SEISMIC STRATIGRAPHY OF THE EXMOUTH PLATEAU

Mark Rudolph

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Dalhousie University

Department of Geology
Halifax, Nova Scotia
Canada B3H 3J5
(902) 494-2358

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AUTHOR Mark Rudolph

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ABSTRACT

The Barrow Group deltaic sediments of the Exmouth Plateau were mapped with forty seismic lines and data from five wells. The mapping shows two deltaic sequences which are separated by a flooding surface. The source areas at the southern margin near Australia have been eroded but still show between 500 and 2 000 m of relief.

Uplift occurred in three areas. One area of uplift occurred close to the continent of Australia. This area was a junction of an extension zone, south of the Exmouth Plateau, and the Cape Range Fracture Zone. The uplift created an area of sediment supply. The second area of uplift occurred on the Cape Range Fracture Zone southwest of the plateau which resulted from motion on the transform fault. This motion created topographic highs for sediment sources and basin lows along the zone of transpression and transtension. Continuing transform fault motion caused the high areas to subside while basinal areas experienced uplift. The third area of uplift appeared at the diverging plateau margin. The origin of this source resulted from volcanic activity along the uplifted margin.

Seismic mapping of the Barrow Group generated isopach and structural contour maps of two sequences. The maps show sequence distribution and depositional surface topography. The lower sequence prograded as a 300 m high delta front to the northwest from both source areas simultaneously. Sediment coverage of the area is 120 km x 150 km. An isopach map of the younger delta shows it also prograded north from both source areas simultaneously on a 200 m high delta front to cover an area 180 km x 150 km.

Well data from five sites in the area show close correlation of the sequence boundaries on seismic profiles to dinoflagellate assemblage zones. These dinoflagellate assemblage zones indicate an age for the lower sequence of Berriasian and the upper sequence of Valanginian.

Key Words: Exmouth Plateau, Barrow Group, sequence stratigraphy, seismic stratigraphy, tectonic sedimentation, divergent margin, deltaic sedimentation, continental shelf, Australian petroleum, Carnarvon Basin

Acknowledgements

I would like to thank Dr. Ron Boyd for teaching me how to map seismic sequences and for his help in creating the final versions of the contour maps. I would also like to thank Tom Duffett for digitizing the database into excellent maps for the final draft. I would also like to thank Cathy Williams for her excellent job in plotting and contouring the isopach and structural contour maps. Finally I would like to thank Andrew Dudka for help in calculating isopach contour values.

CHAPTER 1: INTRODUCTION

1.1 Introduction

The supercontinent of Gondwanaland began to split apart in the Late Jurassic along an axis which extended from the Tethys Sea to Antarctica. Continued rifting in the Early Cretaceous produced oceanic crust. Some of the consequences of this crustal extension were the divergence of the continents of Australia and India, uplift at their margins, and a subsiding basin. The subsidence allowed deposition of 10 km of sediment in the subsiding basin. This concentration of sediment in one area and subsidence of the adjacent oceanic crust created a contrasting relief with the surrounding abyssal plain, thereby forming the Exmouth Plateau. The Exmouth Plateau is a marginal plateau adjacent to the northwest continental shelf of Australia (Fig. 1.1).

The Exmouth Plateau forms a topographic high in the Indian Ocean with water depths varying from 800 m to 2 000 m over 150 000 km2 (Fig. 1.2). Landward of the plateau is the submerged Kangaroo Syncline and the subaerial Precambrian Pilbara blocks. Seaward of the Plateau are the Argo, Gascoyne, and Cuvier abyssal plains (Fig 1.1). The abyssal plains average between 5 000 and 6 000 m below sea level.

1.2 Tectonic Evolution of the Barrow Group

During the Late Jurassic-Early Cretaceous rifting period, the Cape Range Fracture Zone, and Gascoyne and Cuvier Abyssal Plains formed (Fig. 1.1). The Cape Range Fracture Zone is a

