent relative depths of incision of each sandbody; no use was made of the prominent bentonitic horizons which occurred within the J'CAM shoreface sediments and to the west. Their stratigraphy and its inferred record of relative sea level fluctuation indicated three separate lowstand systems tracts underlain by three sequence boundaries (Walker and Wiseman, in prep.).

By utilizing many more cross sections, defining the stratigraphic position of the bentonitic horizons east of J'CAM and uncovering evidence of alongstrike variation in the depth of sandbody erosion, a simpler and perhaps more credible stratigraphic scheme has been developed and is presented in this thesis (see Chapter 7). The key to the simpler scenario are the correlation of the two thick bentonites occurring in the lowermost portion of the (distal) J'CAM shoreface where they essentially lie on top of the ITI at the base of the Joarcam shoreface. This surface has been shown to correlate with the TSE above Lindbrook therefore suggesting that Joarcam deposition (whose distal equivalent is indicated by the bentonites) postdated that at Lindbrook. These bentonitic markers are traced further basinwards where they disappear or are unrecognisable above the BHL shoreface. The truncation of the markers suggests erosion at the base of BHL indicating that it is the youngest sandbody in the study area. Thus, careful correlation of the bentonites in the J'CAM - BHL area suggests that LBK is a lowstand shoreface, J'CAM is transgressive (formed immediately after LBK) and that BHL appears to represent a second lowstand shoreface of younger age than the previous two.

Pattison (1991) correlated distal Sunnybrook 'B' deposits into the Joarcam area where he suggested that they were erosively removed at the base of the Joarcam incised shoreface. The Sunnybrook 'B' and Joarcam shorefaces were included as part of a falling stage systems tract with each shoreface representing a stillstand position on the overall fall of RSL. Within this thesis, it is suggested that the distal Sunnybrook 'B' succession thins to a zero edge west of the J'CAM shoreface as a result of depositional and/or erosional attenuation. This correlation is illustrated in cross section D-D'. Cores which have penetrated the Viking west of Joarcam show a stack of regional coarsening-upward successions that appears to be unaffected by erosion except at the top where a TSE and lag has been developed (see figure 5.10). Correlation of the Sunnybrook 'B' and Joarcam shorefaces in this thesis therefore suggests that they are both transgressive in origin.

5.6 SUMMARY OF STRATIGRAPHIC RELATIONSHIPS

Unfortunately, not all the relationships have been unequivically established because of the complex series of erosional events that has removed much of the stratigraphy between individual sandbodies. Many of the inferred relationships can be better established through a discussion of the plan view geometry (chapter 6). As such, this synopsis is provided as a focal point from which the reader can approach the next chapter.

1) Through the application of the correlation template six incised shorefaces have been defined in the study area.

2) Correlation of bounding discontinuities between individual sandbodies suggest that the incised shorefaces can be characterised as lowstand or transgressive based upon their relative stratigraphic positions. Lowstand shorefaces occur furthest basinward and are the stratigraphically lowest sandbodies recognised within any sequence. Transgressive shorefaces have a 'backstepping' relationship from the lowstand position and may be associated with transgressive filling of incised valleys.

2) The Lindbrook lowstand shoreface is the stratigraphically lowest incised sandbody in the study area. It is underlain by a RSE that has incised into the underlying regional successions and is overlain by a TSE that is

traceable westward into the Joarcam area. This sandbody is approximately 6 m thick in cross section A-A′ but is erosively thinned alongstrike by erosion at the base of the Beaverhill Lake shoreface until it is completely removed to the southeast (section B-B′).

3) The TSE above Lindbrook correlates with the ITI beneath the Joarcam transgressive shoreface therefore indicating their relative stratigaphic positions. In addition, bentonite marker beds can be traced eastward where they overlie the Lindbrook shoreface thus defining the stratigraphic position of distal Joarcam sediments above Lindbrook.

4) The Beaverhill Lake lowstand shoreface is defined below by a RSE that erosively removes both distal Joarcam sediments and the top of the Lindbrook shoreface in the northeast portion of the study area. Alongstrike the depth of incision beneath Beaverhill Lake increases until all record of Lindbrook deposition is completely removed. The top of the Beaverhill Lake shoreface is a TSE that can be traced westward to overlie the Joarcam shoreface. A transgressive package of sediment deposited above this ravinement surface onlaps to the west.

5) The Sunnybrook 'A' shoreface is inferred to have been developed

immediately after deposition of the Joarcam shoreface. Unfortunately, the stratigraphic record between these two shorefaces has been completely removed by erosion at the base of the Sunnybrook 'B' shoreface. Sunnybrook 'A' is defined below by an ITI which incises into portions of the regional successions and above by a TSE which can be traced to the west. A physical connection can be shown to exist between Sunnybrook 'A' and the transgressive valley-fill # 1 at Crystal which suggests their concomitant development.

6) The Chigwell transgressive shoreface is underlain by an ITI that can be traced eastward to overlie the TSE at Sunnybrook 'A'. Chigwell is overlain by a TSE that is also traceable to the southwest where it has been shown to underlie the shoreface trend at Wolf Creek - Gilby - Joffre (Pattison, 1991). The relationship between Sunnybrook 'B' and Chigwell is difficult to establish. However, erosion of 'transgressive' deposits (or possibly some portion of distal Chigwell deposits) above Sunnybrook 'A' (cross section D-D', well 14-11-48-28W4) suggest that Chigwell predates Sunnybrook 'B'.

7) The Sunnybrook 'B' transgressive shoreface is the youngest sandbody recognised in the study area. It is underlain by an ITI which can be traced

eastward to overlie the Beaverhill Lake shoreface. Sunnybrook 'B' progressively incises into the Sunnybrook 'A' shoreface eastward until it has been completely removed. The top of the Sunnybrook 'B' shoreface is a TSE that is traced westward above the Crystal Valley. No clear physical connection can be shown to exist between Sunnybrook 'B' and Crystal valley fill #2. This may be a result of the connection being unrecognised in well logs (core control is also very poor) and/or a function of its removal by later erosive events. The thickest occurrence of the shoreface sandstone occurs directly east of the main arm of this valley and they are generally in an extremely close proximity (mimicing the relationship between Sunnybrook 'A' and Crystal valley fill #2) which suggests their concurrent evolution.

CHAPTER 6: MAPS: GEOMETRY OF FACIES ASSOCIATIONS AND MARKERS AND TOPOGRAPHY ON BOUNDING DISCONTINUITIES

6.1 Introduction

The purpose of this chapter is to detail the areal extent of the main facies associations, marker beds and bounding discontinuities that were described previously in chapters 3 and 5. Total isopach maps illustrate the changes in thickness between bounding discontinuities and/or illustrate topography on particular bounding surfaces.

Isopach maps of the regional coarsening upward successions (FA 1) illustrate original depositional trends and/or later erosional topography; depositional trends from the first two maps show the general depositional strike for the earliest Viking sediments oriented normal to later 'upper' Viking sedimentation. Isopach maps of the incised shoreface successions (FA 2A and 2B) are intended to show overall thickness trends and the isolated nature of the shorefaces. A striking feature common to all these sandbodies is their en-echelon arrangement and northwest - southeast trends. The total isopach map of the 'transgressive' sediments (FA 3 and 4) shows that their extent in the study area is controlled both by erosion on the underlying VE3 and overlying VE4 erosion surfaces. The entire Viking Formation (*senso stricto)* has also been isopached in an effort to illustrate the general areas of thicks and thins in the undifferentiated formation. The total isopach of the Joli Fou Formation illustrates not only trend thicknesses but suggests an antithetical relationship with the overlying regional successions of the Viking Formation. Bounding discontinuities, which were mapped to show topography relative to the base of the Fish Scales Formation, included the erosional top of the Viking Formation and the top of the regional successions. In each case the base of the Fish Scales Formation is assumed to be a flat datum and the topography illustrated is interpreted accordingly.

The total isopach maps were all constructed in the same manner. Using well logs, the thickness between identifiable bounding discontinuities were obtained and recorded in spreadsheet form. The values obtained represent thicknesses between discontinuities which separate individual facies associations or thicknesses which separate bounding discontinuities from the base of the Fish Scales Formation and/or the base of the Viking Formation. The maps were then constructed by hand. The several bounding discontinuities present in the Viking Formation in this area which were the basis for creation of the total isopach maps are discussed in chapters 3 and 5.

6.2 Total Isopach Maps of Regional Successions

6.2.1 Regional Succession 1

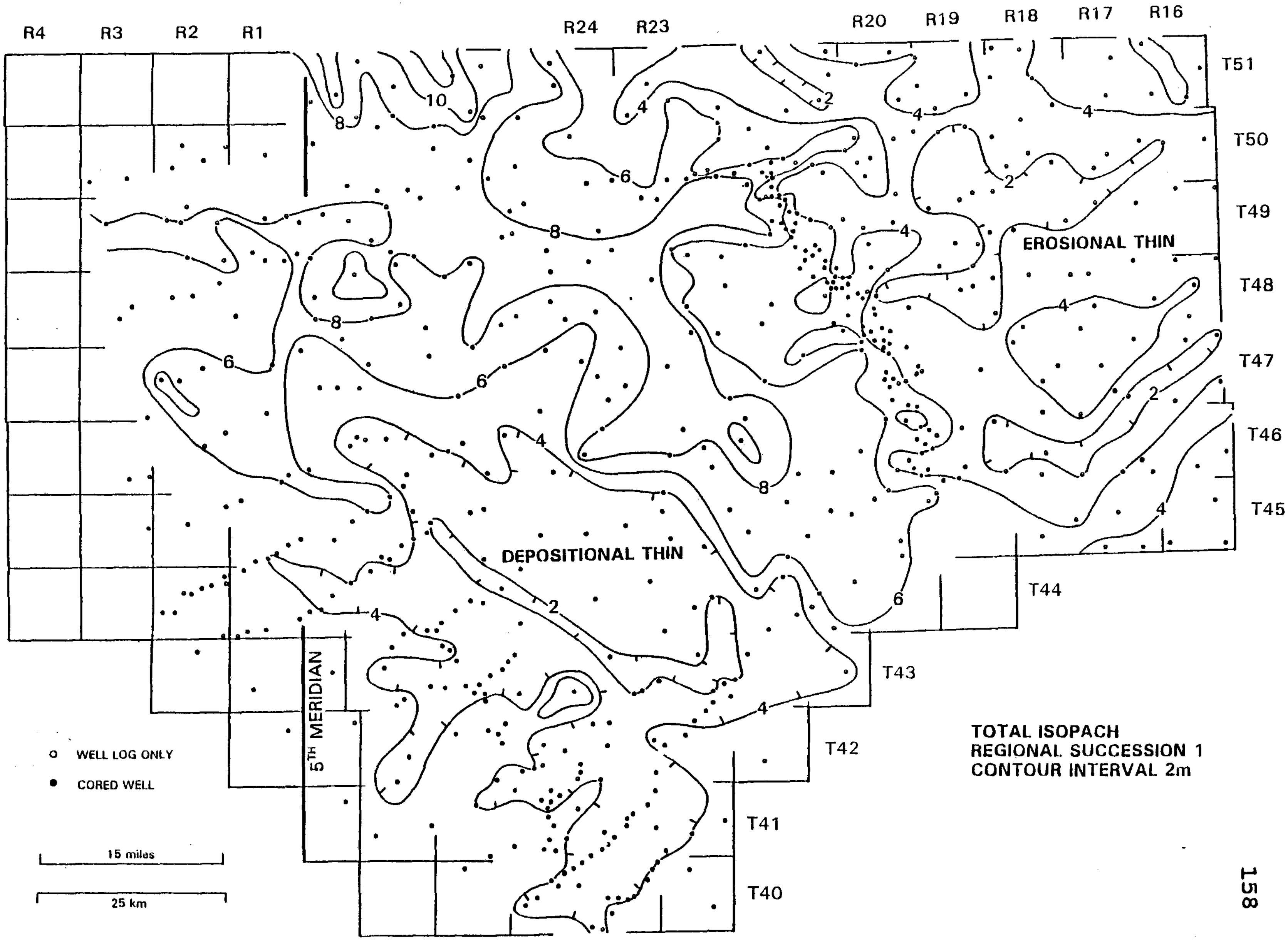
The extensive occurrence of regional succession 1 in the study area is shown by the total isopach map, contour intervals 2 m, illustrated in figure 6.1. In the east, the succession has been erosively thinned by the base of the Joarcam, Lindbrook, and Beaverhill Lake shorefaces. In the southwestern part of the study area, a prominent depositional thin, defined by the 4 m isopach contour, is evident. A lobate thick is situated between these two thin areas, it is defined by the 6 m isopach line and trends northwest-southeast. This trend thickens towards the northwest and suggests that the overall depostional strike is northeast - southwest.

In the study area, regional succession 1 reaches a maximum thickness of 12 m in T51 - R26W4.

6.2.2 Regional Succession 2/3

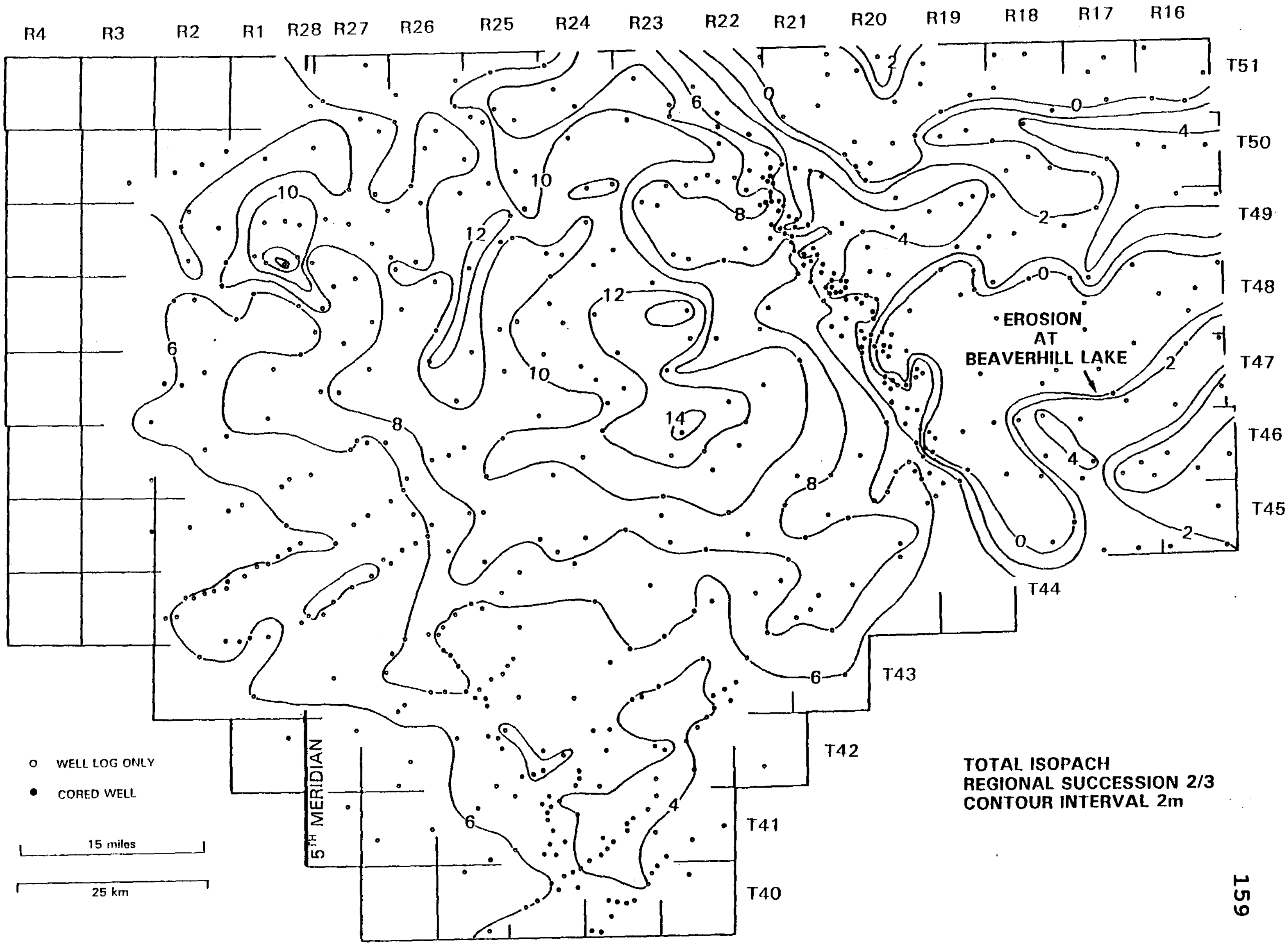
The areal extent of regional succession 2/3 is illustrated by the total isopach map in figure 6.2. Contour intervals on the map are 2 m. The succession is present extensively throughout the area, except in the west where it has been erosively thinned or removed at the base of the Joarcam, Beaverhill Lake, and Lindbrook incised shorefaces. Everywhere else, the map illustrates depositional thickness trends. A depositional thin exists in the southwest which is defined by the 6m isopach line and as with regional succession 1, a prominent northwest - southeast trending depositional thick

Figure 6.1 Total isopach map of regional succession 1 in 2m contour intervals. Note the erosional and depositional thins indicated and the pronounced depositional thick (defined by the 6m contour line) which is oriented northwest - southeast.



TOTAL ISOPACH
REGIONAL SUCCESSION 1
CONTOUR INTERVAL 2m

Figure 6.2 Total isopach map of regional succession 2/3 in 2m contour intervals. Erosional topography is evident to the west while a pronounced depositional thick is visible (defined by the 8m contour line) oriented northwest - southeast.



TOTAL ISOPACH
REGIONAL SUCCESSION 2/3
CONTOUR INTERVAL 2m

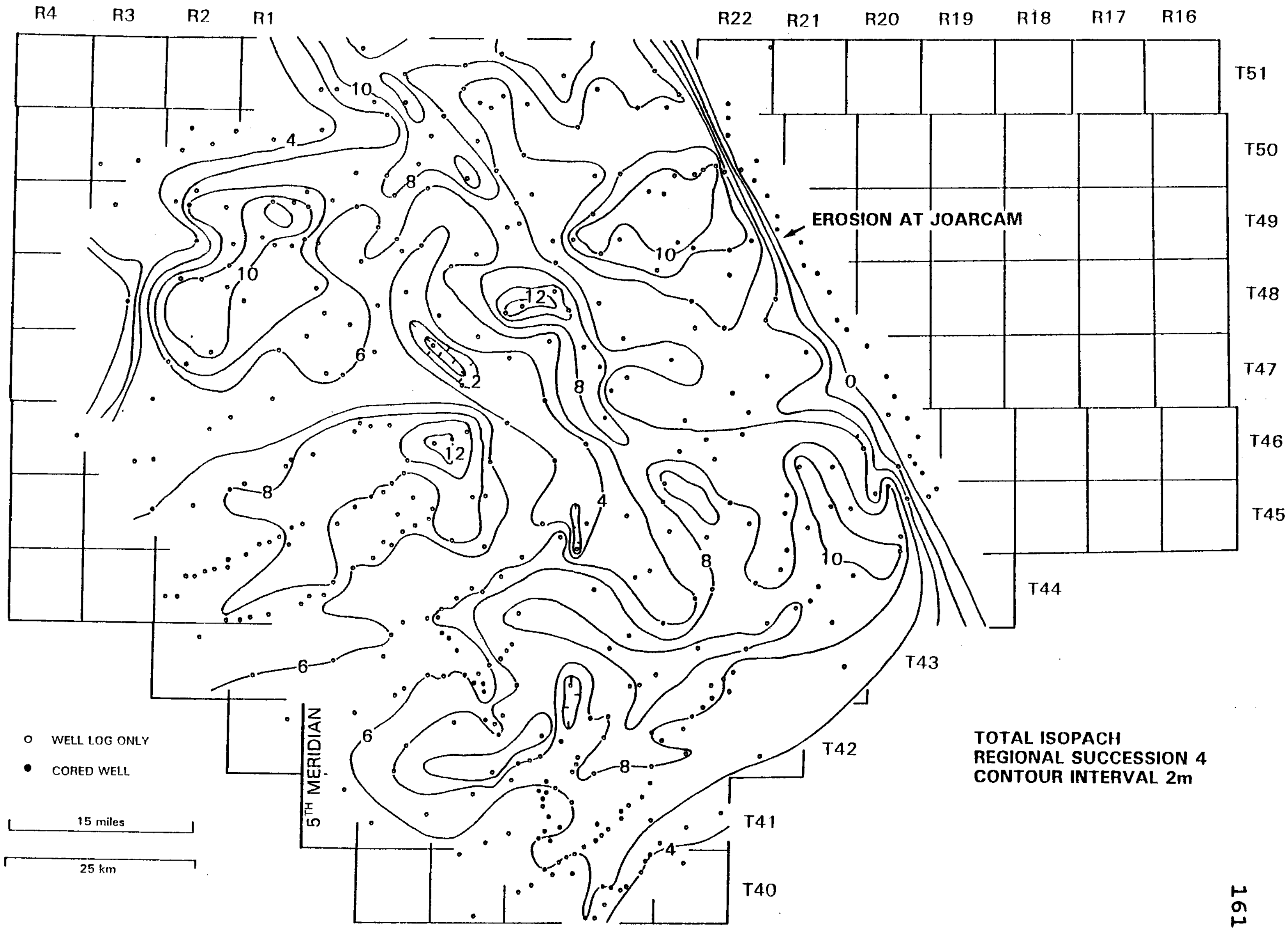
is visible in the central portion of the study area. In general the 'thins' and 'thicks' give the impression that the succession has a southwest - northeast strike. In the area, regional succession 2/3 reaches a maximum thickness of 14 m in T49 R1W5 and a minimum depositional thickness of 4 m in T41 R23W4.

6.2.3 Regional Succession 4

The extent of regional succession 4 in the study area is shown by the total isopach map with 2 m contour intervals, in figure 6.3. This succession has been severely thinned by erosion throughout the study area. An extreme example of this is the pronounced and steeply bounded thin in the east central part of the study area (east of which regional succession 4 is not preserved) which is an erosional edge associated with the base of the Joarcam incised shoreface. Other trends such as the northwest-southeast trending thin in the center of the map, defined by the 4 m contour line, are associated with erosion by the Sunnybrook 'A' shoreface. The northwest-southeast trending thick defined by the 8 m isopach in the central part of the study area may represent an the remnants of an original depositional thick as it occurs in the same area as the thicks in the underlying successions (1 and 2/3).

In the area, regional succession 4 reaches a maximum thickness of 13

Figure 6.3 Total isopach map of regional succession 4 in 2m contour intervals. The succession is eroded virtually everywhere throughout the study area, thus, the map is indicative of erosional topography only.



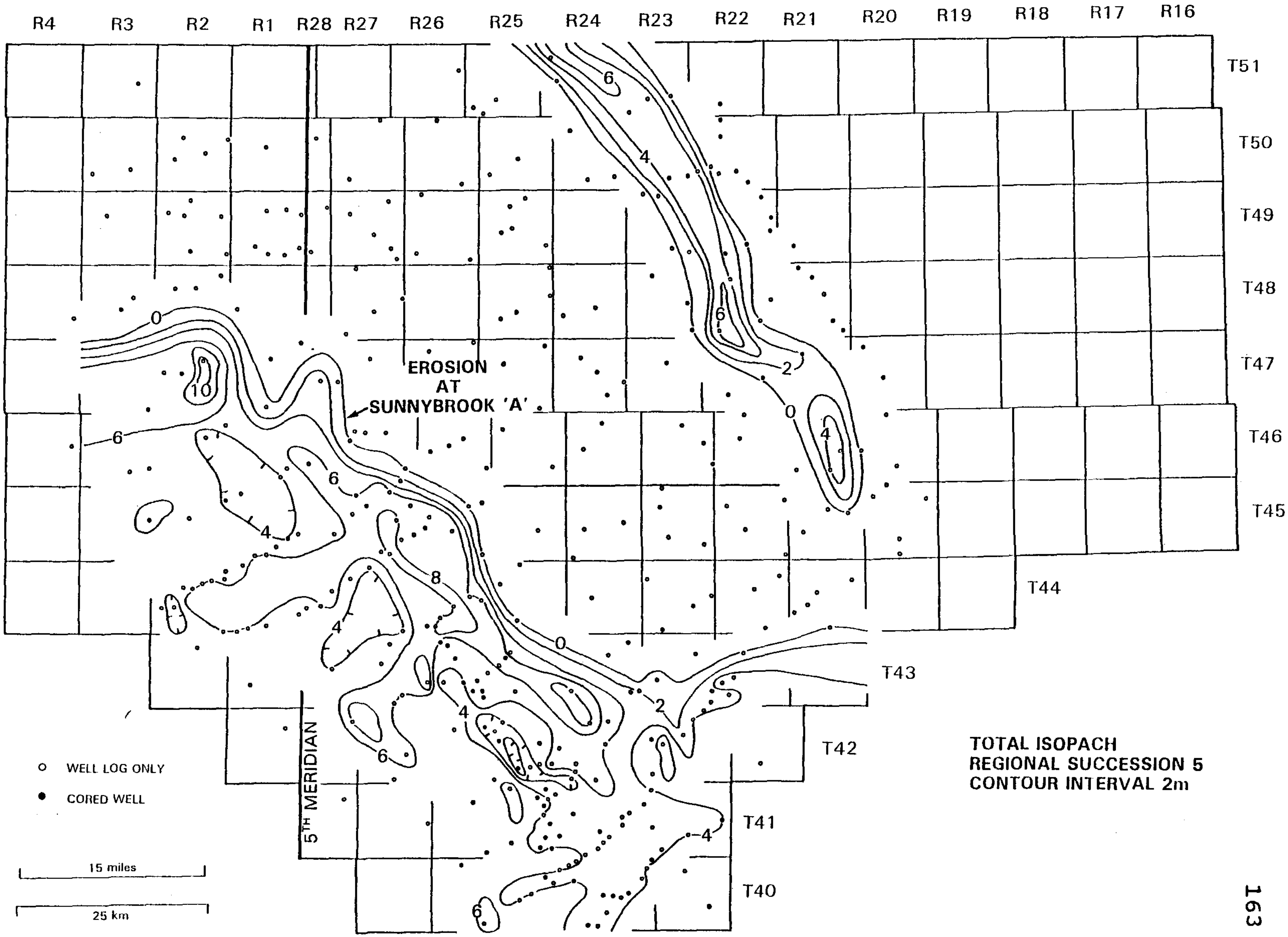
TOTAL ISOPACH
REGIONAL SUCCESSION 4
CONTOUR INTERVAL 2m

m in T49 R1W5 and a minimum depositional thickness of 4 m in T40 R24W4.

6.2.4 Regional Succession 5

Regional succession 5, is completely removed or erosively thinned throughout the study area, thus, the total isopach in figure 6.4 displays an entirely erosional topography. As displayed in the map, the succession is severely eroded throughout the area, preserved remnants occur in the south and west, while a linear shaped 'outlier', oriented northwest-southeast, occurs in the central region. Erosion at the base of several shorefaces can be distinguished by thins in this succession or by its absence. East of the outlier, the Joarcam incision is responsible for the removal of all of succession 5, likewise the Sunnybrook 'A' and 'B' shorefaces remove all of the succession in the area between these two preserved remnants. A thin in the succession, defined by the 4 m contour and a zero depression within, occurs along the erosional incision which defines the base of the Chigwell shoreface. A depositional thick in T47 R2W5 is the result of erosion by the primary and secondary channels of the Crystal incised valley (Pattison, 1991) which creates an outlier of 'regional' sediments which separates the two channels.

Figure 6.4 Total isopach map of regional succession 4 in 2m contour intervals. The succession is severely eroded everywhere throughout the study area and is completely removed in many areas; the outlier west of the Joarcam area is a preserved erosional remnant between Sunnybrook 'B' and Joarcam.



TOTAL ISOPACH
REGIONAL SUCCESSION 5
CONTOUR INTERVAL 2m

6.3 Total Isopach Maps of Incised Shorefaces

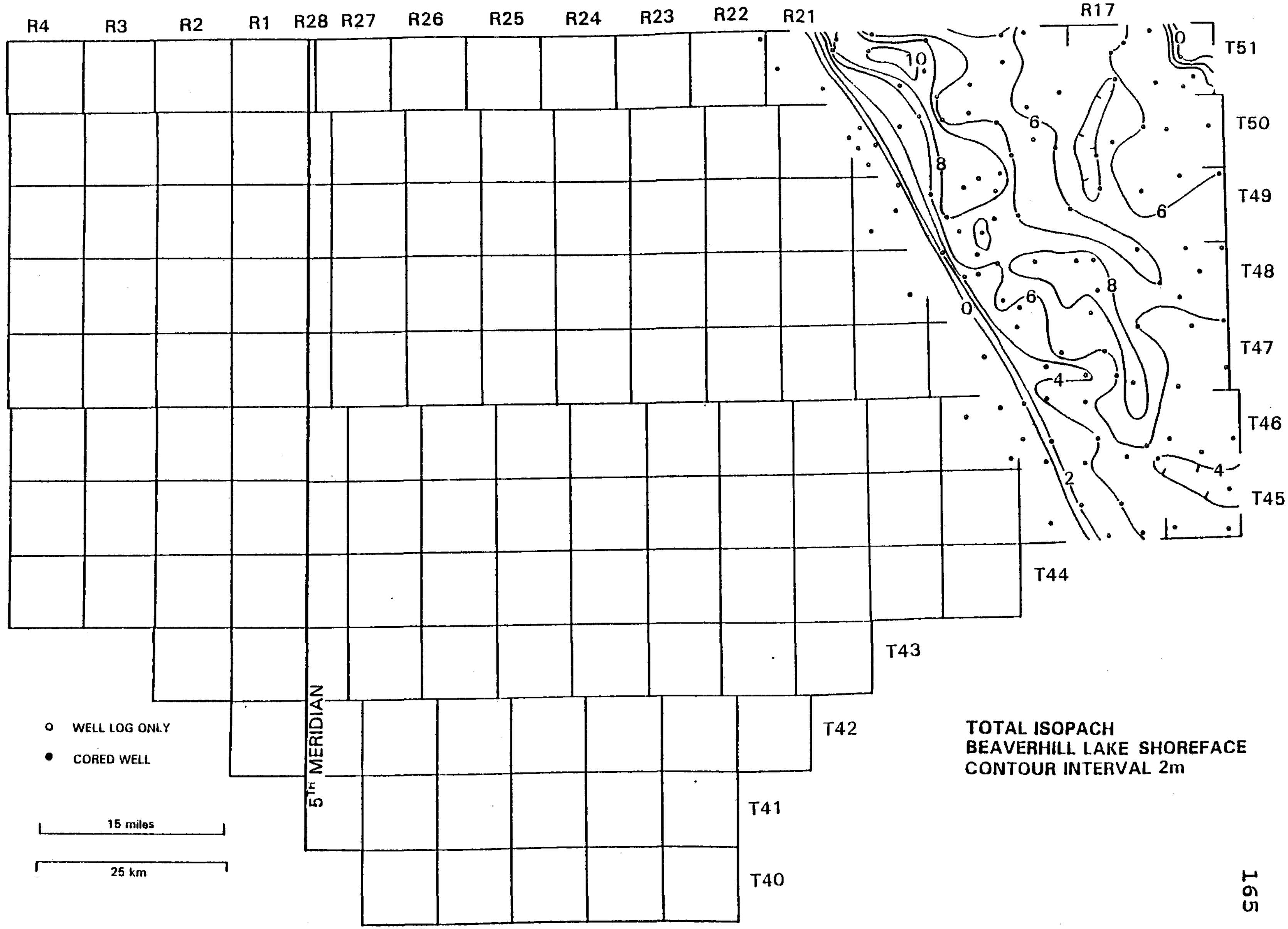
6.3.1 Beaverhill Lake Incised Shoreface

The total isopach map in figure 6.5 illustrates the distribution of the Beaverhill Lake shoreface in the study area; contour intervals are 2 m. This shoreface is the easternmost sharp-based sandbody in the study and only its western edge is visible. The linear, northwest-southeast trending thick defined by the 8m contour line gives a good representation of the overall sandbody geometry. The sandbody reaches a maximum thickness of 10 m in T51 R20 W4 while its zero edge occurs in T51 R16W4 in the far northeast of the study. The sandbody appears to be thickest in the north, thinning towards the southwest. A prominent feature of the shoreface is the steep western edge defined by several closely spaced contour lines. The sandbody thick which is defined by the 8 m contour line occurs just basinwards of the steep edge. Basinwards of this thick, the sandbody generally thins, presumably to a zero edge outside of the study area.

6.3.2 Lindbrook Incised Shoreface

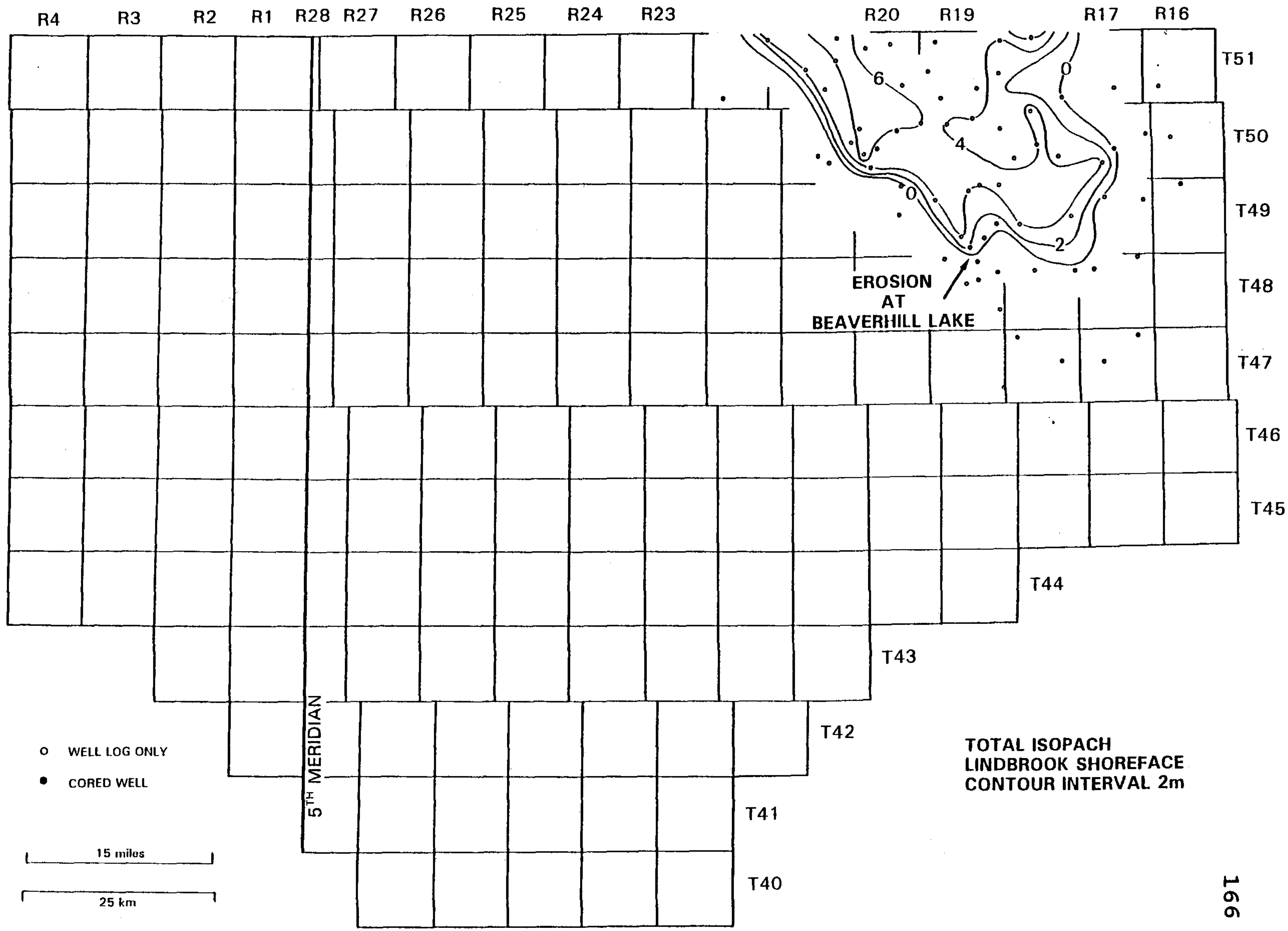
The total isopach map in figure 6.6 shows the distribution of the Lindbrook shoreface. Within the study area, only the southernmost portion of the sandbody is preserved, however, its linear nature is evident and best defined by the 6 m contour line. As with Beaverhill Lake, the linear thick

Figure 6.5 Total isopach map of the Beaverhill Lake shoreface in the study area in 2m contour intervals.



TOTAL ISOPACH
BEAVERHILL LAKE SHOREFACE
CONTOUR INTERVAL 2m

Figure 6.6 Total isopach map of the Lindbrook shoreface in the study area in 2m contour intervals.



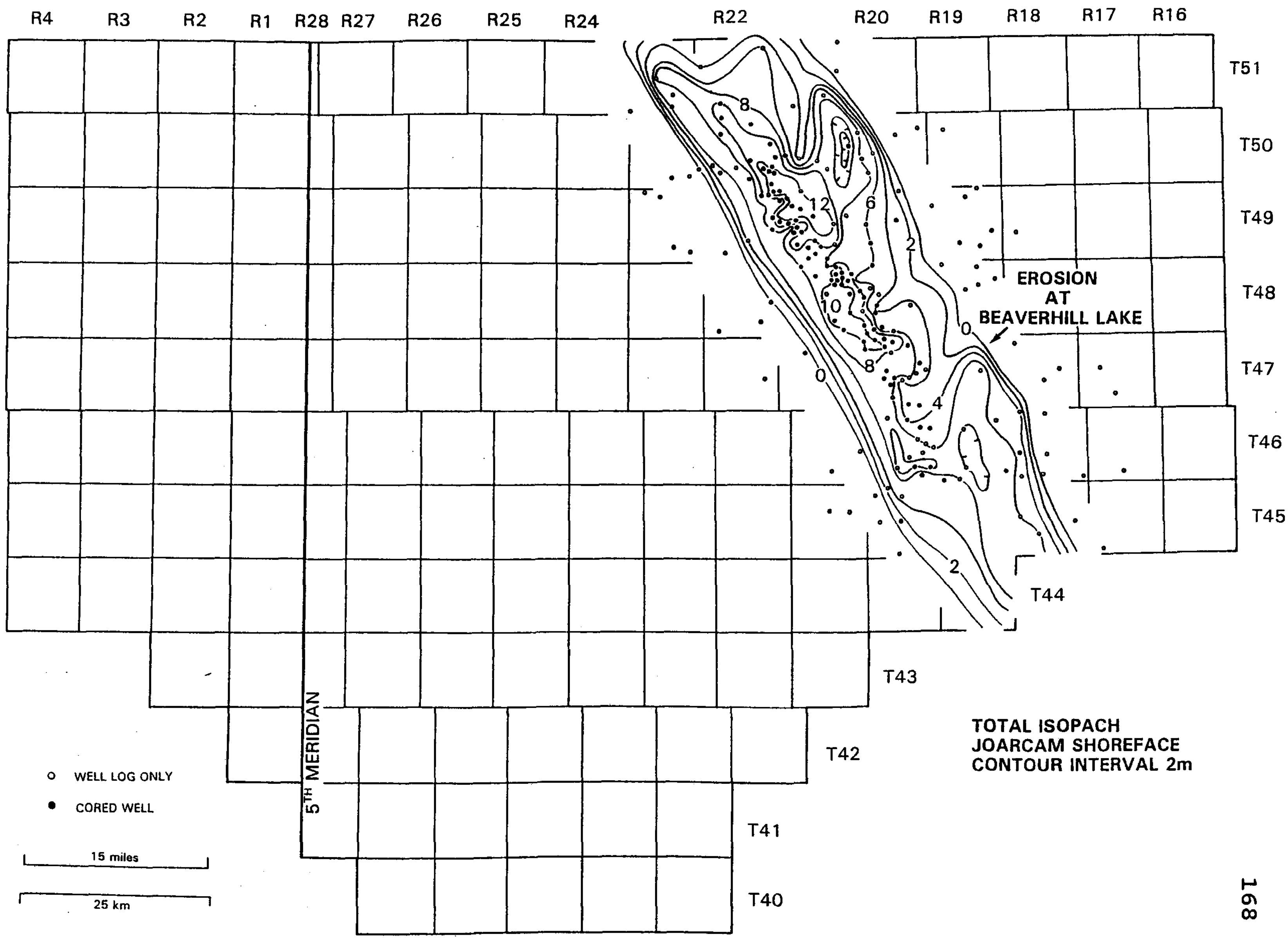
TOTAL ISOPACH
LINDBROOK SHOREFACE
CONTOUR INTERVAL 2m

defining the overall sandbody shape occurs basinwards of a steep edge that defines the western boundary of the shoreface and the total isopach thickness tends to thin towards a zero edge basinwards of the linear thick. This shoreface has been eroded by the stratigraphically higher Beaverhill Lake shoreface in its southern and eastern boundaries as indicated by the text in the figure. This linear, northwest - southeast trending sandbody has a maximum thickness of 7 m in T 51 - R21W4.

6.3.3 Joarcam Incised Shoreface

The distribution of the Joarcam sandbody is illustrated by the total isopach map in figure 6.7. It has a pronounced linear, northwest-southeast trending character defined by its zero edge which bounds the shoreface on the west and east sides. The western zero edge is characterised by a sandbody thick, defined by the 8 m contour line, that is steeply banked up along the western side of the shoreface. Basinward of the thick the sandbody has a more gradational character as it thins eastward due to erosion by the overlying Beaverhill Lake shoreface. The steep nature of the eastern edge of the sandbody in T50/51 R20W4 and T47 R18/19W4 is a direct result of this erosion. The region in between these two areas illustrates a more gradational thinning perhaps representing more of the original depositional topography. The shoreface reaches a maximum

Figure 6.7 Total isopach map of the Joarcam shoreface in the study area in 2m contour intervals. The eastern edge has been erosively thinned by the overlying Beaverhill lake shoreface.


R4
R3
R2
R1
R28
R27
R26
R25
R24
R22
R20
R19
R18
R17
R16
T51
T50
T49
T48
T47
T46
T45
T44
T43
T42
T41
T40
5TH MERIDIAN
EROSION AT BEAVERHILL LAKE
0
2
4
6
8
10
12
WELL LOG ONLY
CORED WELL
15 miles
25 km
TOTAL ISOPACH
JOARCAM SHOREFACE
CONTOUR INTERVAL 2m

thickness of 13 m in T49/50 R21/22W4.