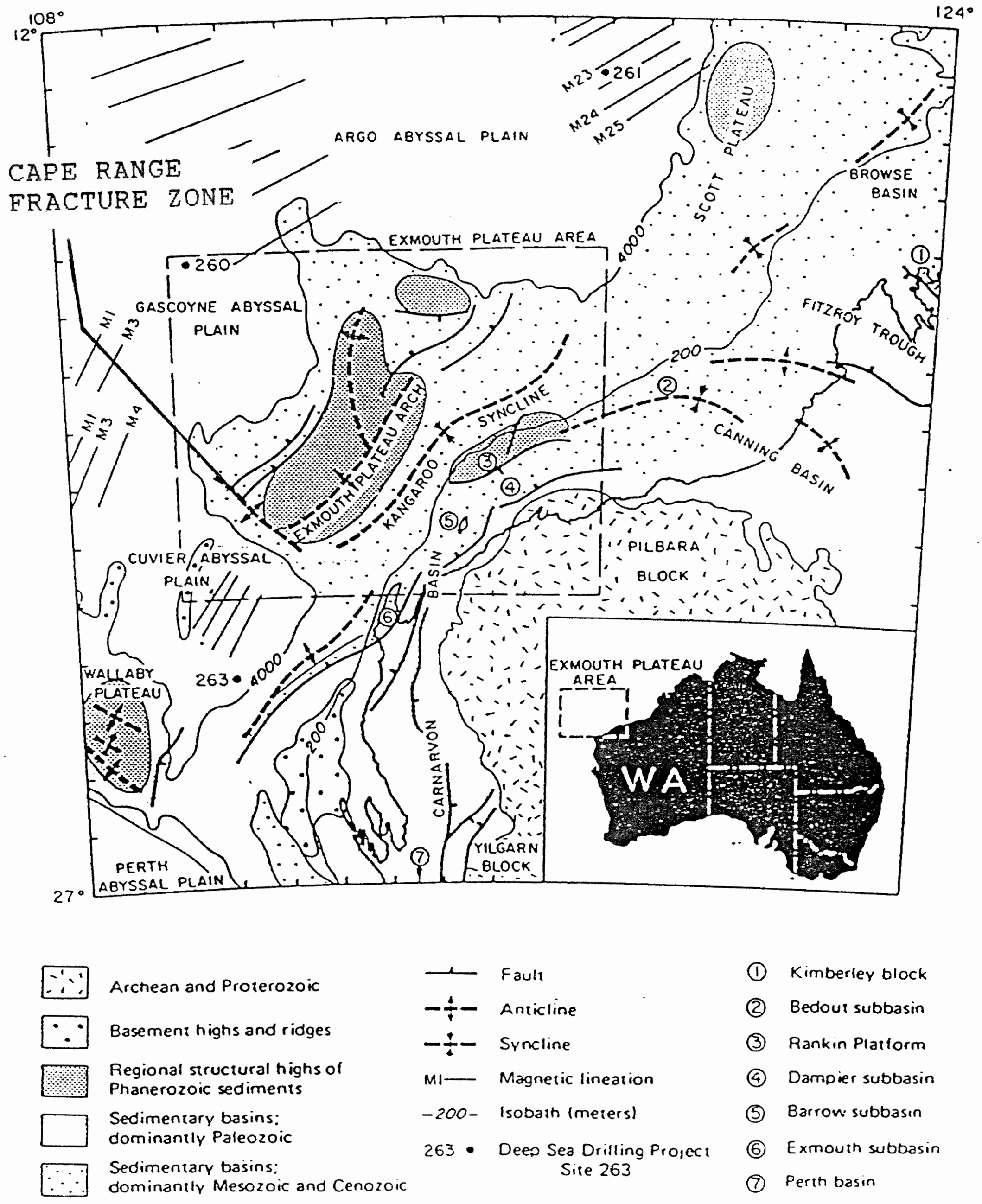

FIGURE.1.1-Regional setting of study area off northwestern Australia. Based in part on *Tectonic Map of Australia and New Guinea* (Geol. Soc. Australia 1971), Larson (1975, 1977), and Symonds and Cameron (1977).

(after Exon and Wilcox 1978)

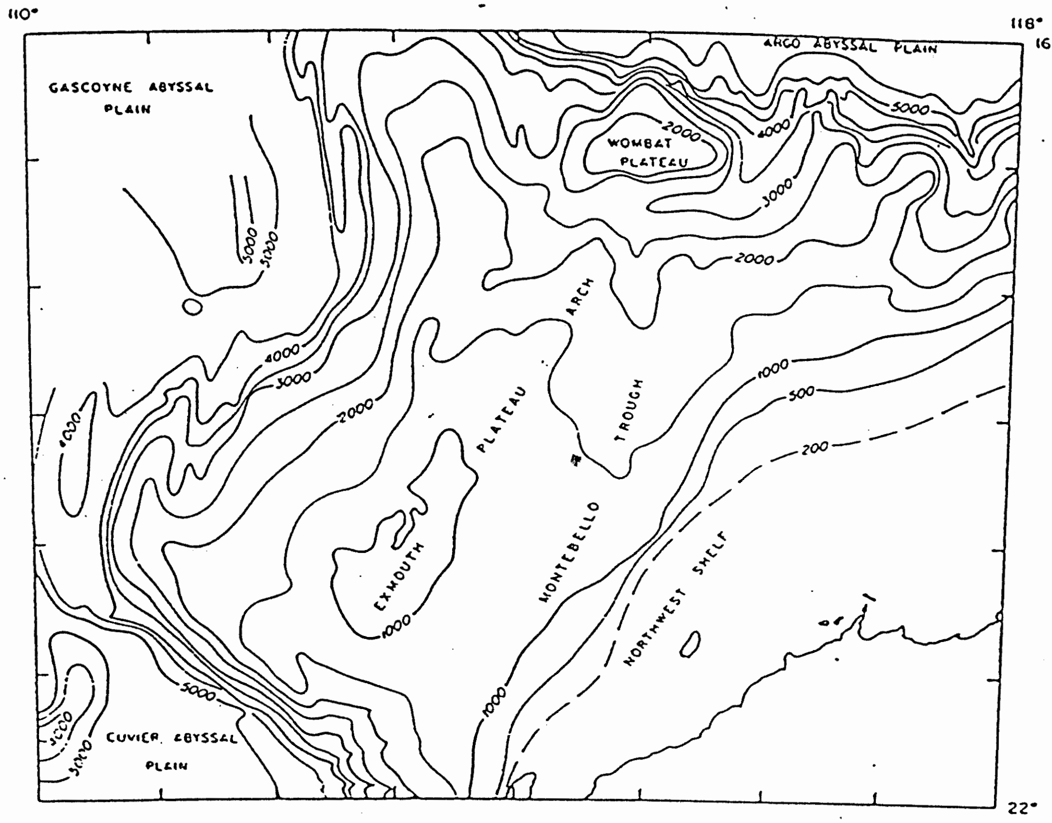

FIGURE 1.2-Bathymetry off northwestern Australia, including areas of Exmouth Plateau, and Argo, Gascoyne, and Cuvier Abyssal Plains of the Wharton Basin. Contours in meters.

(from Exon and Wilcox 1978)

transform fault area on the southern boundary of the Exmouth Plateau. During this period, a deltaic package of sediment known as the Barrow Group accumulated in the subsiding Carnarvon Basin. This phase of sedimentation ended in the Early Cretaceous. The last phases of sediment deposition which occurred prior to continental breakup are the top two deltaic sequences of the Barrow Group (Fig. 1.3). These units are of geologic interest because they formed during the continental rifting period of Gondwanaland and they contain major hydrocarbon reserves (Barber 1988). In addition, there is speculation that the Cape Range Fracture Zone played a role in sediment deposition of the upper Barrow Group. Chapter 2 describes the regional geology in detail.