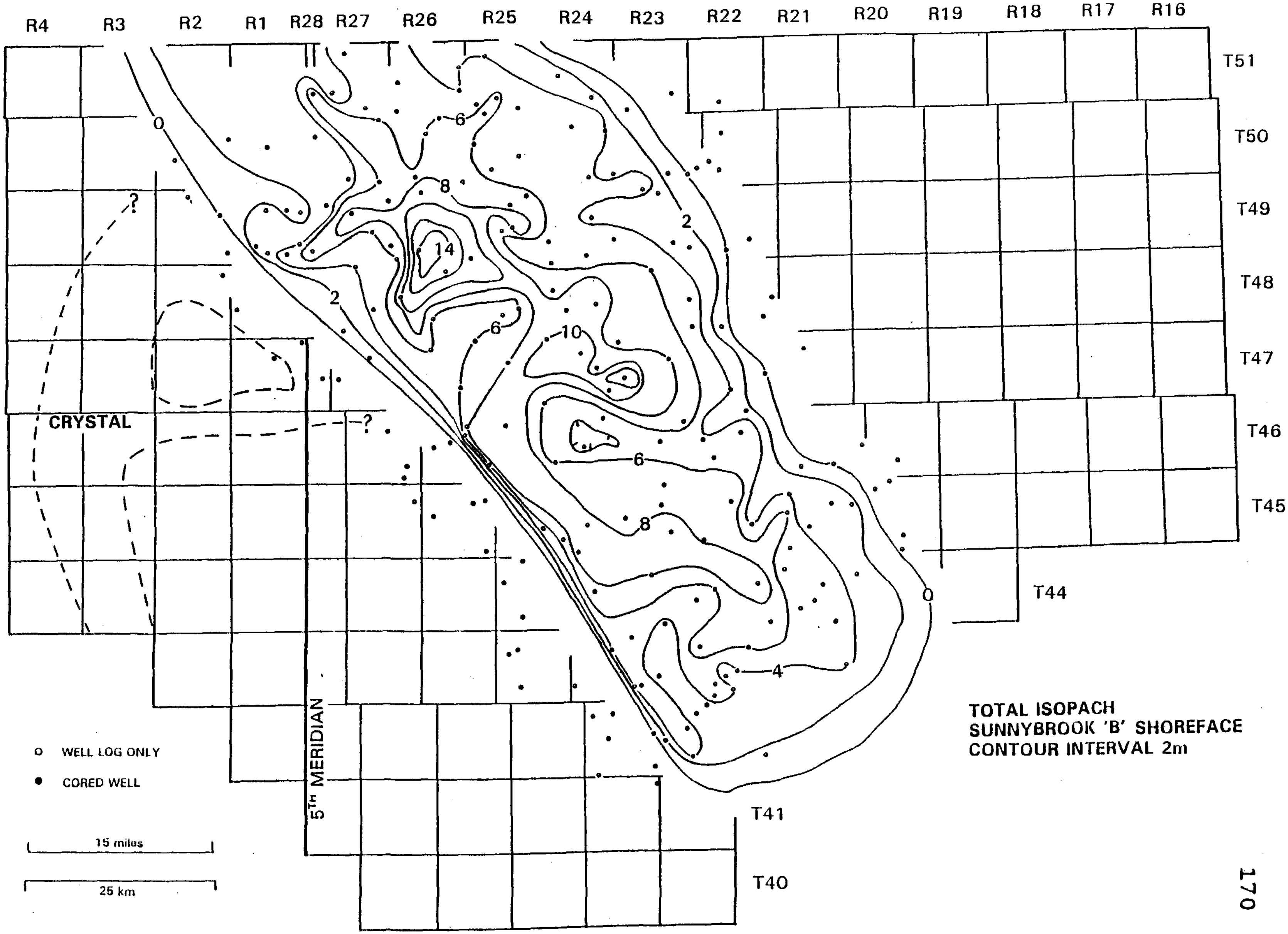
6.3.4 Sunnybrook 'B' Incised Shoreface

The total isopach map in figure 6.8 illustrates the distribution of the Sunnybrook 'B' shoreface. The hatched lines show the erosional edge of the Crystal incised valley (Pattison, 1991). The linear, northwest-southeast trend of the sandbody is the most prominent feature of Sunnybrook 'B'. A sandbody thick defined by the 6 m contour line occurs basinwards of the steep western margin. Two prominent thicks occur seaward of the two arms of the Crystal valley, defined by the 10 m contour lines. As with the previously described shorefaces, the sandbody tends to thin gradationally towards the northeast, basinwards from the main thick. In addition to the northeastward attenuation, there is an alongstrike thinning towards the southwest where the preserved remnants of the shoreface grade to a zero edge. The sandbody reaches a maximum thickness of 14 m in T49 R26W4.

6.3.5 Sunnybrook 'A' Incised Shoreface

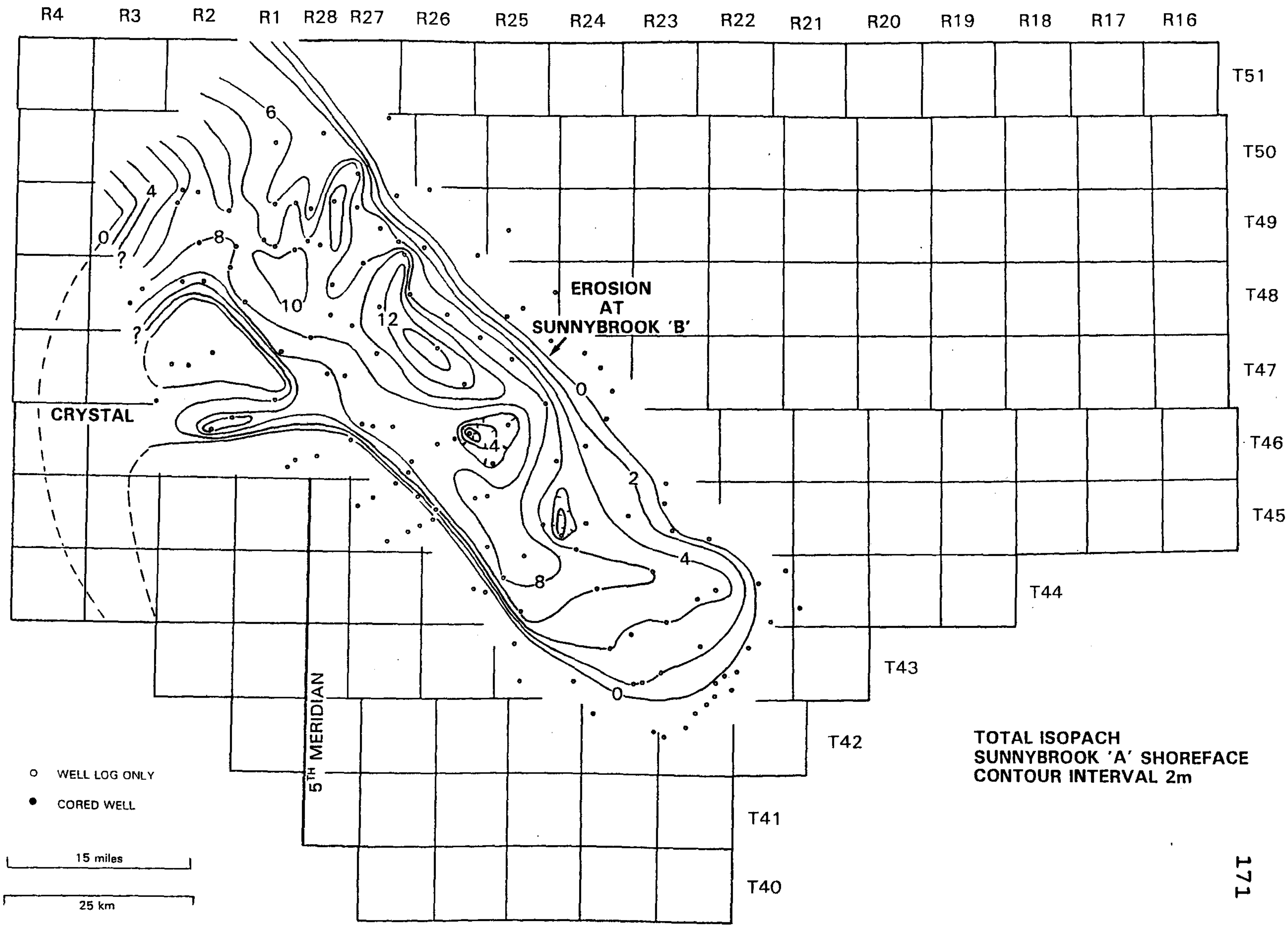
Figure 6.9 is a total isopach map showing the extent of the Sunnybrook 'A' shoreface in the study area. The position of the erosional edge of the Crystal Valley (Pattison, 1991) is illustrated by the hatched lines. Again, the incised sandbody shows a linear, northwest-southeast

Figure 6.8 Total isopach map of the Sunnybrook 'B' shoreface in the study area in 2m contour intervals. Location of the Crystal incised valley 'zero' edge (from Pattison, 1991) is shown by the hatched lines.



TOTAL ISOPACH
SUNNYBROOK 'B' SHOREFACE
CONTOUR INTERVAL 2m

Figure 6.9 Total isopach map of the Sunnybrook 'A' shoreface in the study area in 2m contour intervals. Location of the Crystal incised valley 'zero' edge (from Pattison, 1991) is shown by the hatched lines.



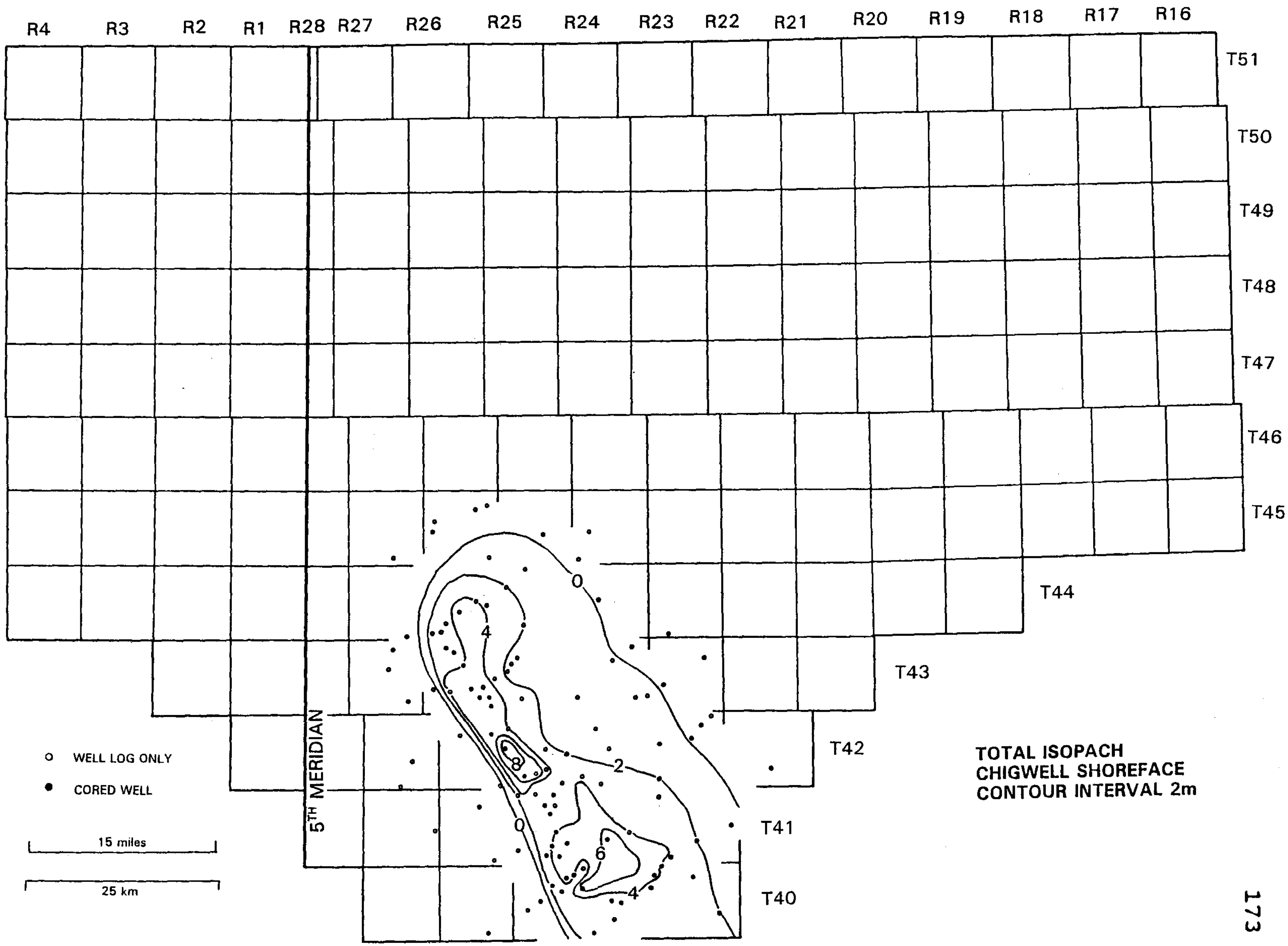
TOTAL ISOPACH
SUNNYBROOK 'A' SHOREFACE
CONTOUR INTERVAL 2m

trend and a sharp western boundary, seaward of which a sandbody thick occurs. In this case, the 'thick' is defined by the 8 m contour line. The eastern boundary to the sandbody is fairly steep and is associated with erosion at the base of the Sunnybrook 'B' shoreface. Several discontinuous thicks, defined by the 10 m contour line occur seaward and south of the main channel at Crystal. The area of greatest thickness of this sandbody occurs in T46 R26W4, basinwards of Crystal, where it is up to 14 m thick. The one distinguishing feature, which differs from all other shorefaces in the area, are the two protrusions of the shoreface sandstone southwestward into the two main arms of the Crystal valley. This is discussed by Pattison (1991) as a major piece of evidence suggesting a physical connection between this particular incised shoreface and the fill #1 of the Crystal valley. The preserved remnants of the Sunnybrook 'A' shoreface thins southward, eventually grading to a zero edge in T43 R23W4.

6.3.6 Chigwell Incised Shoreface

The Chigwell shoreface, illustrated in the total isopach map of figure 6.10, occurs in the far southwest of the study area. It is a linear, northwest - southeast trending sandbody like those previously described. Its western boundary is sharp, basinwards of which a sandbody thick (defined by the 4 m contour) occurs. Basinward of the thick, the shoreface sediments

Figure 6.10 Total isopach map of the Chigwell shoreface in the study area in 2m contour intervals.



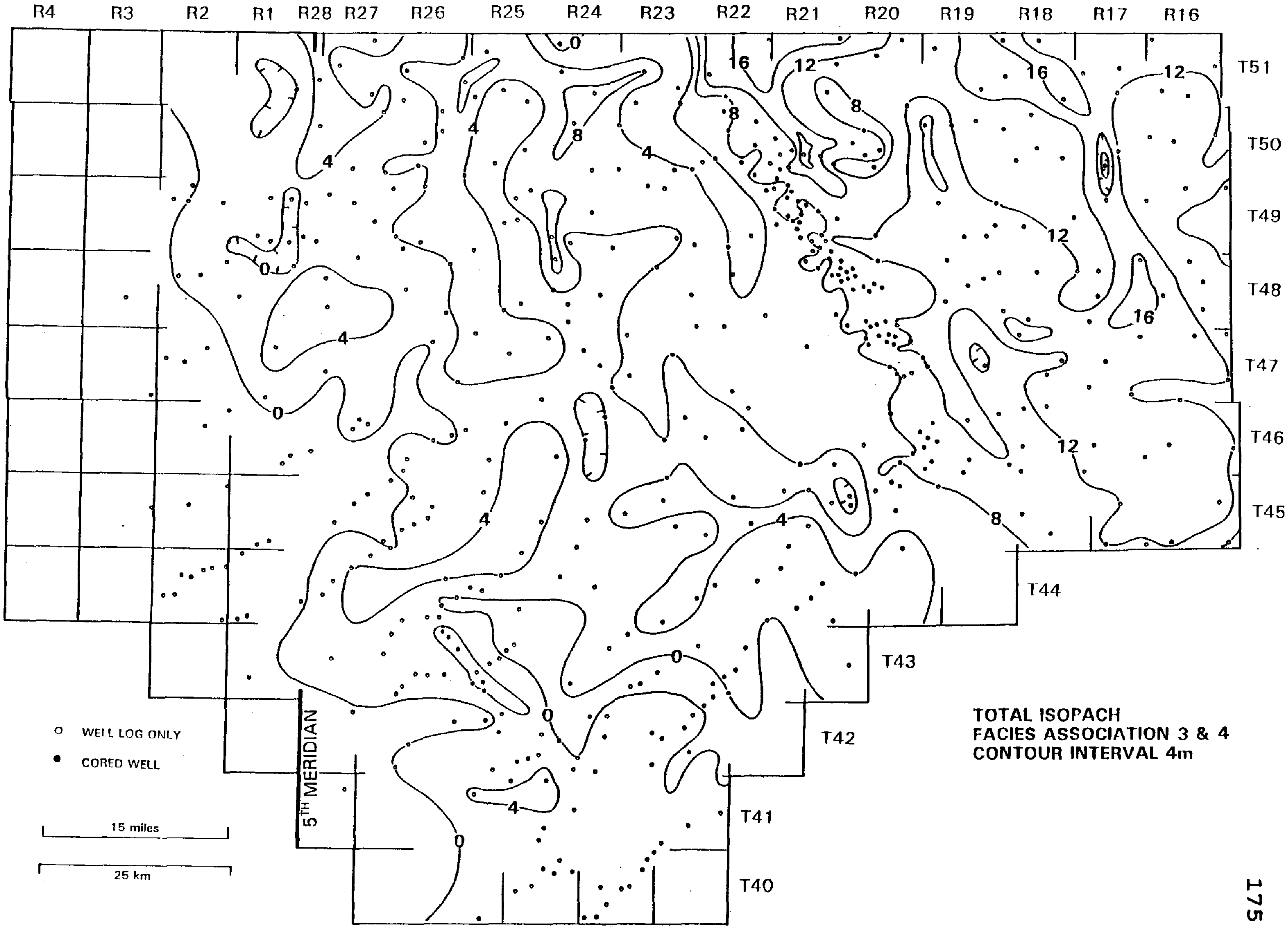
TOTAL ISOPACH
CHIGWELL SHOREFACE
CONTOUR INTERVAL 2m

gradationally thin to a zero edge. To the northwest, the erosional preserved remnants of Chigwell also thin alongstrike to a zero edge. The maximum thickness of this shoreface occurs in T42 R26W4 where it reaches 8 m.

6.4 Total Isopach Map of 'Transgressive' Successions

Facies associations 3 and 4 were grouped as a single unit to construct the total isopach map in figure 6.11. This was necessary because of the difficult separation of the two associations in areas without good core control; this includes most of the study area. For example, in the Joarcam field, good core control and the overall greater thickness of the deposits (generally 4 m or greater for each association) enabled confident identification of individual log characters. These were used to match with wells in which no core were available, thus potentially allowing individual associations to be mapped successfully. However, in the Chigwell area, although sufficient core control was present, the combined thickness of both successions (generally 2-4 m) was inadequate to allow individual well log characters to be identified. In other areas without any cores penetrating these associations (i.e. Sunnybrook and Beaverhill Lake regions) the best interpretation of these deposits was simply as 'transgressive', belonging to either FA 3 and/or FA 4. The best solution has been to characterise the deposits simply as undifferentiated 'transgressive' deposits which can be

Figure 6.11 Total isopach map of the 'transgressive' succession (facies association 3 and 4) in 4m contour intervals.


R4 R3 R2 R1 R28 R27 R26 R25 R24 R23 R22 R21 R20 R19 R18 R17 R16
T51 T50 T49 T48 T47 T46 T45 T44 T43 T42 T41 T40
5TH MERIDIAN
WELL LOG ONLY
CORED WELL
15 miles
25 km
0
4
8
12
16
TOTAL ISOPACH
FACIES ASSOCIATION 3 & 4
CONTOUR INTERVAL 4m

mapped with confidence.

The total thickness of FA 3 and FA 4 in the study area basically illustrates the preserved thickness of these deposits between a VE3 erosion surface (a TSE truncating valley fills or shorefaces) and the VE4 erosional surface. Thus the topography shown by the 4 m contour intervals in the total isopach map in figure 6.11 is an entirely erosional feature. The map generally shows thicks and thins which trend northwest-southeast and mimic the topography of shoreface sandbodies whose erosional 'thins' correspond to the 'thicks' in the transgressive deposits. Thus, the transgressive deposits appear to be thickest where accomodation was greatest or where erosion at the top of the Viking was not too deep. The most striking feature of the map is the easternmost thick which occurs basinwards of the Joarcam shoreface. Here the successions reach a maximum combined thickness of 17 m in T51 R22W4. The thickness of these successions decreases southwestward such that they approximate a southwestward tapering wedge of material that reaches an approximate zero edge just west of the Sunnybrook 'A' and Chigwell shorefaces. Thickness trends of FA. 3/4 is coincident with 3 main 'steps' in the study area; these steps are divided by incision at J'CAM and at SBK 'A' (discussed in section 6.9).

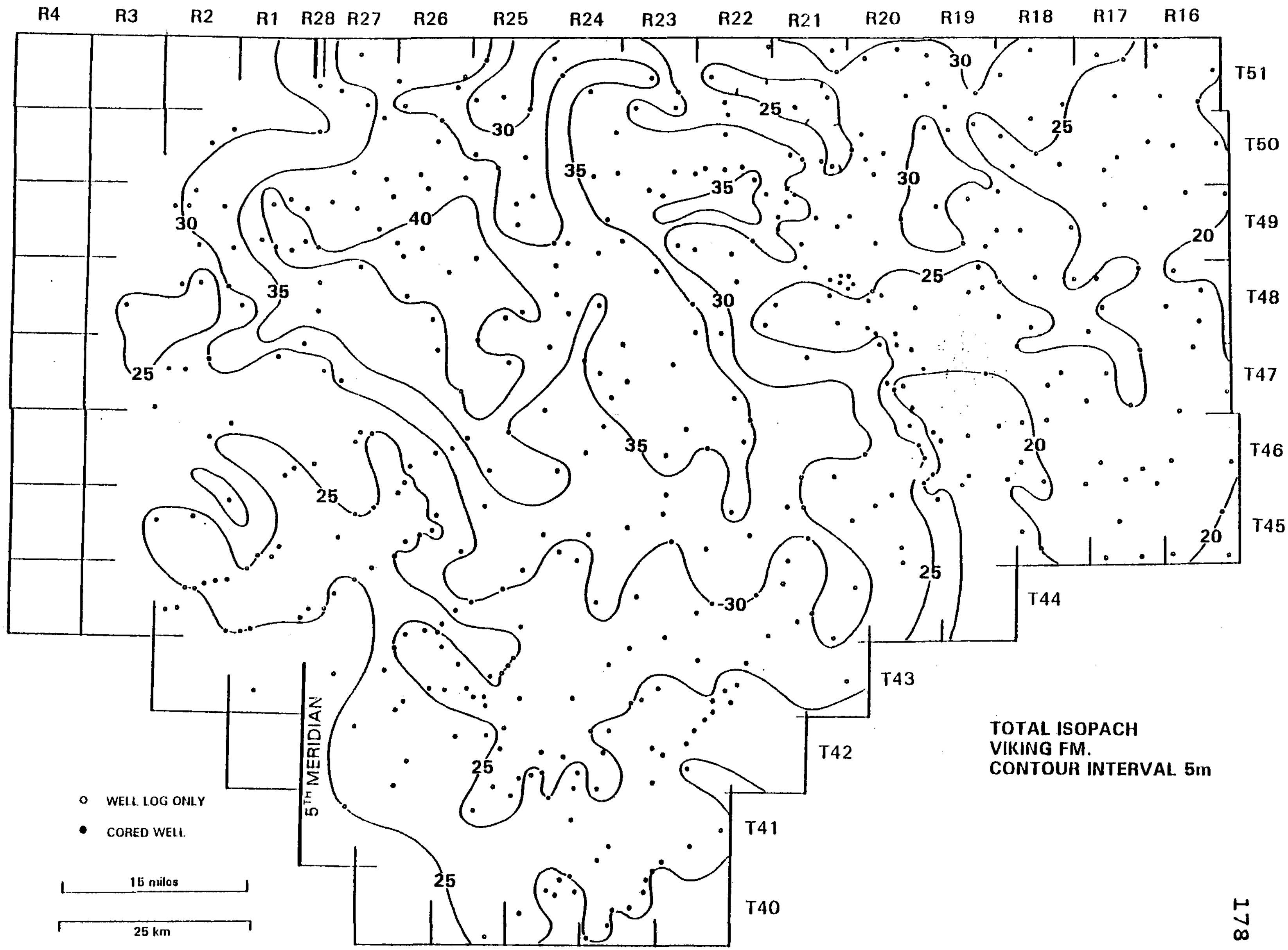
6.5 Total Isopach Map of the Viking Formation

Figure 6.12 illustrates the total isopach thickness of the Viking Formation in the study area, contour intervals are 5 m. The greatest thickness of Viking Formation sediments occur in T49 R1W5 where they reach 44 m in thickness. Generally, the greatest thickness of sediment, defined by the 30 m contour line, delineates a northwest thickening lobe which coincides with thicks in the underlying regional successions and perhaps more importantly the thickest accumulation of incised shoreface sediment in Sunnybrook 'A' and 'B'. The Viking is thinnest in the study area in the southeast where it may only attain 17 m in thickness.

6.6 Total Isopach Map of the Joli Fou Formation

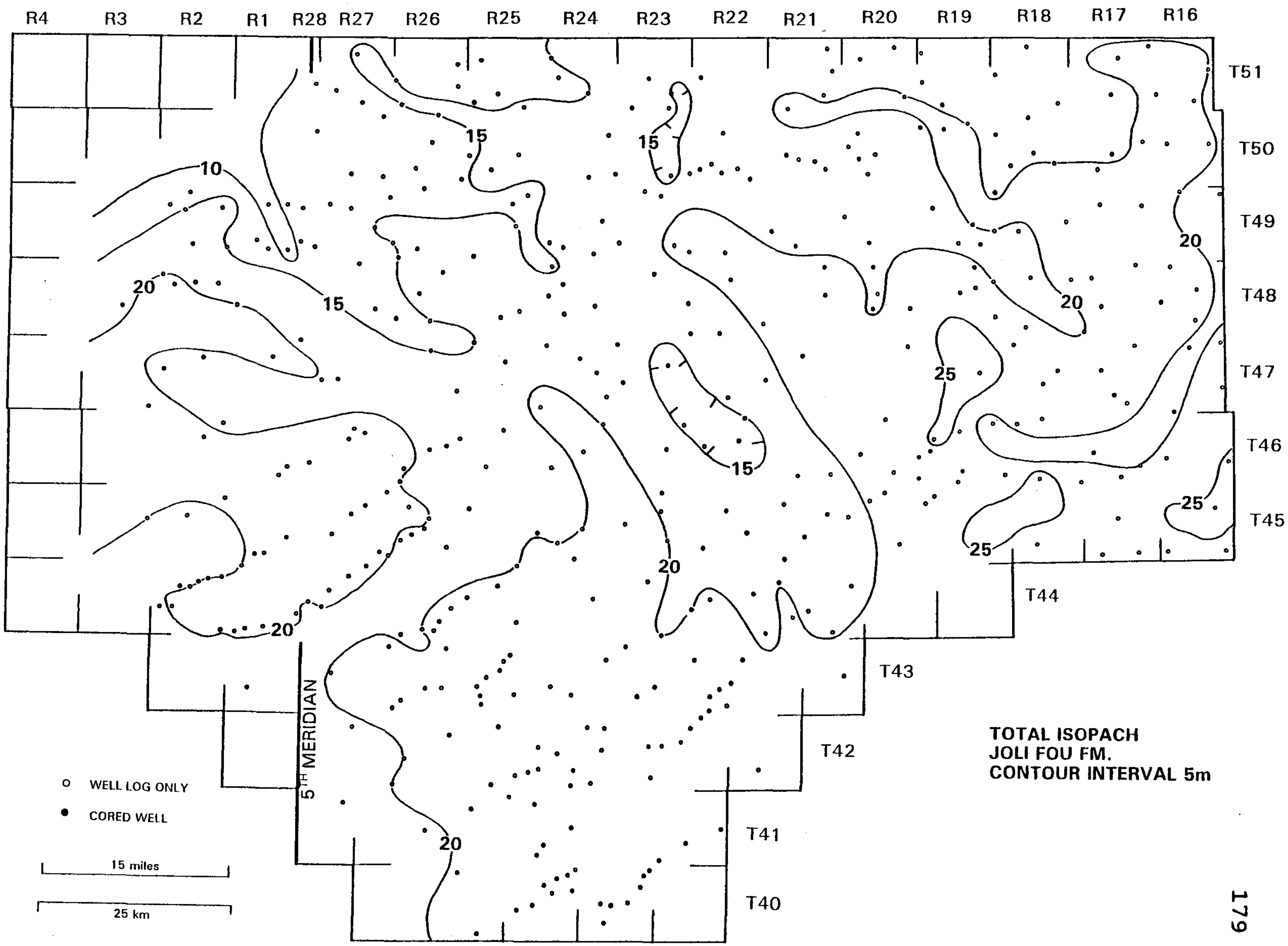
The overall depositional trend of the Viking Formation is illustrated in figure 6.13. The unconformable lower contact of the Joli Fou Formation with the Upper Mannville Group was picked as the inflection point between relatively high resistivity Mannville sediments below to the 'shale line' representing Joli Fou sediments above. The top of the Joli Fou Formation in the study area can appear gradational or sharp with the 'lower' sediments of the Viking Formation. The top was considered to be at the first significant deflection of the resistivity log indicating sandier sediments; generally in the northwest this coincided with a relatively gradational contact while in the

Figure 6.12 Total isopach map of the Viking Formation in 5m contour intervals.



TOTAL ISOPACH
VIKING FM.
CONTOUR INTERVAL 5m

Figure 6.13 Total isopach map of the Joli Fou Formation in 5m contour intervals.



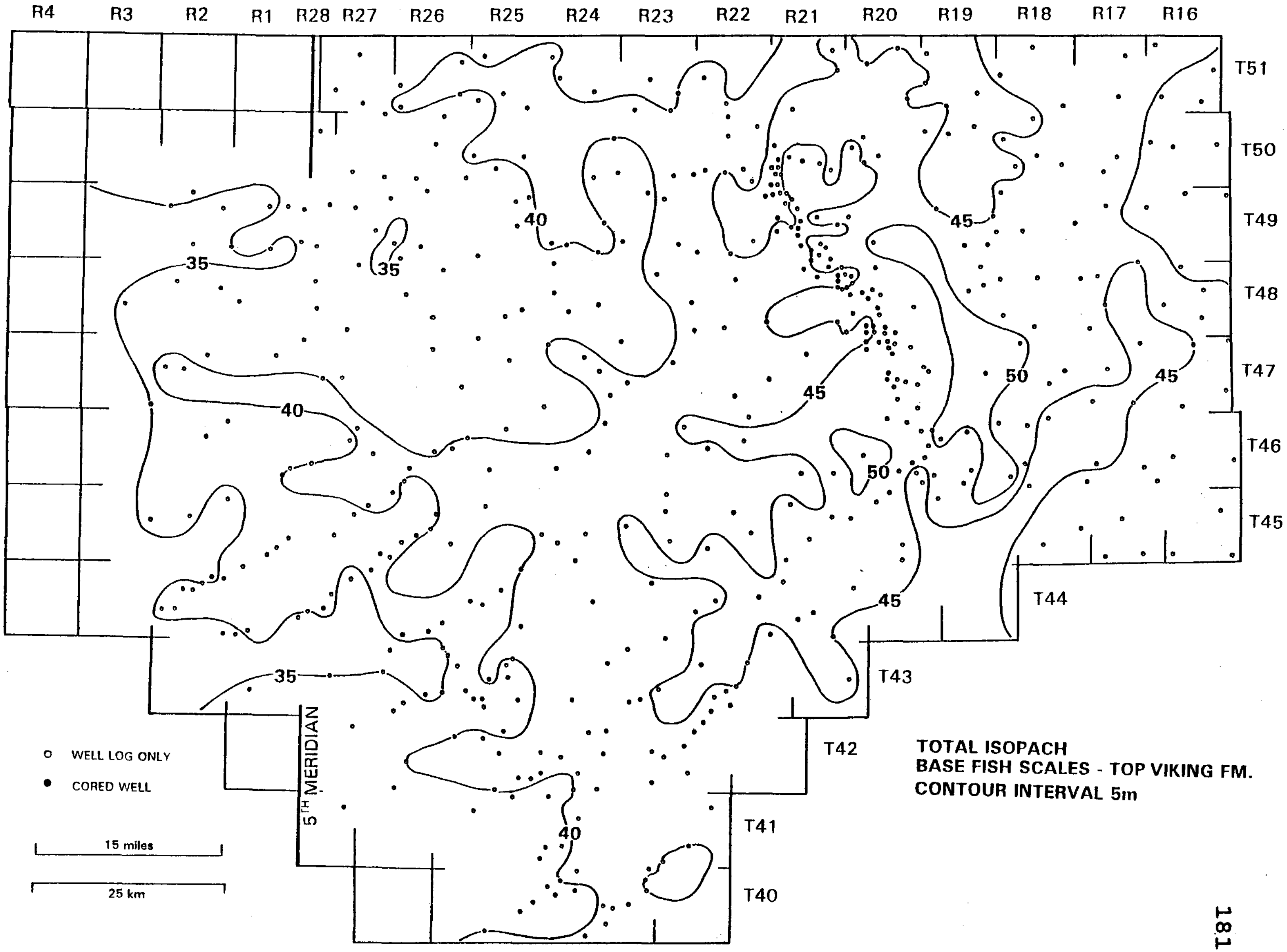
TOTAL ISOPACH
JOLI FOU FM.
CONTOUR INTERVAL 5m

southeast the contact was more abrupt. This total isopach map with 5 m contour intervals show an overall southwest-northeast trending Joli Fou shale which thickens towards the southeast. The general strike of the Joli Fou shale is best represented by the 20 m isopach. The general trend represented by this line coincides with a depositional thick in the total isopach map of regional succession 1 of the overlying Viking Formation. The Joli Fou Formation reaches its greatest thickness of 26 m in T46 R20W4 and a minimum of approximately 10 m in T49 R1W5. Overall this map shows the inverse relationship in terms of thickness trends of the Joli fou and Viking Formations; overall thicks in the Joli Fou are generally coincident with thins in the depositional thickness of regional succession 1, and vice versa.

6.7 Total Isopach Map of the Base Fish Scales Formation - Top Viking Formation

The trend of the thickness of the base Fish Scales (BFS) Formation to the top of the Viking Formation is illustrated in figure 6.14. This map is essentially a total isopach of allomember E (Boreen and Walker, 1991) in the study area in 5 m contour intervals. If the BFS is considered to be a reasonably flat lying surface the topography illustrated by the contours is representative of the topography on the VE4 surface with respect to BFS. Generally, allomember E is thickest in the far east of the study area reaching

Figure 6.14 Total isopach map of the base of the Fish Scales Formation to the top of the Viking Formation in 5m contour intervals. This map can be interpreted as the thickness of allomember 4 (Boreen and Walker, 1989) in the study area, or as essentially the topography on VE4 relative to the assumed flat lying Base Fish Scales Zone.



TOTAL ISOPACH
BASE FISH SCALES - TOP VIKING FM.
CONTOUR INTERVAL 5m

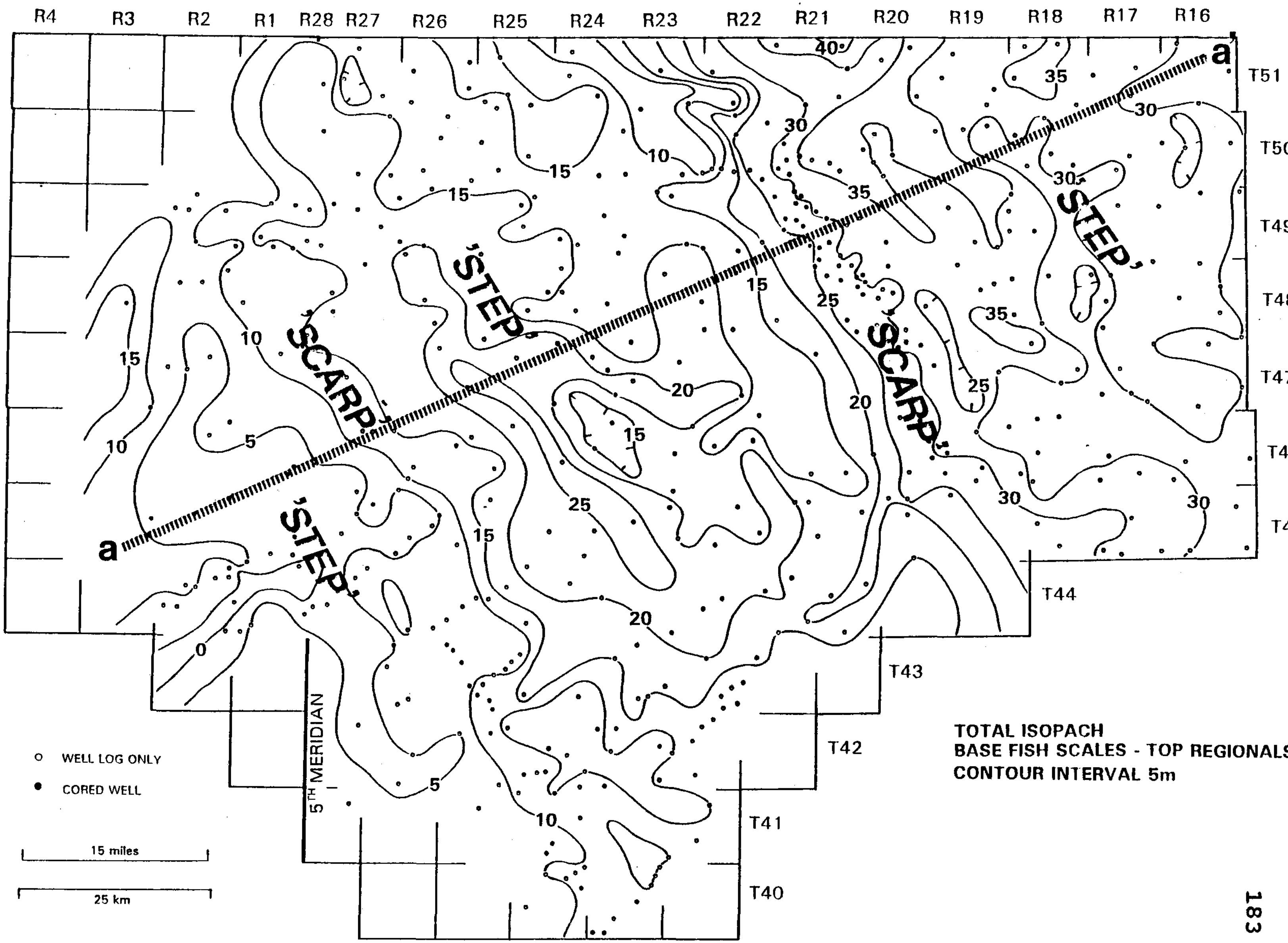
a thickness of 53 m in T49/50 R16W4 and alternately, reaching a minimum thickness of 34 m in several areas (i.e. T43 R27W4, T49 R2W4, etc.) in the west.

The 40 m and 35 m isopach lines illustrate the general trend of allomember E which is roughly oriented north - south or north-northwest to south-southeast. The VE4 erosion surface, which essentially controls the thickness of the allomember, is shown to rise stratigaphically toward the west in a smooth, gradational fashion. The rise in VE4 to the west shown here is in general agreement with the trend defined by previous studies (Davies, 1990; Pattison, 1991; Hadley, 1992).

6.9 Total Isopach Map of Base Fish Scales - Top Regional Successions

Figure 6.15 is a total isopach map in 5 m contour intervals of the relative thickness between the BFS zone and the top of the regional successions. The map illustrates the topography relative to an arbitrary zero in the southeast part of the map area. If the BFS zone is considered to be a flat lying datum, the map shows the erosive topography on the discontinuities which separate underlying regional successions of the 'lower' Viking from incised shorefaces and valleys which comprise 'upper' Viking sediments. These erosion surfaces are cut during major lowstand events or during subsequent transgression.

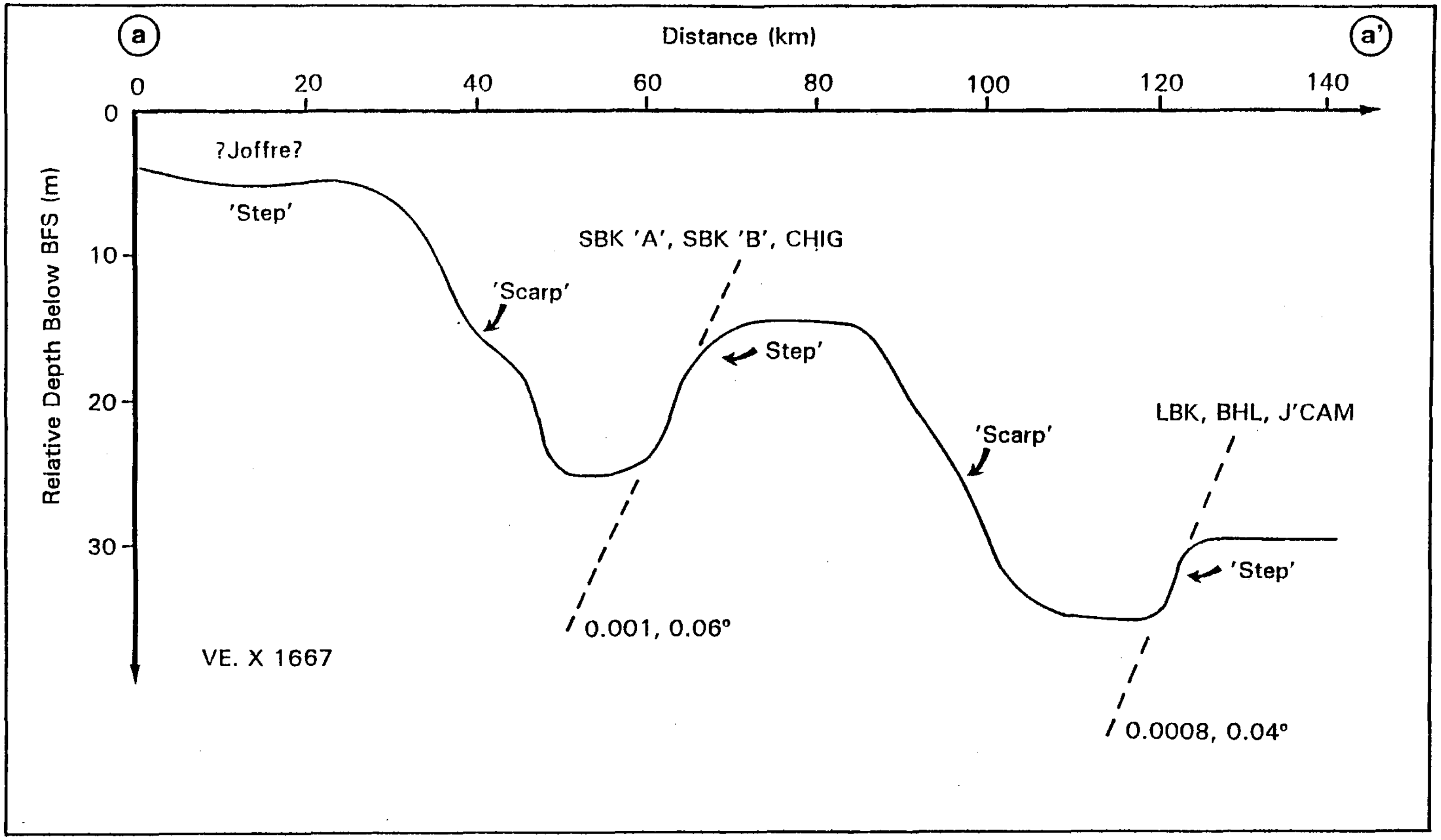
Figure 6.15 Total isopach map of the base of the Fish Scales Formation to the top of regional successions in 5m contour intervals. This map illustrates the 'scarps' cut into the regional successions by erosion surfaces which separate the main areas of shoreface development that occurs in the 'steps'. Note the hatched line a-a' which illustrates the location of the cross section drawn in figure 6.16.