1.3 Database

Sequence stratigraphy is the study of genetically related facies within a framework of chronostratigraphically significant surfaces (Van Wagoner et al. 1990). A sequence is a relatively conformable, genetically related succession of strata bounded by unconformities or correlative conformities (Mitchum 1977, cited in Van Wagoner et al. 1990). A seismic grid of the Exmouth Plateau shows the sequence stratigraphy (Posamentier et al. 1988) from relationships of seismic reflections and well data. The top two deltaic units in the Barrow Group are sequences and they can be defined on seismic lines. Their mapping enables construction of structural contour maps and isopach maps in two-way-travel time. Plotting sequence thicknesses shows their geographic distribution and may indicate sediment source areas and transport

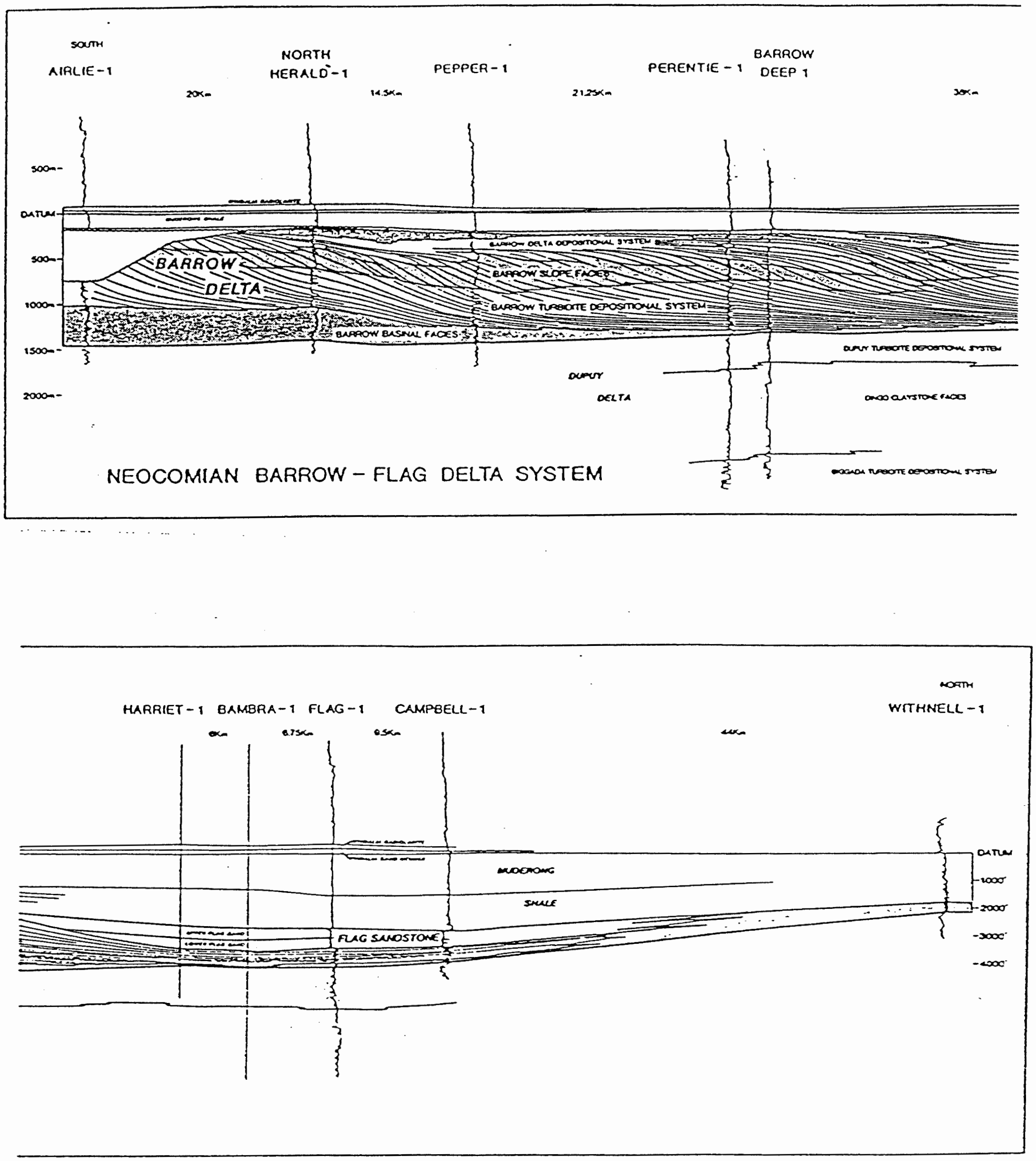

FIGURE 1.3-Generalized facies correlation, upper Neocomian (Barrow delta) depositional sequence, eastern Barrow rift basin (gamma-ray well log correlation).

(from Boote and Kirk, 1989)

pathways.

Data from five wells in the area show the lithostratigraphy and dinoflagellate assemblage zones of both sequences. From the well data, sequence boundaries identified from geophysical well logs and lithostratigraphy can be correlated with seismic sequence boundaries from seismic profiles. Dinoflagellate assemblage zones are groupings of a number of different dinoflagellate species. Boundaries between different zones on the Exmouth Plateau define times at which many species became extinct. The dinoflagellate assemblage zones show the relative time of depositional events of the two sequences. The assemblage zone boundaries are interpreted as time lines and, therefore, are useful tools to correlate time significant sequence boundaries. In addition, dinoflagellate assemblage zone correlations have been made with magnetic reversals by other workers and, therefore, they can show absolute time.

1.4 Purpose and Objectives

One purpose here is to reconstruct the paleogeography of the two upper sequences of the Barrow Group, and to interpret their depositional history. This work also investigates whether the progradation of the two deltaic units was the result of a local event or a eustatic sea level change. In addition, the nature of the source areas will be investigated.

Objectives of this work include using isopach maps of the upper two sequences of the Barrow Group to provide their geographic distribution and depositional paths. Structural mapping will show topographic highs and lows in the study area and reveal the nature of the source areas. An analysis of the sedimentary record before decoupling will show the relationship between sequence geometry and tectonic events.

1.5 Thesis Organization

Chapter 1 presents the background information. The second chapter explains the regional geology by showing the tectonic and stratigraphic evolution of the Exmouth Plateau. Chapter 3 explains the principles of seismic reflection and the methods used in defining the seismic sequence boundaries. Seismic-line mapping of the two seismic units, structure, and isopach contour maps appear in the fourth chapter. In addition, cross-sections of seismic profiles showing important features and relationships occur in Chapter 4. Well-log correlations in the fifth chapter provide a method for checking the proper depths of the sequence boundaries. The sixth chapter discusses the data and presents conclusions concerning the deposition of the upper Barrow Group. This includes the role of eustatic sea level, tectonic subsidence, and sediment supply.