TOTAL ISOPACH
BASE FISH SCALES - TOP REGIONALS
CONTOUR INTERVAL 5m

Three major regions of relatively flat topography define 'steps' and are separated by two prominent 'scarps' of relatively steep topography (figure 6.16). The easternmost 'step' cut into the regional successions occurs east of the 30m contour line near the position of the Joarcam field. This is the stratigraphically lowest step in the area, cutting out all of regional successions 4 and 5 (figures 6.3 and 6.4, respectively) and portions of regional successions 1 and 2/3 (figures 6.1 and 6.2, respectively). This step is bound on its western edge by a steep scarp defined by the 20 to 30 m contour lines which occurs just west of the Joarcam field. The middle step occurs roughly within the area defined by the 15 m contour line in the central portion of the map. This relatively flat area coincides with erosive removal of all of regional succession 5 (figure 6.4) and various proportions of regional succession 4 (figure 6.3). The step is bound to the east by the scarp at Joarcam field, and to the west by the scarp defined by the 10 to 15 m isopach lines occurring in the area just west of the Sunnybrook 'A' shoreface. The westernmost step is roughly defined by the 10 m isopach. It is the stratigraphically highest of the three and is associated with erosion which removes a portion of regional succession 5 (figure 6.4). A prominent northeast-southwest trending thick defined by the 10 and 15 m contour lines occurs within this step in the area of T46-49, R3W5. This incision into the step represents the rough position of the unconformable incised valley at

Figure 6.16 Cross section b-b′ compiled from the total isopach map of the base of the Fish Scale Formation - top of the regional successions. The section is hung on the base of the Fish Scale Formation. Note the three main 'steps' subdivided by two large 'scarps'. Location of a-a′ shown in figure 6.15.


a
Distance (km)
a'
0
20
40
60
80
100
120
140
0
10
20
30
Relative Depth Below BFS (m)
?Joffre?
'Step'
SBK 'A', SBK 'B', CHIG
'Scarp'
Step'
'Scarp'
LBK, BHL, J'CAM
'Step'
0.001, 0.06°
0.0008, 0.04°
VE. X 1667

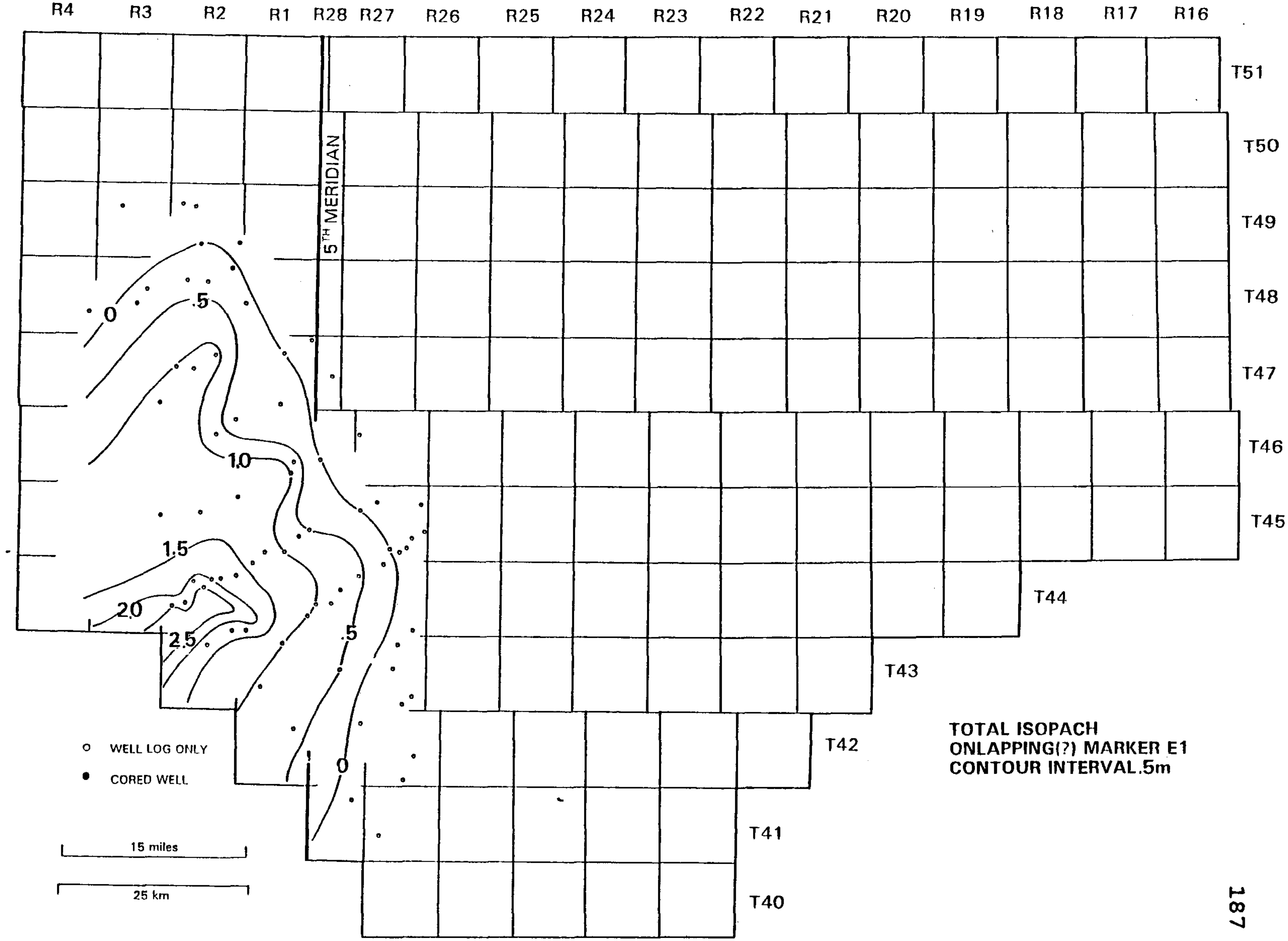
Crystal (Pattison, 1991) which has cut out a variable proportion of the regional successions.

The overall trends of the steep 'scarps' and the 'steps' they define are oriented northwest to southeast and mimic the topographic trends of the overlying incised shoreface successions (see figures 6.1 through 6.10).

6.10 Total Isopach Map of the Thickness of Onlapping Marker E1

Figure 6.17 shows the areal distribution of a gritty, onlapping marker unit (figure 3.22, chapter 3) in 0.5m isopach intervals, which occurs in the southwestern corner of the study area. One core examined for the thesis has penetrated this unit (see FA 6, chapter 3) and has been used to help define the base and top 'picks' for the thickness of the marker. The base of the bed often appears gradational according to the thickness of the bed and the resolution of the resistivity tool being employed; the base is defined on the log as the inflection point between the low resistivity shales of the Westgate Formation below and the higher resistivity marker bed above. The top of the Marker is likewise defined and often has a slightly sharper character allowing easier definition. This bed has been identified as one of several disconformity-bounded units that have an onlapping relationship with scarps in the VE4 erosion surface at positions south and west of this study (Hadley, 1992; Davies and Walker, 1993). This particular marker has been

Figure 6.17 Total isopach map of an onlapping marker (E1 of Davies and Walker, 1993; E4 of Hadley, 1992) in 0.5m contour intervals.



TOTAL ISOPACH
ONLAPPING(?) MARKER E1
CONTOUR INTERVAL .5m

identified as the E1 unit of Davies (1990) and Davies and Walker (1993) and the differently notated E4 marker of Hadley (1992). The approximate zero edge of the bed is illustrated as is the point of maximum thickness which is just over 2.5 m thick.

CHAPTER 7: REGIONAL GEOLOGIC HISTORY

7.1 Introduction

This chapter is intended to integrate the sedimentology, stratigraphy and geometry of facies associations presented in earlier chapters into a coherent regional geologic history. The geologic evidence presented to this point suggests that fluctuations of relative sea level (RSL) have controlled facies distribution within the Viking Formation. In particular, an analysis of the relationship between a pair of incised valleys at Crystal field (Pattison and Walker, 1994) and lowstand and transgressive incised shorefaces to the east suggest two complete stratigraphic sequences (Van Wagoner et al., 1990). Each sequence comprises a lowstand incised valley and associated lowstand incised shoreface as well as transgressive valley fill and related transgressive shorefaces.

7.2 Fluctuations of Relative Sea Level in the Viking Formation

Correlations of well logs and cores presented in chapter 5 and total isopach maps presented in chapter 6 have shown that six incised shorefaces and two valley fills exist within the study area. The valley fills were defined by Pattison (1991) and Pattison and Walker (1994). Because they form an integral component of the regional geologic history in the study area they have been incorporated into this study to provide a comprehensive paleogeographic reconstruction.

The stratigraphic relationships between each of the incised shorefaces or between incised shorefaces and the valleys are at times complicated by multiple erosive events (chapter 5). A key example would be the erosion at the base of the BHL shoreface which has removed much of the older LBK shoreface in the study area. Erosion of the distal SBK 'A' shoreface deposits and bounding discontinuities between this shoreface and J'CAM by later SBK 'B' erosion also complicates the stratigraphy. Nonetheless, lowstand shorefaces at LBK and BHL Lake have been related to the Crystal lowstand valley incisions #1 and #2, respectively. Likewise the SBK 'A' and SBK 'B' transgressively incised shorefaces are directly linked to the transgressive deposits making up Crystal valley fills #1 and #2, respectively. Transgressively incised shorefaces at J'CAM and CHIG represent intermittent stillstand incisions during the overall transgressive movement of sea level which occurred either before or after backfilling of the valleys within each sequence.

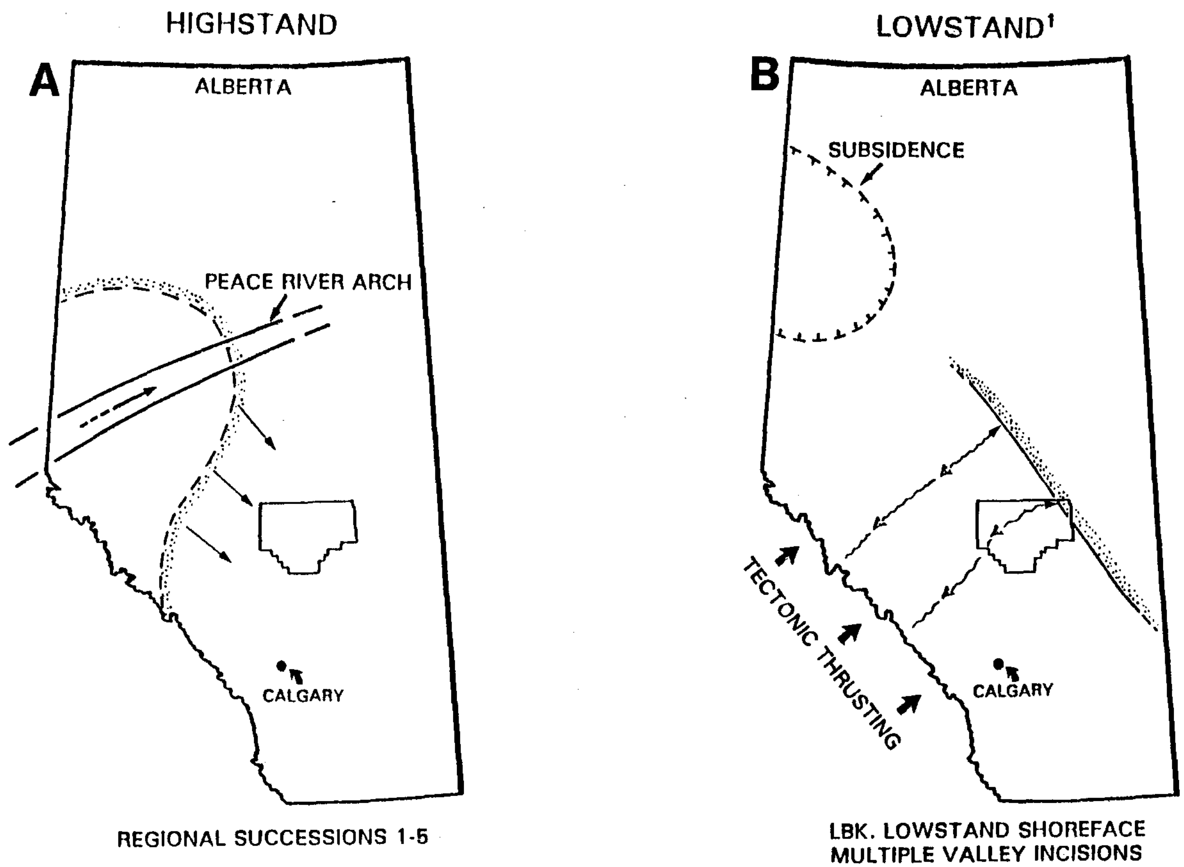
7.2.1 Early Viking Sedimentation: Highstand

The earliest Viking Formation sedimentation (figure 7.1a) in the study

Figure 7.1A Probable paleogeography during development of regional successions 1 through 5. Sediment source was dominantly from the northwest, perhaps in the area of the Peace River Arch.

Figure 7.1B Development of the first recorded major lowstand of RSL. Lowstand incised valleys at Crystal, Sundance-Edson, Cyn-Pem and Willesden Green are cut by fluvial drainage which feeds a lowstand incised shoreface at Lindbrook.

VIKING FORMATION
DEPOSITIONAL HISTORY



SEQUENCE 1

area is represented by the 5 stacked, regionally extensive coarsening-upwards successions that form a progradational parasequence set. These successions thicken toward the northwest, suggesting that earliest Viking shoreline trend was oriented northeast to southwest. This 'early' Viking shoreline orientation is in agreement with other trends reported by Boreen and Walker (1991) and Pattison (1991).

Small scale fluctuations of RSL during overall regressive conditions enabled the development of regionally correlatable flooding surfaces which bound each succession. The uniformity and regionally extensive nature of these deposits is invaluable in defining the relatively 'local' occurrence of sharp based sandbodies comprising incised valley fills and incised shorefaces. These erosively based sandbodies truncate portions of the regional successions and/or markers within them which allows the areal extent of the discontinuities and sandbody geometry which they define to be delineated.

7.2.2 Stratigraphic Sequence 1

a) First Lowstand

A major fall in RSL resulted in the subareal exposure of almost the entire study area and development of a widespread RSE (figure 7.1b). Pattison (1991) suggested that this major lowering may have been a combined result of renewed thrusting and uplift in the Cordillera and a concomitant subsidence of the Peace River Arch. During the lowstand event, fluvial erosion cut major valleys into the exposed highstand systems tract deposits. These dominantly southwest-northeast trending valleys occur at Willesden Green, Cyn-Pem, Sundance - Edson and Crystal (Boreen and Walker, 1991; Pattison and Walker, 1994). Sediment bypass through the valleys carried clastic material to a lowstand incised shoreface at LBK, over 90 kilometers to the northeast of the mouth of the Crystal valley. The resulting lowstand shoreface trend was from northwest to southeast and represented a major reorientation of Viking shorelines as compared to the highstand. It is difficult to determine the distance that the LBK shoreface might have originally prograded due to later erosive events which have removed almost the entire shoreface deposit. No cores penetrate this shoreface, thus making it difficult to determine the grain size of sediment comprising the sandbody. However, given the magnitude of the relative fall in sea level and the expected response of fluvial systems to downcut with rejuvenated stream power, these deposits might be expected to be quite coarse-grained relative to other (ie. transgressive) shorefaces where base level is rising. This shoreface appears quite sharp based in its westernmost occurrence however, as the sandbody is traced to the east it appears to become somewhat more gradational in character, perhaps representing the preservation of offshore facies beneath the prograding shoreface sandstones.

b) Punctuated Transgression

The subsequent rise in RSL was characterised by periodic stillstand events during which shoreface incisions were cut into the regional deposits of the highstand (figure 7.2a, b). In the study area, three stillstand events are recognised within this rise of RSL. A review of the work by Pattison (1991) and Boreen and Walker (1991) shows that at least 2 more stillstands occurred west of this study area.

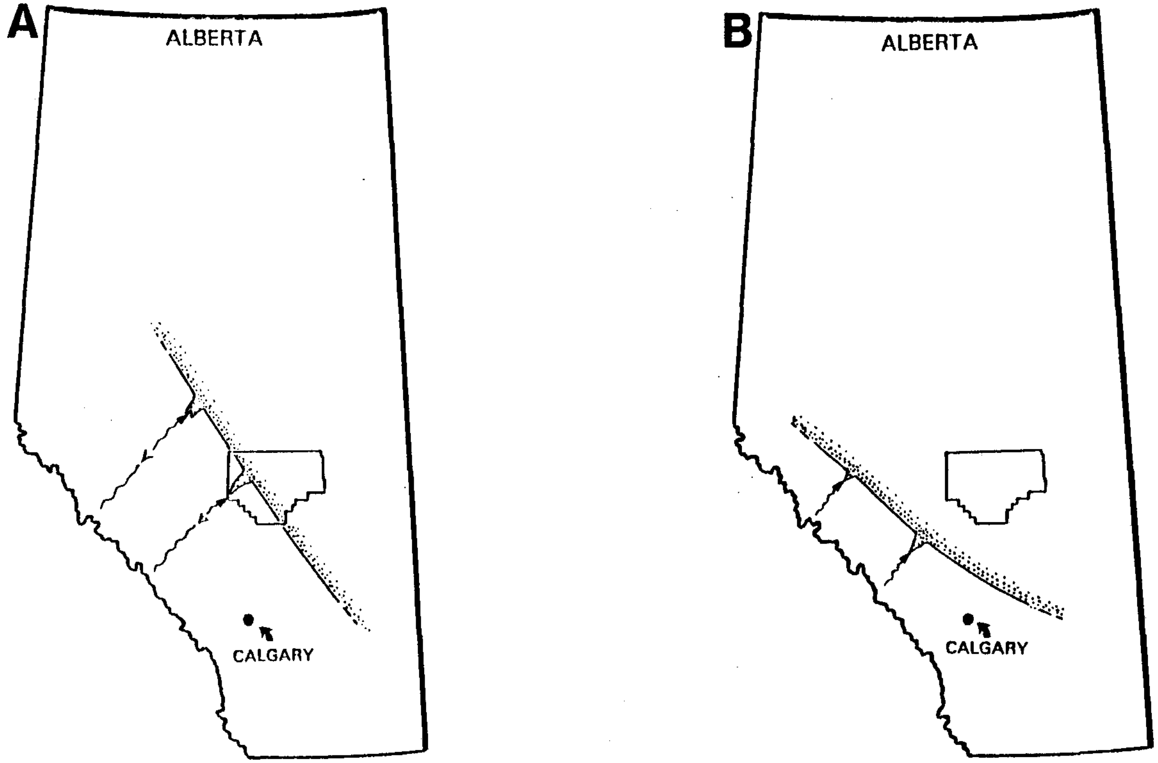
Relative rise of sea level after lowstand deposition at LBK cut a transgressive ravinement surface across the top of the lowstand shoreface as the shoreline translated westward. This ravinement presumably removed any evidence of upper shoreface, beach and non-marine deposits. A stillstand of RSL in the vicinity of J'CAM resulted in the incisement of a shoreface scour which was subsequently filled by prograding shoreface sediments. Bentonitic horizons were deposited within the shoreface sediments as a result of volcanic activity in the rising Cordillera to the southwest (Vuke, 1984). Preserved J'CAM sediments suggest the shoreface prograded at least 13 kilometers because muddy sediments are found to overlie the LBK lowstand shoreface. Later erosion has removed all

Figure 7.2A Transgression brings RSL to the Cyn-Pem - Crystal - Sunnybrook 'A' area where transgressive estuarine deposits backfill the valleys from the fully marine incised shoreface.

Figure 7.2B Renewed transgression (followed by stillstand) brings RSL to the Willesden Green - Sundance-Edson - Wolf Creek-Gilby-Joffre are where transgressive estuarine deposits backfill the valleys from the fully marine incised shoreface trend.

VIKING FORMATION
DEPOSITIONAL HISTORY

PUNCTUATED TRANSGRESSION[1]



A

TRANSGRESSIVE SHOREFACES
J'CAM., SBK. 'A', CHIG.
TRANSGRESSIVE VALLEYS FILLS
CRYSTAL, CYN-PEM

B

TRANSGRESSIVE SHOREFACES
WOLF CREEK-GILBY-JOFFRE
TRANSGRESSIVE VALLEY FILLS
SUNDANCE-EDSON, WILLESDEN GREEN

SEQUENCE 1

evidence of the J'CAM sediments basinwards of the BHL incision.

Transgressive ravinement of the J'CAM shoreface was associated with a rise of RSL that moved the shoreline towards the west. The erosive translation of this shoreline probably severely modified the previously developed lowstand surface of erosion, removing shallow fluvial deposits and any thin paleosols which were possibly developed. The second stillstand in the punctuated transgression occurred when the shoreline was in the vicinity of SBK 'A' at the mouth of the Crystal Valley (figure 7.2a). Again, erosion by wave action in the shoreface cut an elongate scour into the underlying regional sediments which was subsequently filled by shoreface sediments. At the same time sediment was filling the SBK 'A' shoreface incision, marine sandstones were being backfilled into the mouth of the Crystal Valley. Pattison and Walker (1994) described a valley fill characterised by a tripartite facies zonation suggestive of bayhead delta - central basin mudstone - marine sandstone plug (Dalrymple et al., 1992) from the head of the valley in the south to its mouth in the northeast. The lowstand surface of erosion cut in the valley by fluvial incision was extensively modified during the initial marine transgression of the valley. Evidence for the original fluvial incisions which created the unconformable valley were almost entirely removed by the initial transgressive incision/modification of the lowstand surface of erosion. The valley was probably widened and slightly deepened by the effects of tidal scour and wave erosion (Pattison and Walker, 1994).

Resumed rise in RSL truncated the top of both the SBK 'A' shoreface and the Crystal valley fill #1. However, evidence for the ravinement has been removed by later erosional events.

Almost immediately after ravinement of the Crystal and SBK 'A' sandbodies, a stillstand resulted in shoreface incision and development of the CHIG shoreface, southwest of the mouth of the Crystal valley. This shoreface is very thin, narrow and restricted in its areal extent, probably suggesting a very short lived stillstand of sea level. Whatever the duration of the stillstand, no CHIG sediments are recognised in the vicinity of Crystal, perhaps due to later erosion or an originally resticted northward extent of the shoreface.

Resumed transgression truncated the top of the CHIG shoreface and moved the shoreline further southwestward into the area of the subarially exposed Willesden Green valleys.

c) Continued Transgression

At Willesden Green, Boreen and Walker (1991) suggested that valleys to the north and south were infilled with estuarine sediments during stillstand associated with incision and subsequent deposition at a transgressive shoreface represented by reservoir sandstones at at Gilby 'A' and Joffre fields (figure 7.2b). The timing of the transgression which brought the shoreline into this area is suggested to have been sometime after the filling and abandonment of the first Crystal Valley.

Renewed relative rise in sea level presumably eroded the top of the Willesden Green valley fill and possibly moved the shoreline to the southwest. Boreen and Walker (1991) suggested a renewed progradation of a highstand shoreface southwest of their study (allomember D; shoreface at Harmattan East and Garrington) which was responsible for the deposition of a wedge of storm-dominated shoreface and offshore sediments over the top of the Willesden Green valley fill and associated transgressive shorefaces at Gilby 'A' and Joffre. However, in light of the subsequent work at Crystal (Pattison and Walker, 1994) and this present study, it is probable that a second lowstand event preceded the highstand conditions at Caroline - Garrington - Harmattan East and may be responsible for their 'stage 2' channel fill which is remakably similar to fill #2 at Crystal. The presence of the sharp based cross bedded, pebbly sandstone and conglomerate succession (Facies Association C2 of Boreen and Walker, 1991) which infills elongate channels (or valleys?) in the north and south of Willesden Green is explained only on terms of a 'second episode of filling' (Boreen and Walker, 1991). Although it is complete conjecture, it is suggested here that the second stage of filling is related to a second major lowstand event of similar magnitude to that which was responsible for the correlative first incisions at both Crystal and Willesden Green. This second lowstand allowed fluvial systems to become re-entrenched in former valleys such that the second valley at Crystal (Pattison, 1991) and the stage 2 channel at Willesden Green which were presumably incised at the same time. Sediment bypass through both of these incised valleys enabled an ample supply of sediment to the lowstand shoreface at BHL.