1.6 Scope of Thesis

Vertical limits of this study are the upper and lower boundaries of the two youngest, uppermost seismic units of the Barrow Group. Horizontal limits are the farthest progradational limit of these units on the Exmouth Plateau. The events discussed have Early Cretaceous time limits. Data availability contributes to the boundaries of the work. Also, conclusions from seismic profiles and well-log information have minimum resolution limits. Geophysical well-logs can resolve lithologic boundaries to approximately +/- 5 m, and seismic profiles can resolve reflectors with no less than a 10 m separation.

CHAPTER 2: REGIONAL GEOLOGY

2.1 Introduction

The regional geology of the Exmouth Plateau consists of eight large-scale depositional events stacked upon a Permian-Triassic passive margin (Frazier 1974). The total accumulation of sediment is about 10 km. These depositional events resulted from major tectonic events such as crustal extension, tectonic rifting, continental uplift and basin subsidence.

2.2 Tectonic and Stratigraphic Evolution

In the Late Paleozoic, the northwest continental margin of Australia was part of the continental margin of Gondwanaland. At the end of the Paleozoic, fragments of Indo-Chinese continental blocks separated from this margin. These blocks moved north into the Tethys Sea (Boote and Kirk 1989). Consequently a newly created Permian-Triassic passive margin evolved (Fig. 2.1) with extensional listric faulting throughout (Boote and Kirk 1989). A cross-section through the Exmouth Plateau (Fig. 2.2) shows this faulted surface to be the base of the Exmouth Plateau (Fig. 2.3). Subsidence and progradation of fluvial muds and sands followed in the Triassic (Fig. 2.3).

Divergence continued into the Late Jurassic. Subsidence occurred along a margin starting at the Tethys Sea and continued to the south (Fig. 2.1) (Boote and Kirk 1989). Continuing extension in the Callovian-Berriasian period resulted in the decoupling of a continental block (Fig. 2.1). The block moved into the Tethys Sea in a northwest direction. This is shown by

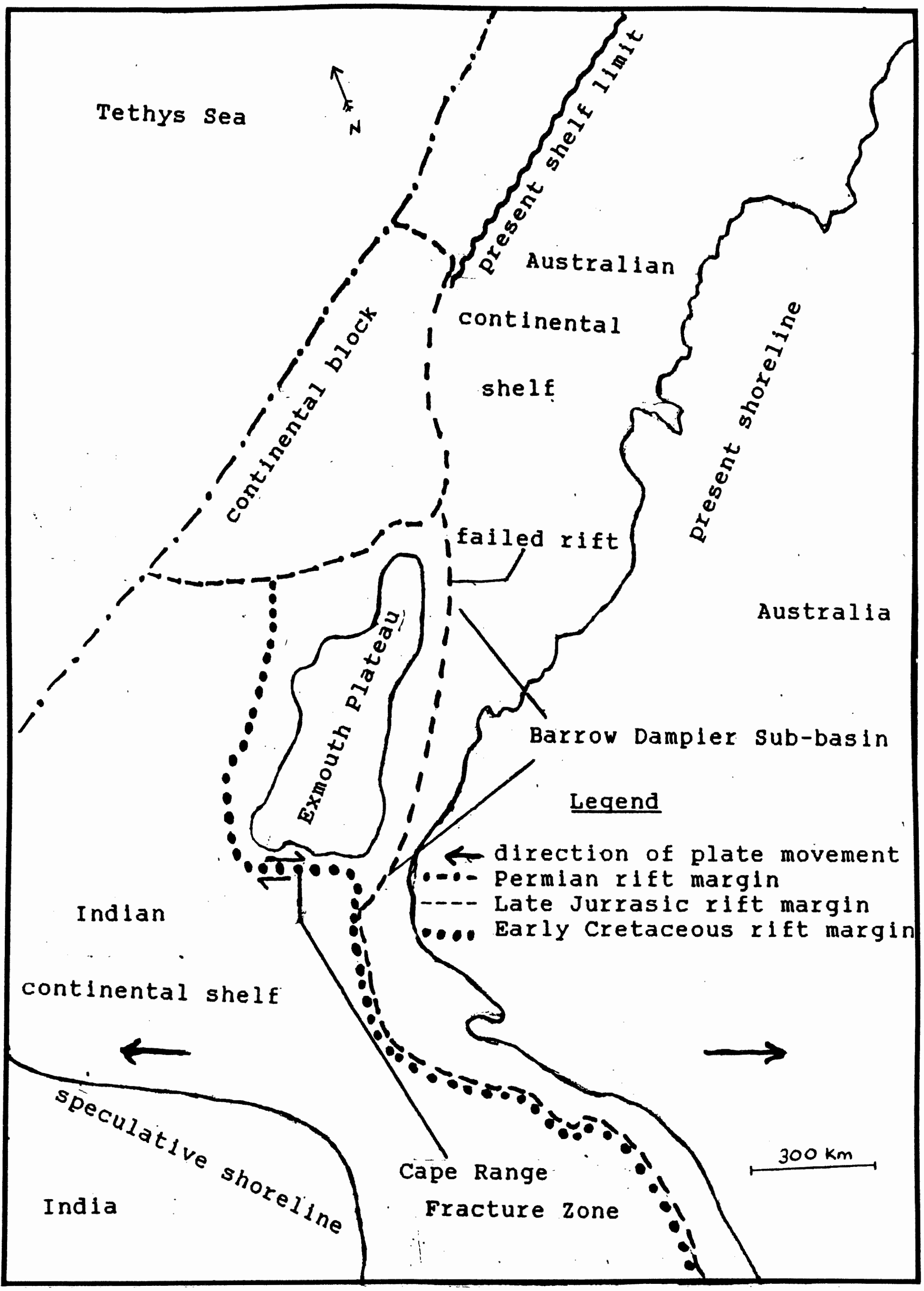

FIGURE 2.1-The tectonic evolution of the Exmouth Plateau. Gondwanaland reassembled in the Triassic.

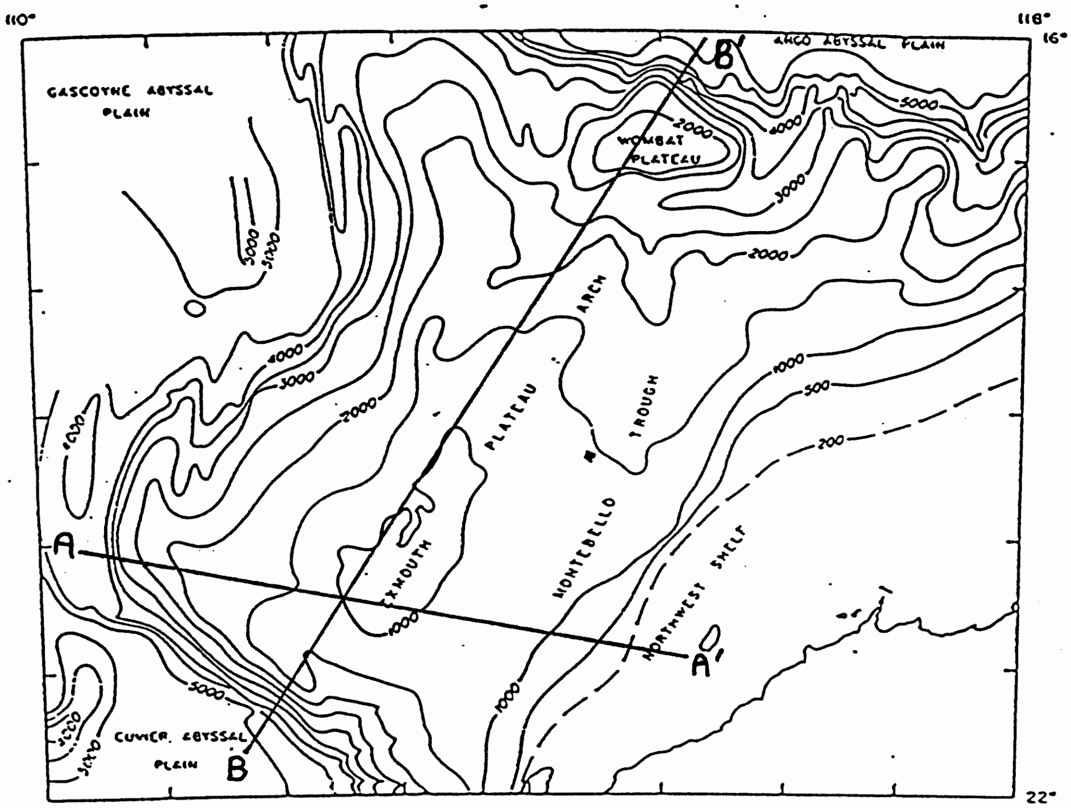

FIGURE 2.2-Cross-section location map of the regional geology of the Exmouth Plateau.

(after Exon and Wilcox 1978)

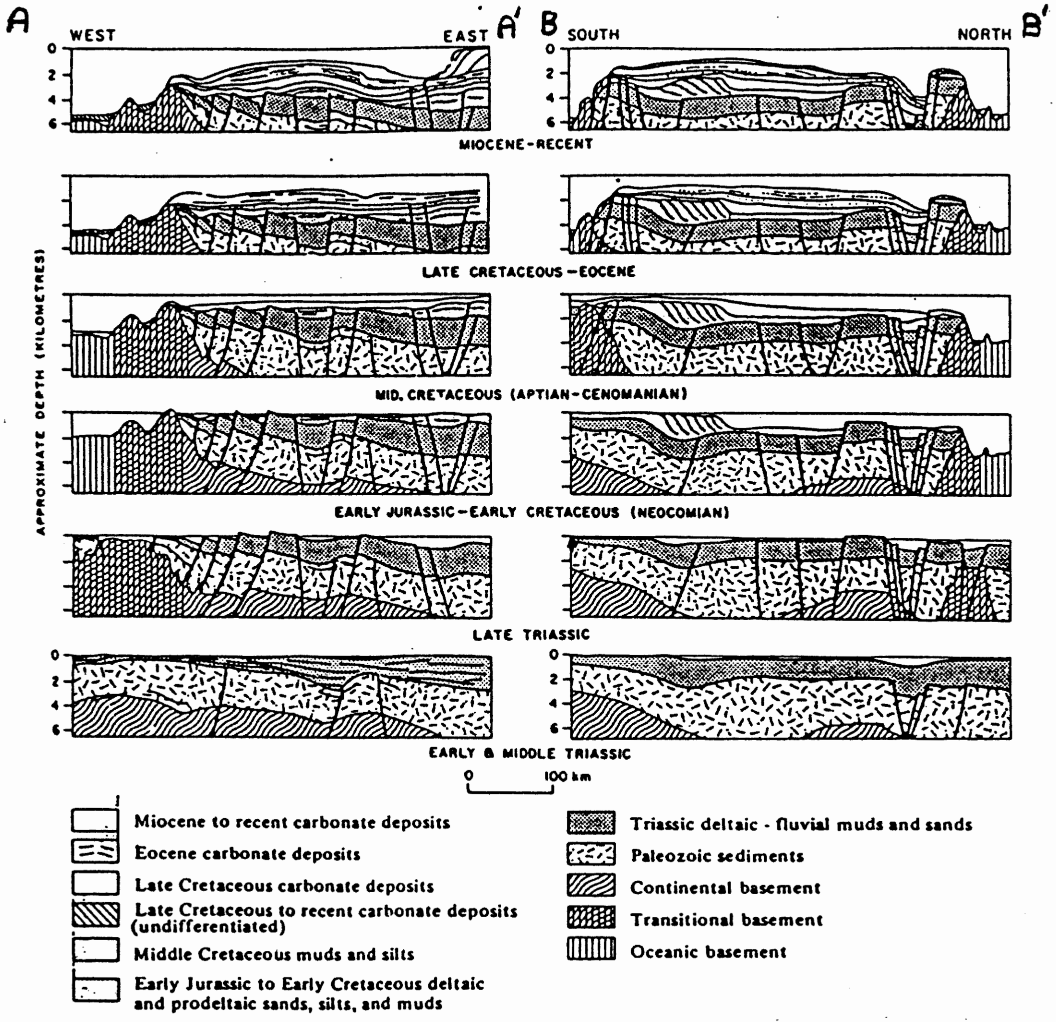

FIGURE 2.3-Schematic cross-sections showing structural evolution of Exmouth Plateau.