7.2.3 Stratigraphic Sequence 2

a) Second Lowstand

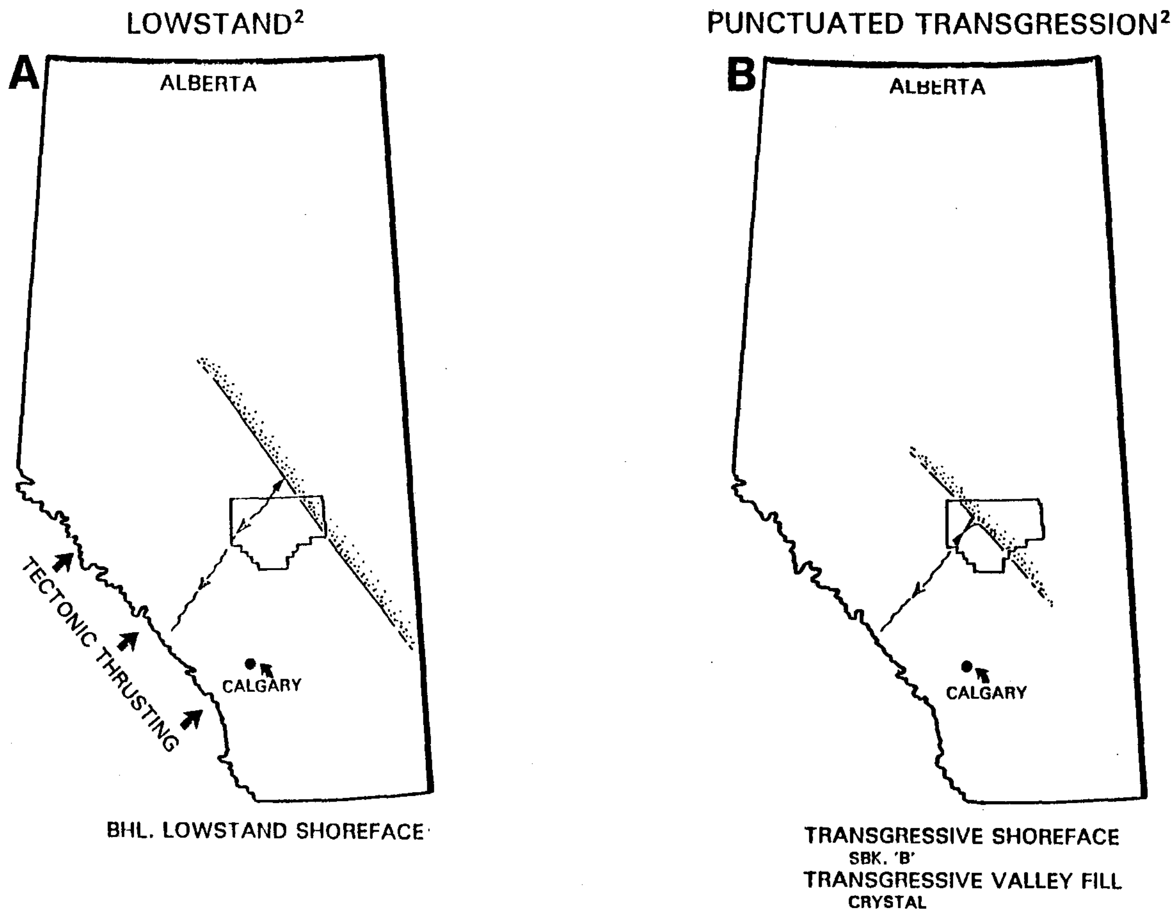
A second major lowering of relative sea level is recorded by re-incision of valleys at Crystal and Willeden Green (figure 7.3a). Sediment bypass through the valleys allowed the development of a second lowstand shoreface within Viking Formation at BHL in the far east of the study area.

It is interesting to note that the re-incised valleys recognised at Crystal and possibly at Willesden Green occur in the axial portions of previously incised valleys and their fill. To the north, incised valleys at Cyn-Pem and Sundance-Edson are recognised as having only a single stage of fill which are correlated with the first fills at Willesden Green and Crystal. The absence of a second stage of cut and fill possibly suggests that they were

Figure 7.3A Following the first highstand of sea level (unknown shoreface) after ravinement of the Willesden Green and Sundance-Edson valley fills, a minimum 30 m drop of RSL moved the shoreline approximately 90 km to the east of the mouth of the Crystal valley. A second set of fluvially incised valleys at Willesden Green and Crystal were cut and sediment bypass through the valleys fed a lowstand shoreface at Beaverhill Lake.

Figure 7.3B Renewed transgression (followed by stillstand) the Sunnybrook 'B' shoreface was incised and the second Crystal Valley was filled with over 30 m of coarse fluvial and estuarine sediment.

VIKING FORMATION
DEPOSITIONAL HISTORY



SEQUENCE 2

either not subarially exposed during the second lowstand event or more probable that fluvial channels were unable to reoccupy their previous valleys.

The BHL lowstand shoreface is relatively thin (generally <10 m) and progaded for up to 23 kilometers as a result of reduced accomodation space and potentially high sediment supply (Walker and Wiseman, in press). The deposits comprising this shoreface would be expected to be quite coarse grained for the same reasons as speculated upon earlier for the LBK shoreface. The erosive emplacement of the lowstand sandbody is demonstrated by the truncation of all or portions of the older LBK and J'CAM shorefaces.

b) Punctuated Transgression

Resumed rise of relative sea level truncated deposition at the BHL shoreface as a ravinement surface was cut across the top of the sandbody during erosive landward retreat of the shoreline. Again, all evidence of upper shoreface, beach and non-marine facies was removed at this time. The transgressive ravinement surface also cut out portions of the older J'CAM shoreface as it moved westward, and transgressive deposits which were laid down seaward of the shoreface erosion onlap the ravinement surface. This rise in relative sea level continued until the shoreline was in the position of SBK 'B', just seaward of the Crystal Valley (figure 7.3b). An ensuing stillstand in the overall transgression led to the incision of the SBK 'B' shoreface. The position of this shoreface seaward of the Crystal Valleys, with thicks in the shoreface isopach corresponding to areas seaward of the valley arms, is strongly suggestive of a coeval relationship. The second valley fill at Crystal is filled mostly with conglomerate and interbedded sandstone of fluvial origin in the south (Pattison and Walker, 1994). These grade northwards into progressively more bioturbated facies of marine origin without any evidence of central basin mudstones. Pattison and Walker (1994) therefore suggest that most of the mud was washed seaward from the valley, effectively precluding development of a turbidity maximum. Deposits in the second valley were truncated by a transgressive ravinement surface associated with relative rise of sea level, although any evidence of that discontinuity has been itself removed by a later erosive event associated with the final stage of Viking sedimentation.

Rise of RSL moved the shoreline into the Willesden Green area during which time the second incised valley was filled with fluvial dominated estuarine deposits (figure 7.4a). This second episode of valley filling corresponds to Boreen and Walker's (1991) 'stage 2' channel fill.

c) Highstand of Relative Sea Level

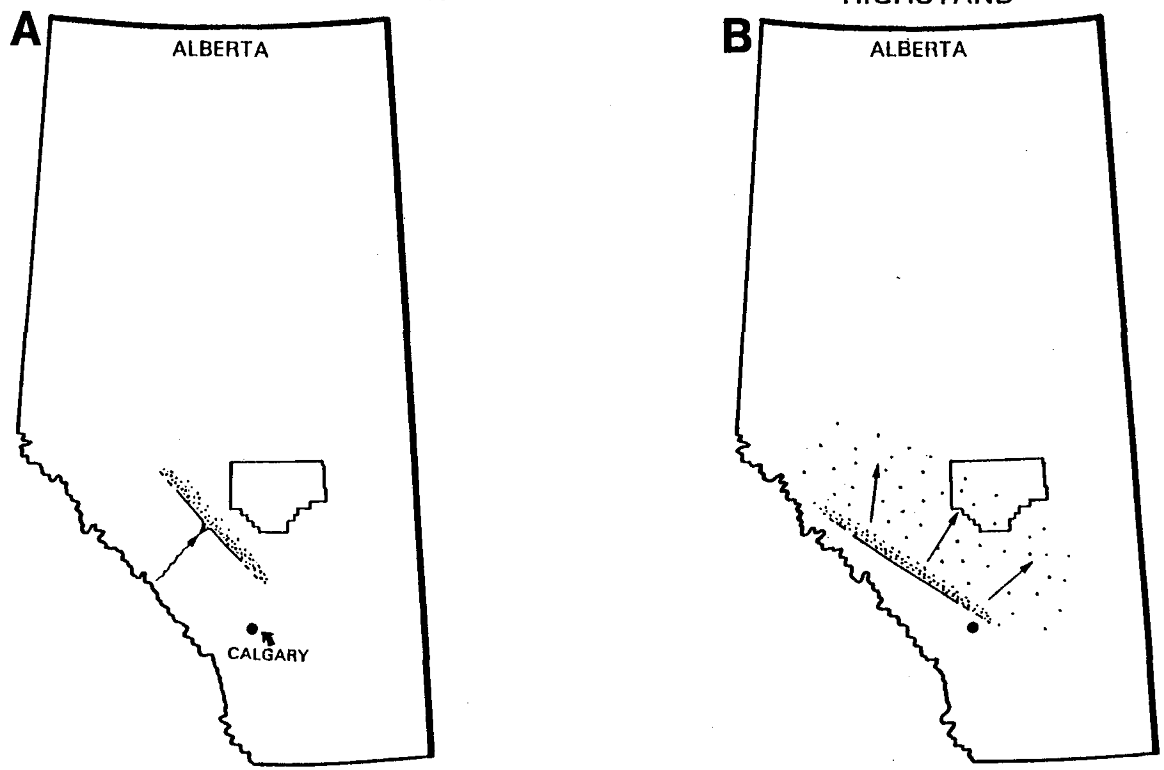
During renewed transgression, the shoreline moved into the Caroline -

Figure 7.4A Renewed transgression ravined the top of the Crystal valley and the Sunnybrook 'B' shoreface and moved the shoreline to the Willesden Green area. Approximately 30 m of coarse fluvial and estuarine sediment filled this valley during overall transgressive conditions.

Figure 7.4B After ravinement of the Willesden Green Valleys, RSL reached a maximum. Progradation of a highstand shoreface in the area of Caroline-Garrington-Harmattan resulted in the widespread deposition of an eastward tapering wedge of offshore-to-shoreface sediments.

VIKING FORMATION
DEPOSITIONAL HISTORY

PUNCTUATED TRANSGRESSION[2] HIGHSTAND



TRANSGRESSIVE VALLEY FILL
WILLESDEN GREEN

HIGHSTAND SHOREFACE
CAROLINE-GARRINGTON-HARMATTAN

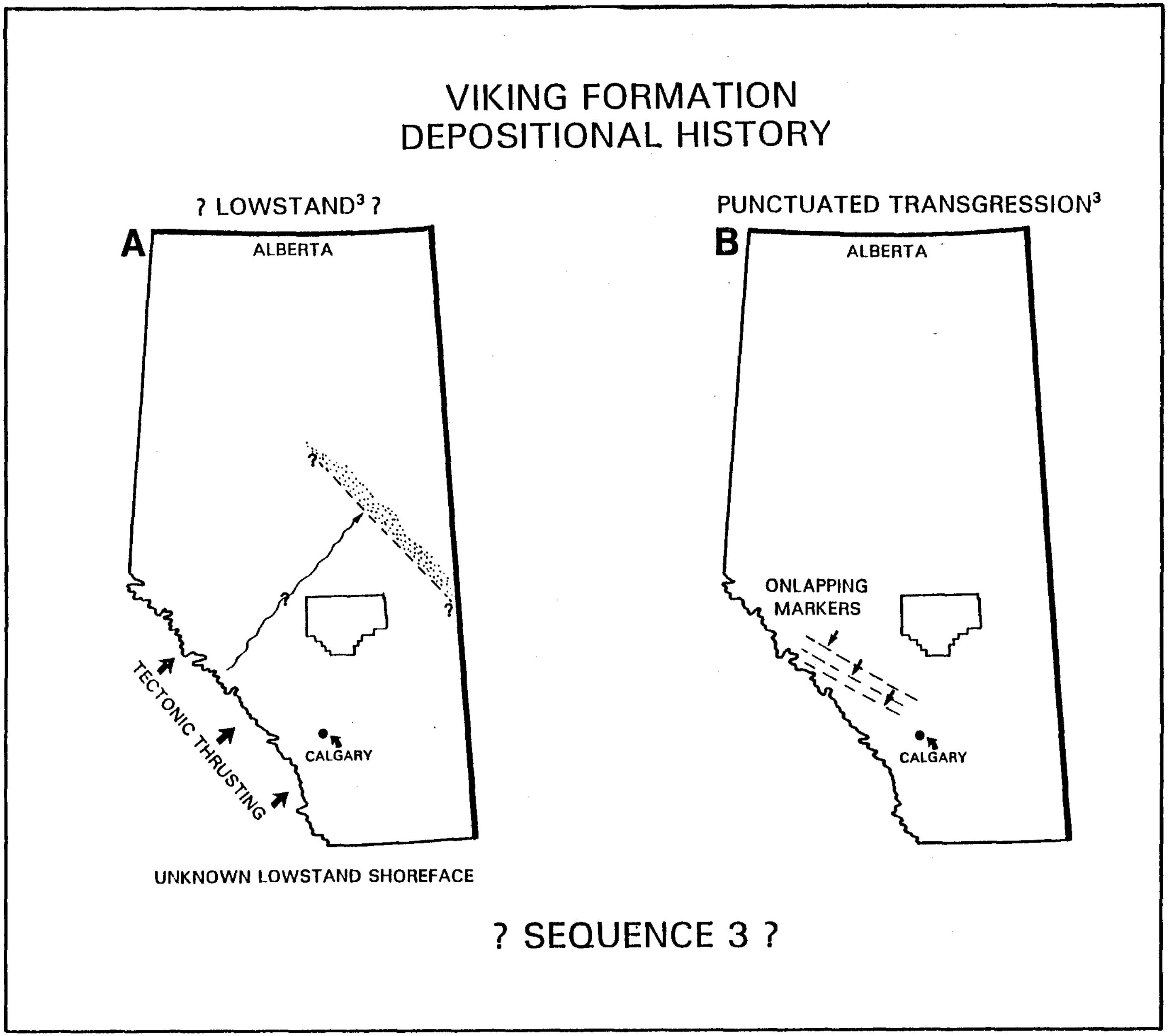
SEQUENCE 2

Garrington - Harmattan area where a large wedge of storm dominated prograding shoreface deposits (overlain by beach and non-marine deposits at Harmattan East) built eastward into the basin (figure 7.4b). These sediments and their offshore equivalents are recognised throughout the study area. The general eastward thinning of the highstand shoreface succession is thought to be related to depositional thinning and/or erosive removal by transgressive incision associated with later erosion at the top of the Viking Formation.

7.2.4 A Possible Third Stratigraphic Sequence?

A basinwide erosion surface has been identified at the top of the Viking Formation and is associated with a major lowering of RSL (figure 7.5a) that exposed much of the Viking Formation (R.G. Walker, pers. comm., 1994). During the subsequent transgression the entire record of subarial exposure was removed erosively (figure 7.5b). The resulting TSE (in essence an E/T surface) and the varied transgressive deposits are the only record of what is probably the most extensive fluctuation of sea level during Viking time. No valleys are recognised immediately below this surface and attempts to define a lowstand shoreline are as yet unsuccessful (R.G. Walker, pers. comm., 1994). Although this package of sediment is different from the prior described sequences, it is nonetheless can probably be

Figure 7.5 Fall of RSL (A) followed immediately by a rapid transgression (B) cut a large RSE/TSE across the basin which defines the top of the Viking Formation. Short lived stillstands allowed minor progradation of coarse onlapping markers in the Caroline-Garrington-Harmattan east area. Maximum transgression was reached with the development of a MxFS represented by the base of the Fish Scale Formation.


VIKING FORMATION
DEPOSITIONAL HISTORY
? LOWSTAND³ ?
A
ALBERTA
TECTONIC THRUSTING
CALGARY
UNKNOWN LOWSTAND SHOREFACE
PUNCTUATED TRANSGRESSION³
B
ALBERTA
ONLAPPING
MARKERS
CALGARY
? SEQUENCE 3 ?

considered a third Viking stratigraphic sequence.

7.3 Application and Amendments of Viking Allostratigraphy

Since the original definition of allomembers in the Viking Formation by Boreen and Walker (1991) several studies have expanded their original work to create a scheme that is applicable basinwide (Davies and Walker, 1993; Pattison, 1991; Hadley, 1992). The original scheme defined six bounding discontinuities (base of the Viking alloformation, VE1 through VE4 and base of the Fish Scale Formation) which subdivide five allomembers (A through E) within the Viking alloformation. An overview of the facies assemblages that comprise each allomember is provided in chapter 2.

Unfortunately, the original scheme recognised only a single major lowstand event which was responsible for the formation of all Viking incised valleys and a single lowstand shoreface of unknown location. Subsequent work by Pattison (1991) showed that two separate valleys were present at Crystal and that each was associated with a substantial (several 10's of meters) lowstand of relative sea level. Lowstand valley incisions at Sundance - Edson and Cyn - Pem were assigned to the first lowstand event (Pattison, 1991) as was the 'stage 1' (allomember C1) channel fill of the Willesden Green valley (Boreen and Walker, 1991). Work presented in this thesis agrees that the first lowering of relative sea level was possibly associated with development of broad unconformable valleys at Crystal, Sundance - Edson, Cyn - Pem and Willesden Green and suggests development of a lowstand shoreface at LBK. After basinwide transgression in which all the valleys were backfilled with stratigraphically complex successions of estuarine origin a second lowstand event occurred. This lowstand was represented by re-incision only at Willesden Green and Crystal where narrow valleys were cut and a lowstand shoreface at BHL developed. Relatively rapid transgression caused the valleys to backfill with dominantly fluvial sediments.

Recognition of two major lowstand events and correlation of lowstand shorefaces to lowstand incised valleys as well as transgressive shorefaces to transgressive fill in the valleys requires the definition of a new allomember and bounding discontinuities. Since the naming of allomembers and numbering of the bounding discontinuities that define them have become established in some of the recent literature (table 1.2) it is difficult and counterproductive to rename all the allostratigraphic elements in light of the recognition of new discontinuities amongst those already defined. An acceptable solution is to formally subdivide allomember C into C1 and C2. Allomember C1 is defined below by the SB 1 or TSE 1 + SB 1 erosion surfaces and above by the TSE 1, SB 2 + TSE 2, or TSE 3 surface. Allomember C2 is bound below by the SB 1 or a SB 1 + TSE 1 surface and above by a TSE 2 or TSE 3 erosion surface. Table 7.1 indicates equivalent surfaces of past authors to those described in this thesis.

The following represent interpretations of bounding discontinuities and the allomembers they define in the study area. The reader may reference figure 7.6a, and 7.6b as an aid in visualizing the relationships and notation presented.

7.3.1 Base Viking Alloformation (BV)

No cores the study area penetrated the base of the Viking Formation. The base is therefore defined by the first deflection to the right of the resistivity log directly above the 'shale line' representative of the Joli Fou Formation. In parts of the study area, especially in the west and northwest, this contact appears relatively gradational. Alternatively, in the east and southeast the change is apparently sharp. No erosion has been demonstrated at this contact and as such it is considered to be a generally sharp but conformable transition.

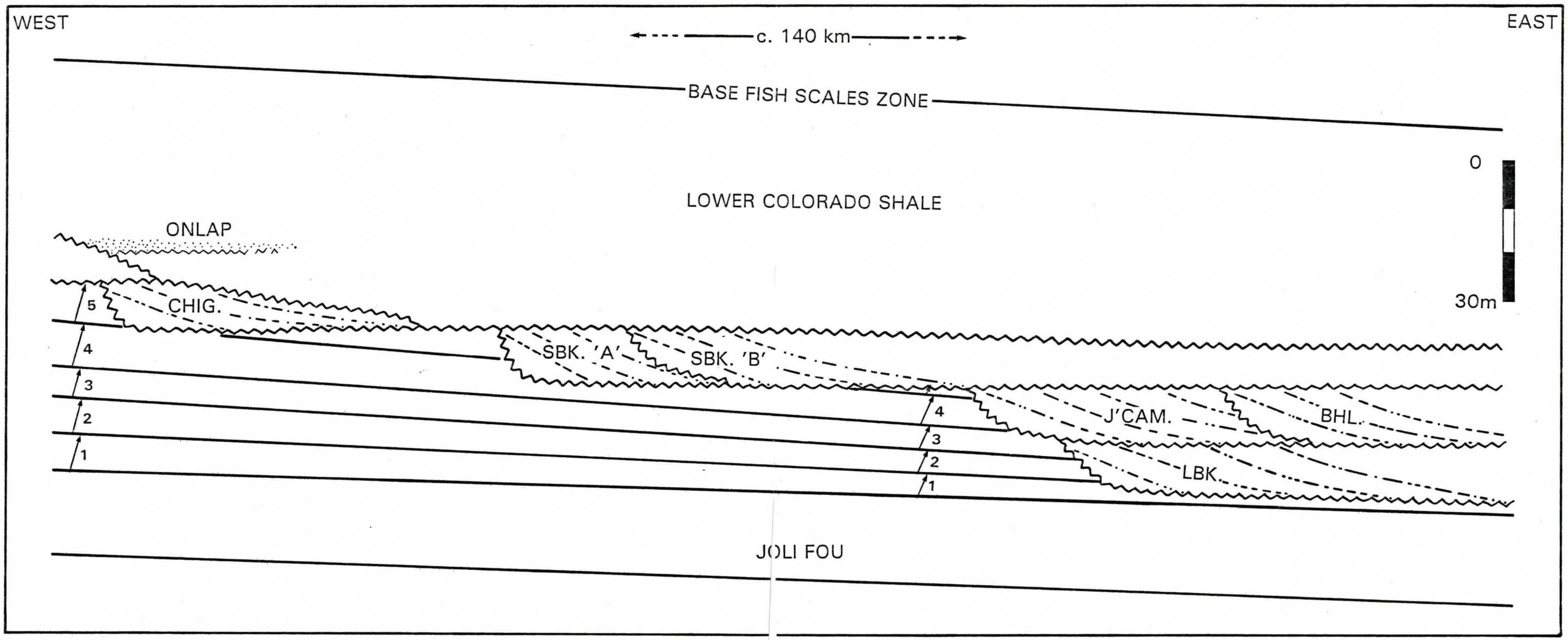
7.3.2 Allomembers A and B

Allomembers A and B are represented in the study area by a stack (maximum of 5) of regional coarsening upward successions that form a highstand progradational parasequence set (figure 7.6a,b). As described,

Table 7.1 Equivalent allostratigraphic terminology of other workers.

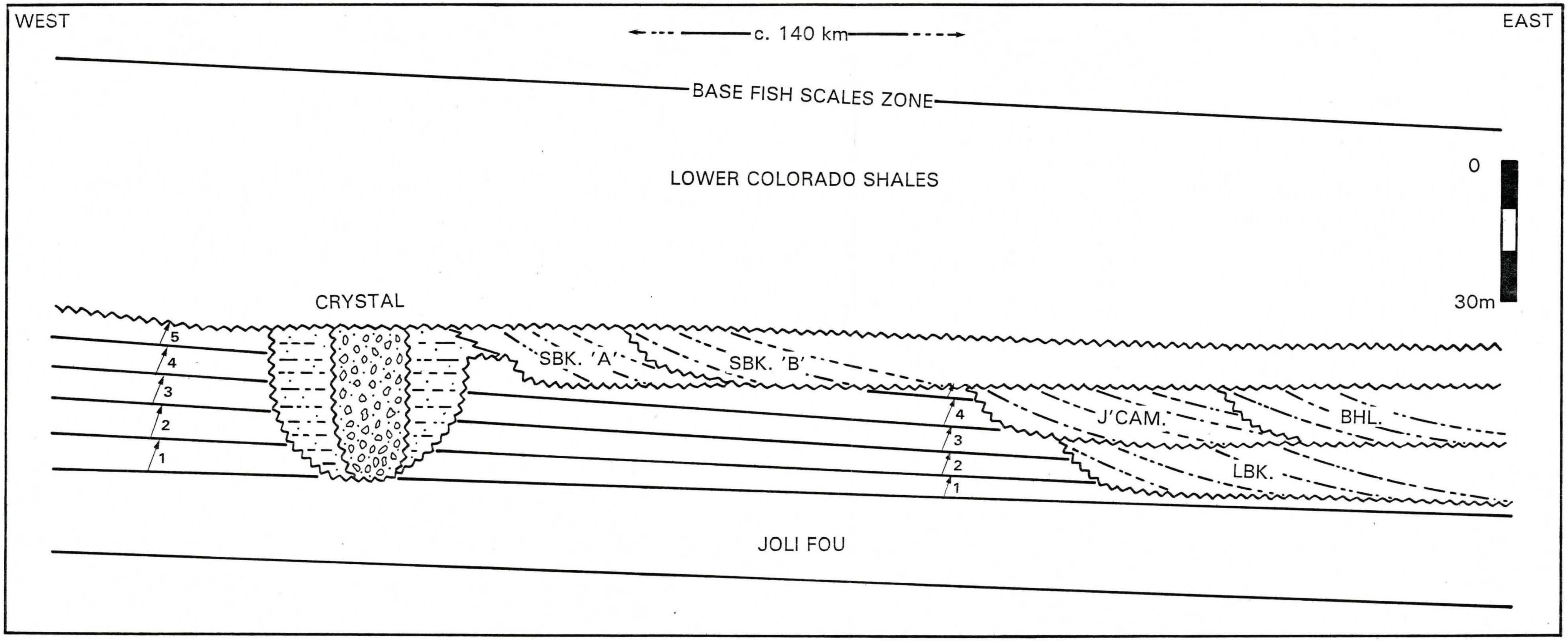
Reference	Equivalent Terminology To That Used In This Thesis						
	SB 1	TSE 1	SB1+TSE1	SB 2	TSE 2	SB2+TSE2	TSE3
Downing & Walker, 1988	-	E1/CM5	-	-	-	-	E3
Raychaudhuri, 1989	VE2	VE3	VE3	-	-	-	VE4
Boreen, 1989	VE2	VE3	VE3	-	-	-	VE4
Davies, 1990	VE2	VE3	VE3	-	-	-	VE4
Pattison, 1991	VE2	VE3	VE2/3	VE3-?	VE3-?	VE3-?/VE3-?	VE4
Hadley, 1992	VE2	VE3	VE3	-	-	-	VE4
Pattison & Walker,	SB 1	TSE 1	SB1 + TSE1	SB2	TSE 2	SB2 + TSE2	TSE4

Figure 7.6a Stratigraphic relationships in the Beaverhill Lake - Chigwell area. Bounding discontinuities are indicated and regional successions 1 through 5 are also illustrated with arrows.



WEST
EAST
c. 140 km
BASE FISH SCALES ZONE
0
30m
LOWER COLORADO SHALE
ONLAP
5
CHIG.
4
SBK. 'A'
SBK. 'B'
3
2
1
4
3
2
1
J'CAM.
BHL.
LBK.
JOLI FOU

Figure 7.6b Stratigraphic relationships in the Beaverhill Lake - Crystal area. Bounding discontinuities are indicated and regional successions 1 through 5 are also illustrated with arrows.


WEST
c. 140 km
EAST
BASE FISH SCALES ZONE
LOWER COLORADO SHALES
0
30m
CRYSTAL
5
4
3
2
1
SBK. 'A'
SBK. 'B'
4
3
2
1
J'CAM.
BHL.
LBK.
JOLI FOU

the lower contact of the basal succession is thought to be a sharp but conformable contact with the underlying Joli Fou Formation. The upper boundary to the stack is always sharp and disconformable with the SB 1, SB 1 + TSE 1, SB 2, SB 2 + TSE 2 or TSE 3 erosion surfaces. The VE1 surface (Boreen and Walker, 1991) which is interpreted to erosively separate allomember A from B in northeast of Alberta, is thought to be a correlative conformity in this area.

7.3.3 SB 1 (Lowstand of Relative Sea Level)

The SB 1 erosion surface was not observed in core in the study area. The surface is a major lowstand surface of erosion that forms broad unconformable valleys at Crystal, Cyn - Pem, Sundance - Edson and Willesden Green (Boreen and Walker, 1991; Pattison, 1991) and forms an asymmetrical shoreface scour where it underlies the LBK lowstand incised shoreface (figure 7.6a,b). Basinward of the lowstand shoreface a correlative conformity to SB 1 exists which is overlain by distal Lindbrook shoreface sediment. The only 'unmodified' (ie. not erosively reworked) portion of this extensive unconformity exists underneath the LBK shoreface where it cuts out all of regional successions 3, 4, and 5 and portions of successions 1 and 2. Pattison and Walker (1994) reported over 30m of relief on SB 2 at Crystal where it downcuts through allomembers A and B.

7.3.4 TSE 1 (Transgression)

The TSE 1 erosion surface was cut during an overall transgression immediately following the SB 1 lowstand. Punctuated stillstands enabled the development of incised shorefaces and the modification of fluvially cut valleys at Crystal, Cyn - Pem, Sundance - Edson and Willesden Green. Each of the stillstands is denoted by the name of the shoreface formed during pause in transgression. For example TSE 1 (J'CAM) indicates the surface underlying the J'CAM shoreface.

a) TSE 1 (J'CAM)

This surface occurs at the base of the J'CAM transgressive shoreface and is correlative with the transgressive surface of erosion that truncated deposition at the LBK lowstand shoreface (figure 7.6a). Underneath J'CAM, TSE 1 has 'modified' the pre-existing SB 1 lowstand surface. Thus, this surface can be classed as an E/T surface; initially formed during lowstand and subsequently re-eroded during transgression. This surface removes all of regional succession 5 and 4 and portions of succession 2/3 and was probably cut by wave action in the shoreface.

b) TSE 1 (SBK 'A')

This surface occurs at the base of the SBK 'A' transgressive shoreface and is correlative with the transgressive ravinement at J'CAM (figure 7.6a). This surface is also found beneath the first transgressive valley fill at Crystal (figure 7.6b). This surface may be classed as an E/T surface due to modification of the SB 1 lowstand surface. At SBK 'A' this modification takes the form of an asymmetrical shoreface scour. At Crystal, this surface has modified the valley cut by erosion on the SB 1 surface through wave and/or tidal scour during transgression (Pattison, 1991).

c) TSE 1 (CHIG)

The TSE 1 surface underlies the CHIG shoreface where it forms an erosional discontinuity with sediments of regional succession 5 (figure 7.6a). This surface is correlative with the transgressive ravinement at SBK 'A' and at Crystal (where it is modified by later erosion). The rise in relative sea level forming the ravinement at Crystal moved the shoreline to the southwest where during stillstand the erosion surface underlying CHIG was cut.

d) TSE 1 (W.C.-G.-J.)

The TSE 1 erosion surface is represented in the study area by the ravinement surface at CHIG which truncates the top of the sandbody and presumably has removed any upper shoreface, beach and non-marine facies that may have been developed. It is possible that this surface underlies the Wolf Creek - Gilby 'A' - Joffre shoreface trend as well as the 'stage 1' channel fill at Willesden Green. Correlations by Pattison (1991) suggest that distal Wolf Creek - Gilby 'A' - Joffre deposits overlie CHIG. Boreen and Walker (1991) correlated the incision underlying this extensive shoreface trend to the incision beneath the Willesden Green Valley 'stage 1' fill.

7.3.5 Allomember C1

In the study area, allomember C1 comprises incised shorefaces of FA 2A and 2B and an incised valley fill (Fill 1 at Crystal) (figure 7.6a,b). This allomember is bound below by the SB 1 or the SB 1 + TSE 1 erosion surface and above by a SB 2, SB 2 + TSE 2, TSE 2, or TSE 3 erosion surface. Outside of the study area, the Wolf Creek, Gilby 'A', Joffre and Bickerdike shoreface trends, as the valley fills at Sundance - Edson, Cyn - Pem, and the 'stage 1' fill at Willesden Green are all probably contained within this allomember. Essentially the definition of this allomember remains unchanged from that of Boreen and Walker (1991).

7.3.6 SB 2 (Lowstand of Relative Sea Level)

The SB 2 erosion surface was not observed in core in the study area. This surface represents a second major lowstand event and like SB 1 forms unconformable valleys at Crystal and Willesden Green and an asymmetric shoreface scour where it underlies the BHL lowstand incised shoreface (figure 7.6a,b). A correlative conformity to SB 2 exists basinwards where distal BHL sediments imperceptively overlie regional sediments. This unconformity erosively truncates the J'CAM and LBK sediments at BHL and cuts into portions of regional successions 1 and 2/3. The depth of erosion tends to increase southward such that the LBK shoreface sediments are preserved only in the northeast of the study area. Everywhere else, this lowstand event would have resulted in subareal exposure; evidence of this exposure at Crystal and Willesden Green is in the form of narrow unconformable valleys. Over 33m of relief was reported on the second incised valley at Crystal which indicates the magnitude of the fall was possibly comparable to that of SB 2.

7.3.7 TSE 2 (Transgression)

This surface was cut during an overall relative rise of sea level following the SB 1 lowstand. As with the TSE 1 transgression, each stillstand of relative sea level resulted in the development of an incised shoreface. Valley fills which occur at Willesden Green and Crystal typically comprise much coarser sediment then valley fills associated with the TSE 1 transgression and as such may represent fluvial deposits (lowstand systems tract) and/or the deposits of fluvial dominated estuaries (transgressive systems tract).

a) TSE 2 (SBK 'B')

The TSE erosion surface underlies the shoreface at SBK 'B' which has incised into the regional successions 5 and 4 of allomembers A and B and also into portions of the SBK 'A' shoreface and its overlying transgressive deposits (figure 7.6a,b). This surface might also underlie the very seaward end of the valley fill (#2) at Crystal where the fluvial dominated valley may have graded into the fully marine shoreface at SBK 'B'. In the valley the surface has been termed SB 2 + TSE 2 (Pattison and Walker, 1994) to denote its modified nature with possible preserved lowstand deposits. This surface is also correlative with the transgressive ravinement surface at BHL and at J'CAM. This incised shoreface is recognised as the only representation of a stillstand event during the TSE 2 transgression.

b) TSE 2 (Willesden Green)

This disconformity forms a transgressive ravinement surface in the SBK 'B' and Crystal areas and was formed during renewed relative rise of sea level. To the west, this surface is thought to truncate the Willesden Green valley deposits and has been correlated westward by Boreen and

Walker (1991) where it is suggested to underlie the highstand prograding shoreface at Caroline - Garrington - Harmattan East.

7.3.8 Allomember C2

Allomember C2 is composed of incised shorefaces and incised valley fills (figure 7.6a,b). In the study area the BHL and SBK 'B' shorefaces and the Crystal valley fill #2 make up this allomember. The 'stage 2' channel fill at Willesden Green is a possible component of this allomember southwest of this study. Erosional surfaces SB 2, SB 2 + TSE 2 or TSE 2 underlie the allomember while a TSE 2 or the TSE 3 surface overlies it.

7.3.9 TSE 3 (Lowstand? and Transgression)

Following highstand sedimentation in the Caroline - Garrington - Harmattan East area, a major lowstand surface of erosion was cut across the entire basin to an unknown lowstand position probably east or northeast of the study area presented in this thesis (R.G. Walker, pers. comm., 1994). Since no valleys are recognised immediately below this surface and no expression of non-marine facies has ever been identified above this surface, both the lowstand and transgressive events have been simply termed TSE 3 (figure 7.6a,b). During the ensuing transgression the TSE 3 erosion surface was cut and all evidence of previous subareal exposure was completely removed. This surface truncates the top of allomembers A, B, C1, C2 and D in the study area. It is characterised by an extremely sharp basal contact which may be mantled by a wide variety of coarse grained sandstones, conglomerates and/or muddy bioturbated sandstones. The topography on this surface in the study area is fairly smooth as it rises stratigraphically upwards to the west. In the area of Caroline - Garrington - Harmattan East the surface has a step-like morphology which causes it to rise dramatically southwestward (Hadley, 1992; Davies and Walker, 1993). This surface is interpreted as having formed initially during a major lowstand event, the resulting subareal surface of erosion was transgressively modified by the ensuing relative rise in sea level.

7.4 Revised Sea Level Curve for the Viking Formation

A relative sea level curve has been developed for the Viking Formation based upon work contained within this study as well as the work of Downing and Walker, 1988; Power, 1988; Raddysh, 1988; Raychaudhuri, 1989; Pattison, 1991; Boreen and Walker, 1991; Hadley, 1992; Davies and Walker, 1993 and Walker and Wiseman, in prep. The sea level curve (figure 7.9) illustrates the relative positions of lowstand and transgressive incised shorefaces and their stratigraphic position with respect to lowstand incised valleys or their transgressive fill. The sea level curve presented here incorporates Viking stratigraphy outside the study area, using in part the work of the authors cited immediately above. The diagram is an expanded and revised version of that originally proposed by Pattison (1991).

There are probably three major lowstands of relative sea level within the Viking Formation. On the relative sea level curve the maximum extent of the lowstands are represented by deposition at the LBK, BHL and another lowstand shoreline of unknown location; these are associated with the SB 1, SB 2 and ?SB 3? 'lowstand events'. The magnitude of the first two lowstands can be estimated to have been a minimum of 30-33m based upon the preserved depths of incision at the Willesden Green and Crystal valleys. Each of the first two lowstands appears to have subarially exposed much of the western interior and pushed shorelines up to 90 km to the east of the Crystal valley. Since no valleys have been recognised to have been cut during the VE4 lowstand it is difficult to estimate the possible magnitude of this event. However, the persistence of this erosion surface throughout the basin suggests the lowering and subsequent rise in relative sea level responsible for its formation would have been even greater then the SB 1 and SB 2 events, perhaps as much as 42 m (R.G. Walker, pers. comm., 1994).

Although three major lowstand events have been recognised only one highstand shoreface has been identified at Caroline - Garrington - Harmattan;

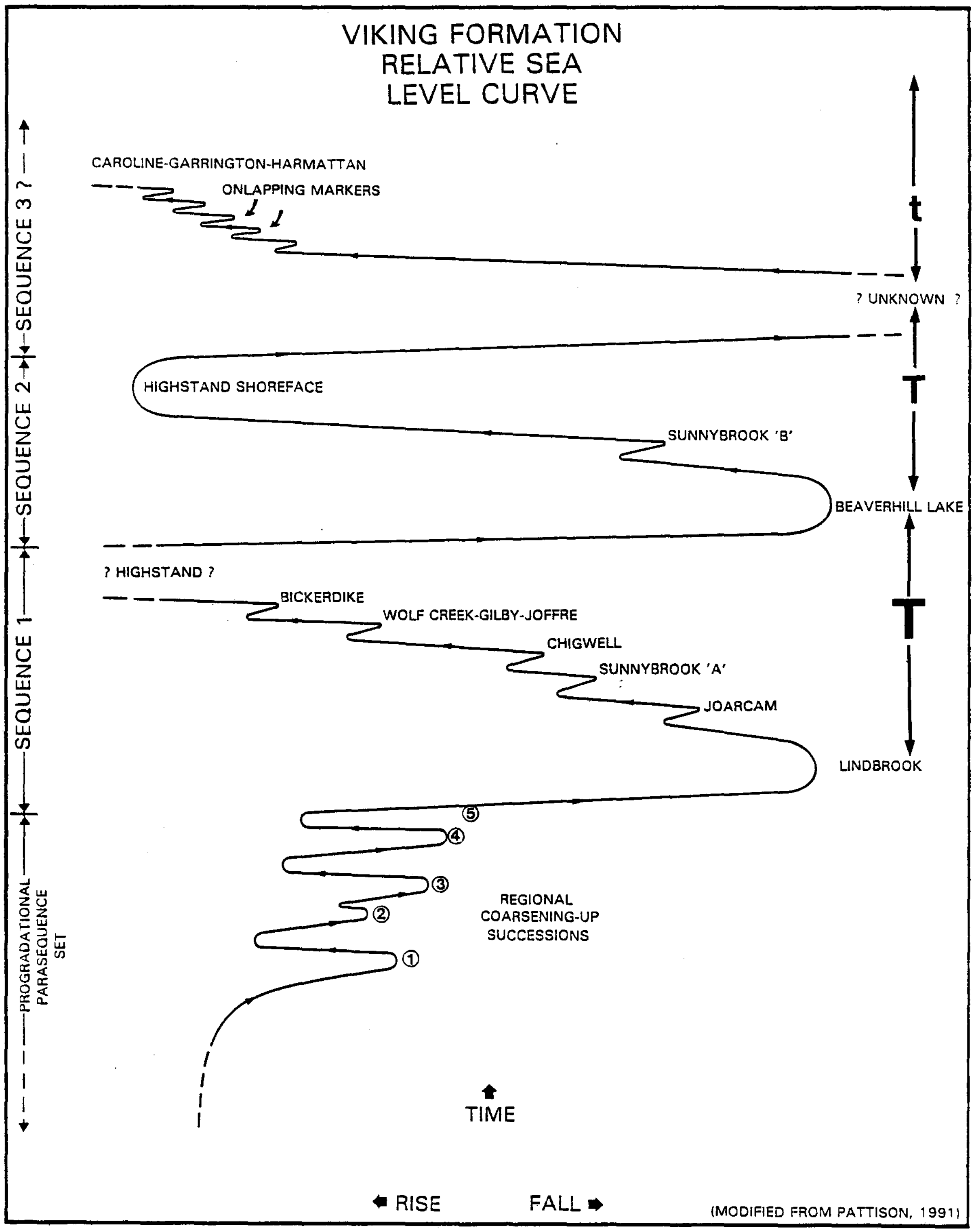
it formed after the maximum extent of the SB 2 transgression (Boreen and Walker, 1991; Pattison, 1991; Hadley, 1992; Davies and Walker, 1993). According to this scheme, a highstand shoreface would be expected to exist and be correlatable to the TSE 1 surface of erosion. The potential highstand shoreface would have been developed after maximum transgression associated with the development of a ravinement surface at the top of the 'first' Willesden Green valley. However, no such shoreface is presently known. Transgression associated with TSE 3 and the development of allomember E may have reached maximum extent with the development of a condensed horizon at the base of the Fish Scale Formation. This transgression was of basinwide extent and resulted in the inundation of the entire Western Interior of Canada and the United States from the Gulf of Mexico to the Arctic (Caldwell, 1984). This relative rise was of much greater extent then the previously documented transgressions within the Viking Formation.

7.5 Comparison of Each Sequence and Their Bounding Discontinuities

A comparison of the shape of the transgressive 'limbs' of each of the three cycles of sea level fluctuation seems to suggest an evolution through time of the transgressing relative sea level (figure 7.7).

The TSE 1 transgression was punctuated with multiple stillstands

Figure 7.7 Relative sea level curve for the Viking Formation. Two full stratigraphic sequences are recognised and a third is probable. Horizontal axes for the curve are indicated.


VIKING FORMATION
RELATIVE SEA
LEVEL CURVE
CAROLINE-GARRINGTON-HARMATTAN
ONLAPPING MARKERS
t
? UNKNOWN ?
HIGHSTAND SHOREFACE
T
SUNNYBROOK 'B'
BEAVERHILL LAKE
? HIGHSTAND ?
BICKERDIKE
WOLF CREEK-GILBY-JOFFRE
T
CHIGWELL
SUNNYBROOK 'A'
JOARCAM
LINDBROOK
REGIONAL
COARSENING-UP
SUCCESSIONS
TIME
RISE
FALL
SEQUENCE 3 ?
SEQUENCE 2
SEQUENCE 1
PROGRADATIONAL PARASEQUENCE SET
(MODIFIED FROM PATTISON, 1991)

which are responsible for all but one of the transgressively incised shoreface trends that have been analysed allostratigraphically. Several of the largest linear sandbodys known to exist in the Viking, namely the SBK 'A' (~200 km long) and the Wolf Creek - Gilby 'A' - Joffre (~400 km long) trends, were developed during stillstands on this overall transgression. In addition, three of the four incised valleys (Crystal, Willesden Green, Sundance - Edson) were filled at this time by a stratigraphically complex estuarine succession having a tripartite facies zonation. The position of the extensive incised shorefaces directly seaward of the mouth of these three valleys enabled the tripartite fill to develop by providing the marine sand plugs which tended to fill the seaward end of the estuaries during transgression (Pattison, 1991).