(from Exon and Wilcox 1978)

seafloor spreading ridge magnetic reversal patterns (von Rad et al. 1989) on the Argo Abyssal Plain. During the continental fragmentation, graben-forming processes continued along the rest of the axis to the south. With graben formation, thick Jurassic syn-rift sediments collected in the grabens of the Barrow-Dampier Sub-basin (Boyd et al. in press).

Early Cretaceous subsidence in the basin and uplift on its shoulders started the progradation of clastic sediments across the evolving Exmouth Plateau. These sediments were a deltaic unit now known as the Barrow Group (Fig. 2.3). The oldest strata in this group are Tithonian (136 Ma) and the youngest are Valanginian (124 Ma) (Boyd et al. in press).

In the Early Cretaceous, the northern end of the rift axis changed its position. It switched from the Barrow-Dampier Sub-basin to a location 400 km west creating the rifted western margin of the Exmouth Plateau (Fig. 2.1). The Cape Range Fracture Zone is a transform fault connecting the two rift margins. Eruption of basalt and creation of oceanic crust in the new rift zone occurred in the earliest Hauterivian (121 Ma) (Haq et al. 1987). This extensional event formed the Cuvier and Gascoyne Abyssal Plains. Basinal subsidence and cratonic erosion from the increased tectonic activity caused progradation of muds and silts in the Middle Cretaceous (Fig. 2.3)

A Late Cretaceous erosional event occurred after deposition of the muds and silts. After the erosional event, carbonate deposition occurred on the Exmouth Plateau. Between 500 and 1 000 m of carbonate accumulation since the Late Cretaceous now covers the Exmouth Plateau (Fig. 2.3) (Boyd et al. in press).

2.3 The Barrow Group

Early Cretaceous subsidence in the Carnarvon Basin and Barrow-Dampier Sub-basin allowed progradation of the Barrow Group. Continental uplift during rifting created the source areas for most of the sediment, however some sediment may have also come from uplift along the Cape Range Fracture Zone (Fig. 2.1). Judging from appearance of topset, foreset, and bottomset beds in seismic sections, the Tithonian to Valanginian age Barrow Group sediments are deltaic in nature (Hocking 1988; Kopsen and McGann 1985). A thick submarine fan, termed the Flag Sandstone, terminated deposition in the Barrow Group in the Barrow-Dampier Sub-basin and marked the separation of India and Australia (Boote and Kirk 1989).

CHAPTER 3. SEISMIC SEQUENCE ANALYSIS

3.1 Introduction

An effective method to image deeply buried strata is seismic reflection. Seismic reflection surveys use an energy source to create an acoustic disturbance which travels through the crust. When a disturbance reaches a contrast in seismic impedance, a percentage of the energy reflects and returns to the surface. These impedance contrasts result from changes of rock density and/or sonic wave velocity. Changes of lithology create changes of rock density and velocity. In addition, processes such as compaction, dewatering, erosion, and bioturbation cause density and velocity changes. These processes occur preferentially on a surface of deposition (stratal surfaces), or during a hiatus of deposition or from erosion (an unconformity).

Seismic reflection profiles consist of lines or reflections that represent time-significant unconformities or stratal surfaces (Vail et al. 1977). Terminations of these reflections occur at depositional sequence boundaries. A depositional sequence is a relatively conformable, genetically related succession of strata bounded by unconformities and their correlative conformities (Vail et al. 1977). Sequences form by three major processes: aggradation (vertical filling from suspension), progradation (basin filling from the margin), and lateral accretion (lateral buildup of sediment). Depositional sequences which appear on seismic profiles are termed seismic sequences. This chapter deals with identifying seismic sequence boundaries or unconformities by locating reflector terminations.

3.2 Unconformities

Structural relations between underlying and overlying rocks classify unconformities as follows:

(i) Angular unconformities are surfaces in which the older strata below dip at a different angle than the younger strata above. Usually a deformation event folds the older rocks and erosion truncates them before deposition of younger beds on top.

(ii) Non-conformities consist of younger strata resting upon older metamorphic and granitic rocks.

(iii) Disconformities are unconformities in which the beds above and below are parallel, but there is a break in time of the rock record.

3.3 Terminations

The termination of one reflector against another indicates a sequence boundary. Terminations can be erosional or lapout. Lapout terminations may be either downlap, toplap, or onlap. Concordance shows the absence of lapout terminations.

Two types of terminations may occur against an upper sequence boundary. Erosional truncation implies the deposition of strata and their later tilting and removal along an unconformity surface (Fig. 3.1a(1)). Toplap consists of strata terminating against an overlying surface as a result of non-deposition (Fig. 3.1a(2)). Concordance of strata with an upper sequence boundary may also occur (Fig. 3.1a(3)).