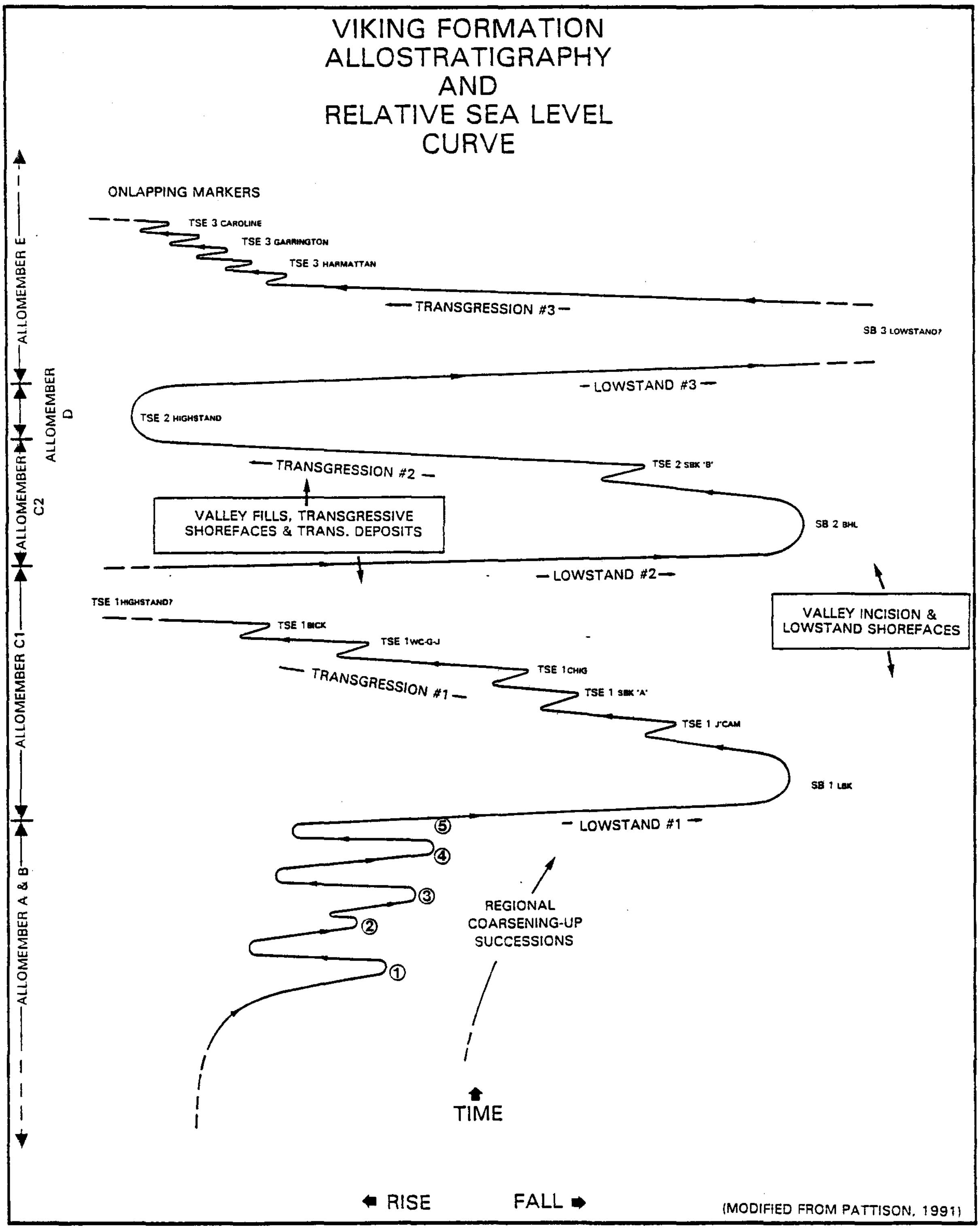
The TSE 2 transgression has just a single stillstand punctuation which is responsible for development of the SBK 'B' shoreface. Following development of this shoreface the TSE 2 transgression appears to have proceded relatively smoothly to its probable maximum extent just west of the Caroline - Garrington - Harmattan East area where a highstand shoreline is preserved. Valley fills at Willesden Green and Crystal associated with this transgression are filled with dominantly coarse grained deposits interpreted as being fluvial or fluvially-dominated estuarine in origin. These fills might represent the overall rapid nature of the transgression without associated stillstands or simply the narrow nature of estuary might have been more prone to be dominated by fluvial processes. Another striking feature of these valleys are their narrow nature which probably represents the morphology of the narrow fluvial channels which cut them. Rapid overall transgression without stillstands may have precluded a concomitant widening of the second episode of valleys during filling. Stillstand at the mouths of valleys would surely increase the chances that the valleys would become widened through modification by tidal scour and waves.

The transgressive limb of the TSE 3 cycle of sea level fluctuation appears to have been formed most rapidly. In the vicinity of the TSE 2 highstand shoreface at Caroline - Garrington - Harmattan several 'steps' have been cut into sediments underlying TSE 3 that are suggestive of short stillstands (Hadley, 1992; Davies and Walker, 1993). Progradation during stillstand has formed onlapping markers (five to six are recognised) that die out basinwards. These are the only record of stillstand punctuations on this overall smooth southwestward transgression that culminated in the deposition of the base of the Fish Scale Formation.

7.6 The Viking Formation: A Record of Albian Sea Level Fluctuations

The Viking sediments record a variety of relative sea level fluctuations that appear to exist on several different scales (figure 7.8). Regional

Figure 7.8 Relative sea level curve and allostratigraphy for the Viking Formation. Bounding discontinuities are indicated for each sandbody.


VIKING FORMATION
ALLOSTRATIGRAPHY
AND
RELATIVE SEA LEVEL
CURVE
ONLAPPING MARKERS
TSE 3 CAROLINE
TSE 3 GARRINGTON
TSE 3 HARMATTAN
TRANSGRESSION #3
SB 3 LOWSTAND?
LOWSTAND #3
TSE 2 HIGHSTAND
TRANSGRESSION #2
TSE 2 SBK 'B'
VALLEY FILLS, TRANSGRESSIVE
SHOREFACES & TRANS. DEPOSITS
SB 2 BHL
LOWSTAND #2
TSE 1 HIGHSTAND?
TSE 1 BICK
TSE 1 WC-G-J
TSE 1 CHIG
TSE 1 SBK 'A'
TSE 1 J'CAM
TRANSGRESSION #1
VALLEY INCISION &
LOWSTAND SHOREFACES
SB 1 LBK
LOWSTAND #1
REGIONAL
COARSENING-UP
SUCCESSIONS
TIME
ALLOMEMBER E
ALLOMEMBER D
ALLOMEMBER C2
ALLOMEMBER C1
ALLOMEMBER A & B
RISE
FALL
(MODIFIED FROM PATTISON, 1991)

coarsening-upward successions are each bound by flooding surfaces that represent fluctuations of RSL during highstand sedimentation that occurred frequently and perhaps without significant effect on the overall paleogeography of the time. Lowstand incised valleys and their associated shorefaces represent regressive-transgressive events that occurred perhaps only three times during the entire Albian and had profound effects on Viking paleogeography. Superimposed on these large scale regressive-transgressive cycles are stillstands representing a higher order cyclicity of sea level fluctuations that resulted in incised shoreface development. Even higher scales of relative fluctuation might be expected to have been responsible for the deposition of coarse grained sandstones which onlap erosive scarps cut by TSE 3. An excellent treatment of the entire topic of sea level variations is provided in Pattison (1991). Further discussions may be found in Power (1988). Readers are directed to these sources for a discussion of the timing, magnitude, and potential controls on the scales of fluctuation of RSL in the Viking Formation.

7.7 Sequence Stratigraphy

A comprehensive sequence stratigraphic analysis is provided in Pattison (1991) and discussions may also be found in Posamentier and Chamberlain (1989, 1991) and Posamentier et al (1992, 1993). However, the results presented herein extend the work of these authors. Readers are directed to Van Wagoner et al. (1990) for a discussion of the terms and concepts associated with sequence stratigraphic analysis.

7.7.1 High Resolution Sequence Stratigraphy

Posamentier and Chamberlain (1989) were the first to apply the concepts of sequence stratigraphy to the Viking Formation in the J'CAM area when they defined highstand, lowstand and transgressive systems tract deposits. The highstand systems tract was suggested to comprise a stack of coarsening upward successions that formed an off-field association to the west of J'CAM. The lowstand systems tract formed reservoir quality sandstones (Main sandstones of industry) that were separated from the HST below by a lowstand surface of erosion and the TST above by a TSE. The transgressive systems tract was described as an assemblage of coarse grained sandstones, conglomerate, and shale (Third sandstones of industry) that formed an onlapping succession. Further refinements of the sequence stratigraphic analysis were proposed by Posamentier et al. (1992, 1993) for areas east of the J'CAM field. Pattison (1991) and Pattison and Walker (1994) subdivided the Viking into a sequence stratigraphic framework which recognised three sequence boundaries in the Crystal area. Walker and Wiseman (in prep.) suggest revisions to the scheme proposed by

Posamentier and Chamberlain (1989) and Posamentier et al (1992, 1993) in the J'CAM - BHL area based upon a large number of cross sections in the immediate area and toward the west into Crystal.

The sequence stratigraphic analysis presented in this thesis (figure 7.8) suggests that there are three sequence boundaries (SB #1, SB #2 and SB #3?) which subdivide 2 stratigraphic sequences (sequence 1 and sequence 2). Sequence 1 is bound below by the SB 1 erosion surface and above by the TSE 1 erosion surface, while sequence 2 is bound below and above by SB 2 and TSE 2 respectively.

The positions of these sequence boundaries do not necessarily coincide everywhere with those proposed by Pattison (1991) but are in agreement with those of Pattison and Walker (1994). For example, J'CAM is placed within the LST of sequence 2 by Pattison (1991) where in this thesis it is placed within the TST of sequence 1. Generally, Pattison's (1991) sequence 2 west of Crystal coincides with sequence 1 established herein.

As described, the regional coarsening upward successions form HST deposits. Both sequence boundaries 1, 2 and 3 variably incise into these successions.

Sequence 1 comprises a single lowstand shoreface (LST deposits), 5 transgressive incised shorefaces and 4 valley fills (TST deposits). Sequence

2 comprises a single lowstand shoreface and associated fluvial deposits preserved in the Crystal and Willesden Green valleys (LST deposits), 1 transgressively incised shoreface and portions of 2 valley fills (TST deposits) and a highstand shoreface (HST deposits). Sequence 3 comprises no valley fills or incised shorefaces and is at this point in time only a 'suspected' or probable candidate that consists of little more than transgressive lag and onlapping markers (TST deposits).

CHAPTER 8 SUMMARY AND CONCLUSIONS

1) Seven facies associations have been identified within the Viking alloformation in the study area. These associations may form coarsening-upward, fining-upward or non-sequential successions. One association is recognised within the 'regional' deposits, two are recognised within the incised shoreface deposits and four are categorised as being 'transgressive'.

2) The Viking Formation can be subdivided into highstand (HST), lowstand (LST) and transgressive systems tracts (TST) through the recognition of regionally extensive bounding discontinuities.

a. HST deposits comprise a series of regional coarsening upward successions (FA 1) that form a progradational parasequence set. The depositional thickness of the earliest successions tends to increase towards the northwest suggesting early Viking shorelines oriented southwest-northeast.

b. LST deposits form isolated linear sandbodies resting in elongate asymmetric scours which are interpreted as incised shorefaces (FA 2A & 2B). These shorefaces form the most basinward incised sandbodies in the study area and are underlain by 'unmodified' sequence boundaries. These shorefaces trend northwest-southeast as a result of a major paleogeographic re-orientation which was possibly controlled by uplift in the Cordillera to the southwest and subsidence of the Peace River Arch to the north.

c. TST deposits are composed of a wide variety of sediments including incised shorefaces (FA 2A & 2B), onlapping transgressive deposits (FA 3 & 4), erosive lags (FA 5) and thick marine mudstone successions (FA 6). The erosion surfaces cut at the base of the TST 'modify' sequence boundaries and remove all evidence of subareal exposure associated with development of the LST.

3. Sharp based sandbodies which rest in elongate and asymmetrical scours are interpreted to form incised shorefaces based upon application of a correlation template developed at Joarcam field. Correlation of bounding discontinuities (defining the base and top of the shorefaces) beyond field boundaries establishes the relative stratigraphic positions of each of the shorefaces.

4) Six shorefaces (2 lowstand, 4 transgressive) are recognised in the study area. These shorefaces are assembled into one of two stratigraphic sequences which are correlated to 2 separate episodes of valley cut and fill at Crystal field (Pattison and Walker, 1994).

5) Lowstand shorefaces associated with development of lowstand incised valleys while transgressive shorefaces may be directly correlated with the transgressive valley fill deposits in the two incised valleys at Crystal.

6) Each established stratigraphic sequence comprises lowstand incised valley and lowstand incised shoreface as well as transgressive valley fill and transgressive shorefaces. Erosion at the base of sequence 2 has removed all of the underlying sequence in several locations (ie. Sunnybrook 'B', Beaverhill Lake) and has resulted in the removal of important stratigraphic evidence which tie the deposits together and making direct correlation of sandbodies to one another difficult.

7) The recognition of the 2 stratigraphic sequences has important implications for development of other sandbodies in the Viking which occur outside the study area. A tentative grouping of known Viking shoreline, incised valley and onlapping marker trends using the scheme developed within the study area is presented.

8) Comparitive analysis of each of the cycles of RSL fluctuation shows a secular evolution with each sequence comprising less and less time. Four

incised valleys (Crystal, Willeden Green, Cyn-Pem, Sundance-Edson) and seven shoreline trends (Lindbrook, Joarcam, Sunnybrook 'A', Chigwell, Wolf Creek-Gilby-Joffre, Bickerdike) are developed within the first sequence; two incised valleys (Willesden Green, Crystal) and two shorefaces (Sunnybrook 'B', unnamed highstand shoreface) are recognised in second sequence; while no incised shorefaces or valley fills are recognised in the potential third sequence. This temporal evolution of the sequences suggests that the development of reservoir grade deposits would be favoured in the earliest sequence.

9) Sharp based incised shoreface successions (ie. FA 2A) may give way to gradationally based incised shoreface successions (ie. FA 2B) if sufficient accomodation space is available for the deposition of offshore silty shales beneath the prograding succession. Generally, in the Joarcam area FA 2A is inferred (from well logs) to be developed where accomodation space was less then FWWB ($\sim$20 m) and FA 2B appears to be developed where accomodation was greater then FWWB. The region where FA 2A is thought to be developed at Joarcam is entirely water wet and is not cored and thus interpretations are made on the basis of well logs only.

10) Viking allomember C of Boreen and Walker (1991) has been split into

allomember C1 and C2. Rather than applying the increasingly confusing 'VE' terminology a new vernacular has been used which utilises SB (esquence boundary) for 'unmodified' RSEs, SB + TSE for RSEs modified by TSEs, and TSE for unmodified TSEs. Numbers denote the particular sequence in which an erosion surface was cut and the use of the modifiers (ie. J'CAM) establishes the resulting incised sandbody.

11) Valley fills within sequence 1 appear to occur within broad valleys and are dominantly estuarine in origin with well developed tripartite facies zonation. Valley fills within sequence 2 appear to occur within narrow valleys and tend to be fluvial dominated with a much coarser grain size then the predecessor fills into which they incise.

12) Incised shorefaces occur within three main 'steps' cut into regional deposits of the HST. The steps are separated from one another by two prominent 'scarps' which form steeply banked erosional features.

13) 'Transgressive' successions form a westward tapering wedge of onlapping material that represents sediment ravined from the top of the upper shoreface, tops of valley fills and regional deposits or distal prograding shoreface deposits that are preserved between TSE 2 and TSE 3.

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APPENDIX 1

Core Location	Cored Interval (m)		Recovery (m)	Core Size (inches)
	Top	Base		
06-06-40-24W4	1401	1414	6.5	4
13-16-40-24W4	1418	1439	18.2	1
16-17-40-24W4	1442	1451	9.4	1
14-24-40-25W4	1420	1438	7.5	3
04-27-40-25W4	1484	1497	13.3	3
11-08-41-24W4	1348	1379	21.0	1
10-03-41-25W4	1396	1409	12.7	2.5
10-04-41-25W4	1427	1439	12.4	3
07-10-41-25W4	1405	1415	8.8	3
11-11-41-25W4	1395	1413	18.0	4
10-15-41-25W4	1408	1418	9.0	3
15-22-41-25W4	1419	1431	12.6	4
10-28-41-25W4	1444	1463	19.6	4
06-34-41-25W4	1444	1465	20.9	3
06-05-42-25W4	1449	1467	17.9	4
08-24-42-24W4	1303	1332	25.1	1
06-07-42-25W4	1396	1414	17.9	4
06-24-42-26W4	1370	1389	19.4	4
06-26-42-26W4	1370	1388	18.8	3
06-30-42-2W5	1669	1687	18.0	4
12-01-43-26W4	1388	1407	18.8	4
06-11-43-26W4	1407	1424	17.2	4
06-12-43-26W4	1392	1406	14.4	3
08-15-43-26W4	1422	1441	18.8	4
16-21-43-26W4	1410	1416	6.4	3
14-28-43-26W4	1407	1425	18.2	3

Core Location	Cored Interval (m)		Recovery (m)	Core Size (Inches)
	Top	Base		
08-32-43-26W4	1403	1422	19.1	3
05-05-44-23W4	1212	1221	8.9	1
08-15-44-23W4	1188	1204	13.7	1
06-29-45-27W4	1424	1443	10.8	3
15-11-45-01W5	1513	1540	17.0	1
14-25-45-02W5	1613	1631	18.3	4
06-24-45-03W5	1669	1688	19.4	4
04-06-46-19W4	968	983	15.7	3
05-09-46-19W4	947	956	9.3	3
10-02-46-20-W4	973	982	9.5	4
08-10-46-20W4	993	1002	7.4	2
04-12-46-20W4	966	984	18.0	4
03-14-46-20W4	982	991	8.9	3
14-14-46-20W4	982	1000	18.6	3
07-23-46-20W4	983	994	11.8	3
06-24-46-20W4	974	989	14.4	4
06-25-46-20W4	977	995	18.5	3
10-27-46-20W4	982	994	9.6	3
03-34-46-20W4	965	975	8.8	2
14-28-46-24W4	1151	1184	24.9	1
01-20-46-26W4	1295	1326	26.9	1
05-01-47-20W4	983	991	7.5	3
08-02-47-20W4	985	994	8.4	3.5
01-09-47-20W4	977	994	8.1	2
15-09-47-20W4	984	994	9.3	3
04-15-47-20W4	981	991	9.3	3

Core Location	Cored Interval (m)		Recovery (m)	Core Size (Inches)
	Top	Base		
10-16-47-20W4	984	995	9.3	3
02-21-47-20W4	981	991	10.2	3
06-24-47-20W4	948	970	22.1	3
15-28-47-20W4	974	982	8.1	3
02-31-47-20W4	980	997	14.2	3
15-31-47-20W4	982	993	10.2	3
14-32-47-20W4	976	991	10.6	4
02-33-47-20W4	971	981	9.2	3.5
10-33-47-20W4	968	979	10.9	3
12-33-47-20W4	970	983	13.0	3
04-35-47-20W4	952	990	32.5	2
06-29-47-21W4	1022	1040	18.5	3
09-14-47-22W4	1034	1040	6.4	1
15-21-47-23W4	1096	1144	20.4	1
05-11-47-24W4	1130	1149	17.2	1
01-21-47-24W4	1119	1142	12.4	1
06-20-47-02W5	1542	1558	15.9	3
04-01-47-03W5	1571	1589	17.3	3
10-04-48-20W4	967	977	9.9	3
04-05-48-20W4	977	988	11.6	3
07-05-48-20W4	966	991	25.1	3.5
10-06-48-20W4	972	986	14.4	3
14-08-48-20W4	963	978	14.4	3
02-17-48-20W4	970	985	14.7	2.5
02-19-48-20W4	969	988	19.8	3
04-19-48-20W4	975	989	14.0	3

Core Location	Cored Interval (m)		Recovery (m)	Core Size (Inches)
	Top	Base		
14-32-48-20W4	971	989	17.4	4
08-01-48-21W4	982	999	17.1	4
06-11-48-21W4	1000	1011	9.9	3
16-12-48-21W4	972	990	18.4	4
07-24-48-21W4	978	993	11.3	3
01-25-48-21W4	986	1000	13.8	3
08-25-48-21W4	989	1001	12.5	3
12-25-48-21W4	980	990	10.0	3
02-26-48-21W4	988	1001	10.6	3
03-26-48-21W4	988	996	8.5	3
04-26-48-21W4	990	996	6.0	3
06-26-48-21W4	988	1002	14.4	3
07-26-48-21W4	982	995	13.1	3
08-26-48-21W4	979	995	16.5	3
16-28-48-21W4	995	1005	8.5	3
10-32-48-21W4	1009	1024	15.6	3
15-34-48-21W4	973	991	17.1	3
07-35-48-21W4	979	995	16.6	3
15-14-48-23W4	1076	1090	11.2	1
08-16-48-03W5	1513	1539	20.0	3
11-08-49-20W4	987	1000	12.0	4
08-22-49-20W4	930	943	9.2	4
02-03-49-21W4	982	1000	15.4	4
11-03-49-21W4	984	997	13.3	3
06-04-49-21W4	1000	1013	9.9	3
09-04-49-21W4	995	1010	11.5	3

Core Location	Cored Interval (m)		Recovery (m)	Core Size (Inches)
	Top	Base		
06-08-49-21W4	985	1013	28.2	3
04-09-49-21W4	987	1005	16.0	3
09-09-49-21W4	990	1001	11.4	3
04-10-49-21W4	982	995	12.0	3
04-17-49-21W4	983	1003	20.0	4
12-17-49-21W4	980	995	15.2	3
06-18-49-21W4	1013	1020	7.1	2
03-19-49-21W4	991	1011	18.1	4
05-20-49-21W4	987	1005	18.5	4
07-21-49-21W4	974	1000	20.1	3
07-29-49-21W4	995	1013	18.0	4
11-29-49-21W4	1000	1017	14.0	4
04-31-49-21W4	1000	1015	13.5	3
06-31-49-21W4	993	1008	14.6	3
11-31-49-21W4	982	1009	22.8	2
14-05-49-22W4	1037	1050	12.0	3
11-10-49-22W4	1034	1041	7.9	3
10-13-49-22W4	1000	1018	18.6	3
10-24-49-22W4	1017	1032	15.3	3
07-35-49-22W4	1034	1046	12.3	3
11-36-49-22W4	1006	1019	13.4	4
16-36-49-22W4	984	998	12.5	3
06-09-49-02W5	1371	1387	14.6	3
16-13-50-21W4	925	933	8.2	3
05-18-50-21W4	979	1002	22.9	3

Core Location	Cored Interval (m)		Recovery (m)	Core Size (Inches)
	Top	Base		
02-01-50-22W4	991	1001	4.2	3
10-03-50-22W4	1020	1036	6.2	3
05-12-50-22W4	988	1000	7.7	3
07-12-50-22W4	1041	1060	17.2	3
10-12-50-22W4	1048	1058	9.0	3
15-12-50-22W4	978	990	12.6	3
12-24-50-22W4	989	1007	18.5	3
06-29-50-22W4	1011	1029	13.8	3
14-32-50-22W4	997	1013	16.7	3
01-34-50-22W4	998	1008	10.1	3
14-04-51-22W4	997	1018	19.4	3
16-18-52-05W5	1393	1425	33.3	3