Two types of terminations may occur against a lower

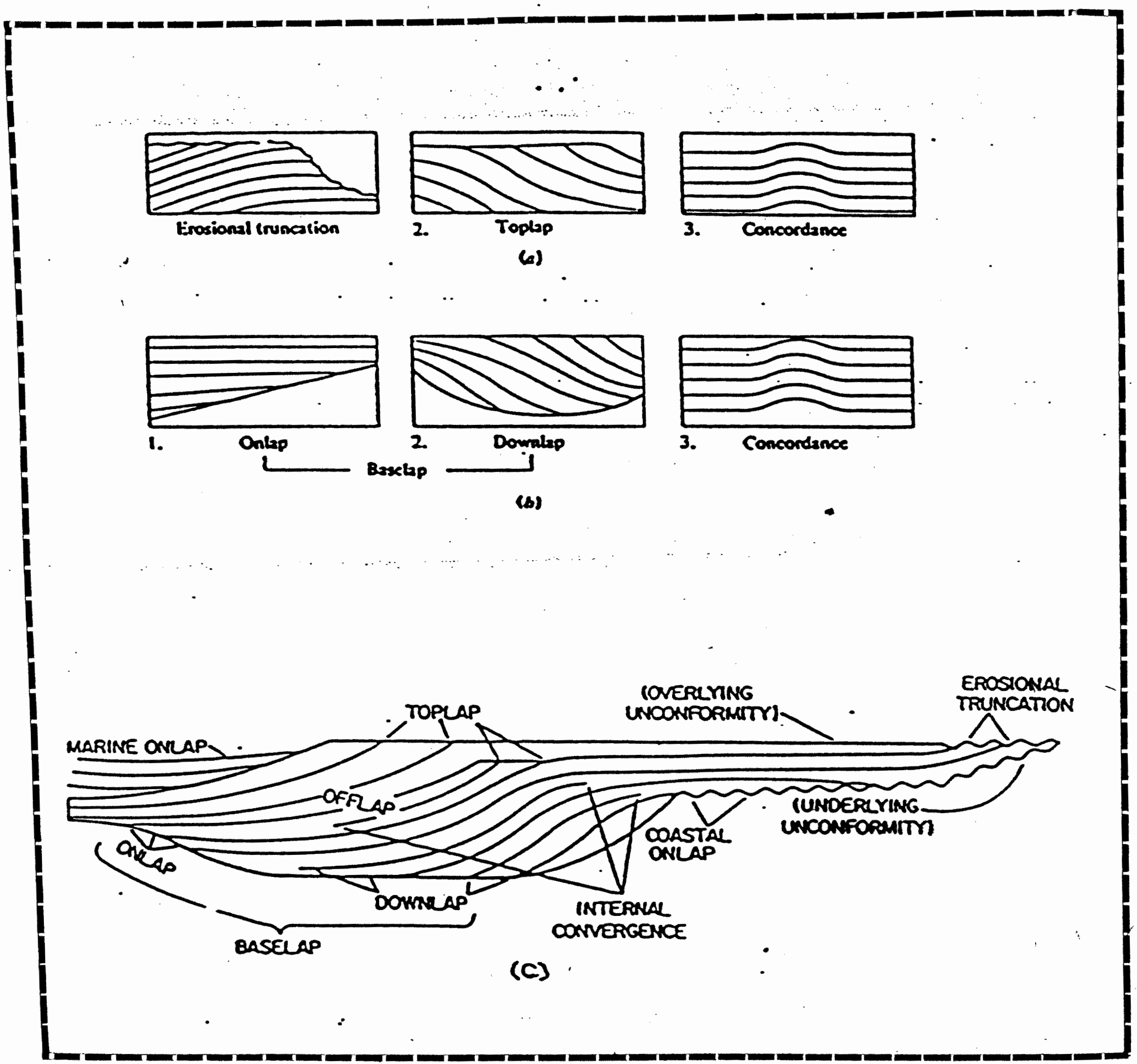

FIGURE 3.1-Reflections at boundaries of seismic sequences. a) Relations at top of sequence unit, b) at base of unit, and c) relations within an idealized unit.

(from Mitchum et al. 1977)

sequence boundary. An onlap termination occurs at the point where horizontal or inclined strata terminate against a surface with a greater inclination (Fig. 3.1b(1)). Downlap terminations occur at points where inclined strata terminate down dip against a surface of lesser inclination (Fig. 3.1b(2)). The concordance of strata with a lower sequence boundary also occurs (Fig. 3.1b(3)).

An idealized sequence with reflector terminations and bounding unconformities appears in Figure 3.1c.

3.4 Seismic Mapping on the Exmouth Plateau

Figure 3.2 shows the boundaries of the top two seismic sequences of the Barrow Group on a typical seismic line (X78A-33) from the study area. Mapping of these reflectors on a seismic line shows their two-dimensional distribution. Surfaces of lapout and erosional truncation show the bounding unconformities for both sequences. Mapping both units on a number of seismic lines creates a seismic grid which shows their geographic distribution. Grid mapping of boundary depths creates a database for structure and isopach contouring. The seismic line grid used for this work appears in Chapter 4.

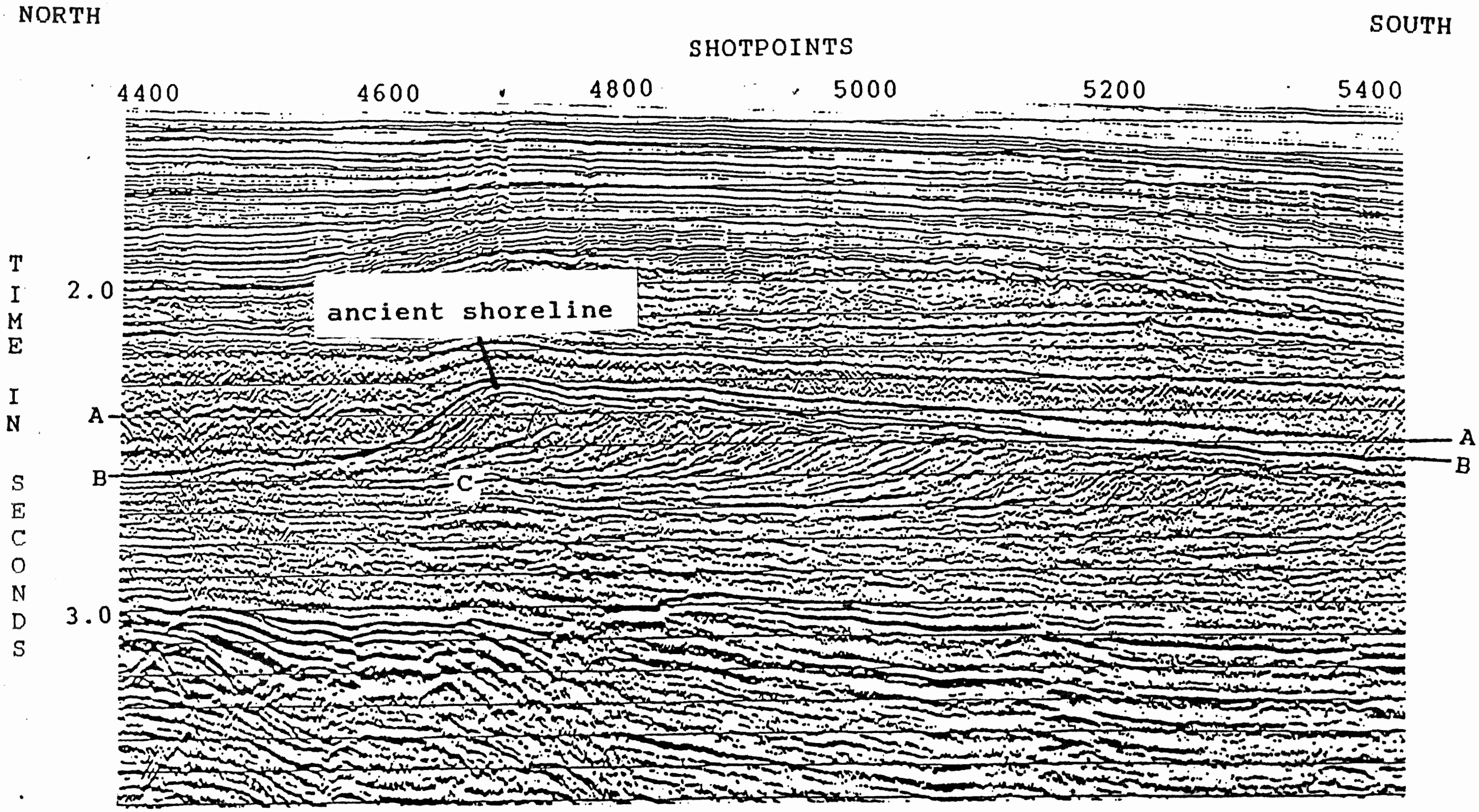

FIGURE 3.2-Line X78A-33. A north-south seismic profile which shows the northward dipping sequences of the Exmouth Plateau. The upper sequence appears between reflectors A and B and the lower sequence appears between reflectors B and C. The ancient shorelines for both sequences also appear in the profile.

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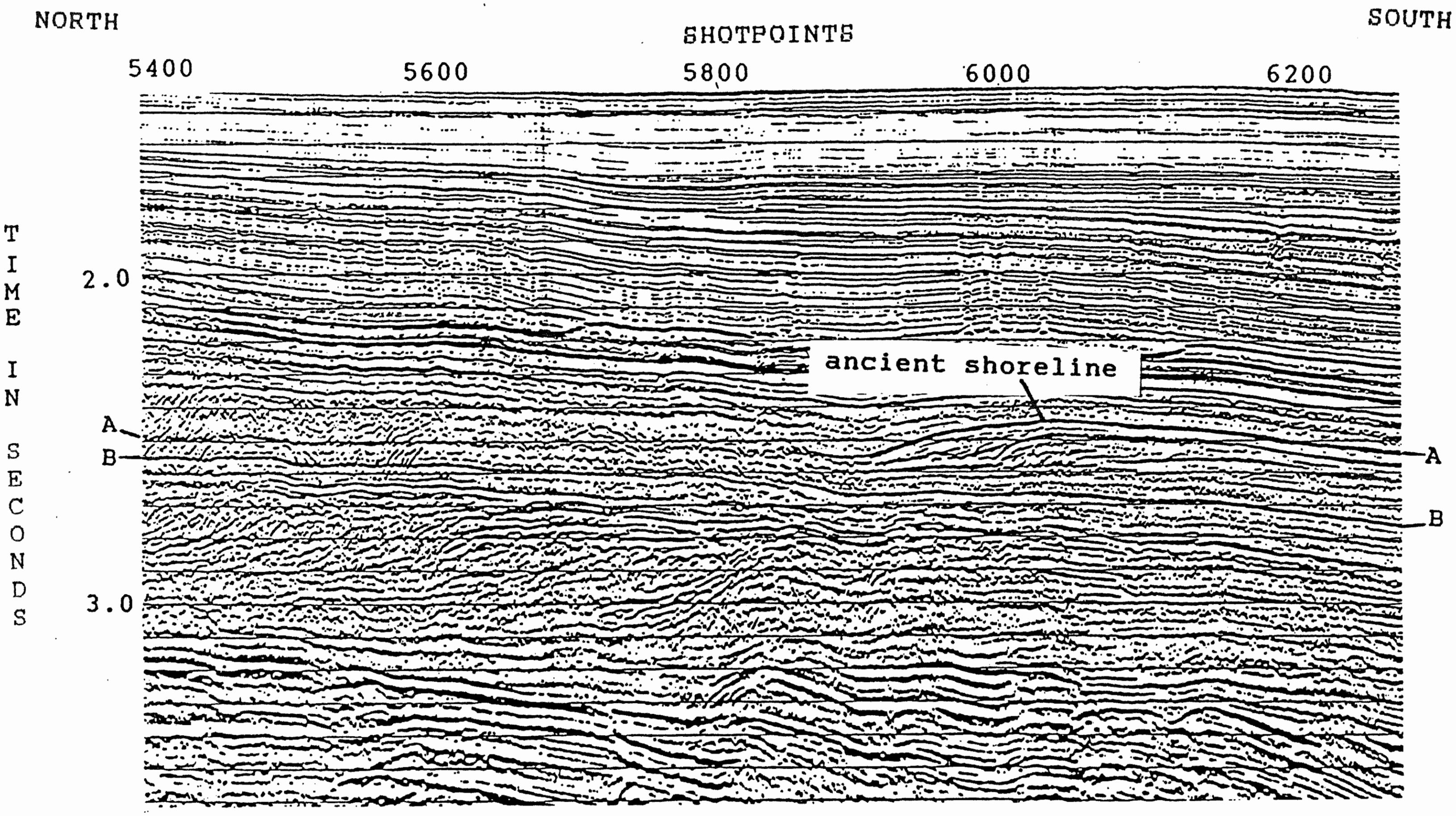

Figure 3.2 continued from previous page

CHAPTER 4: SEISMIC ANALYSIS RESULTS

4.1 Introduction

This chapter presents the results of seismic analyses in the form of structure and isopach contour maps developed from a grid of seismic lines covering the Exmouth Plateau (Fig. 4.1). Seismic lines show seismic cross-sections of the Exmouth Plateau. These cross-sections show various geologic features such as: erosional truncation, ancient shorelines, seismic reflection terminations (toplap, downlap, and onlap). These terminations on seismic profiles occur at sequence boundaries.

Data from seismic cross-sections enables isopach and structural contour map construction. Production of these maps involves measuring the depths in two-way time to the upper, middle, and lower sequence boundaries at each shotpoint. The middle boundary separates the upper from the lower sequence. The structure contour map shows the depth in two-way-time to a sequence boundary. A structure contour map of the middle surface shows the topography present prior to deposition of the upper unit. This topography also represents the surface on which the upper unit accumulated. An isopach map shows the difference in two-way travel time between two sequence boundaries. Isopach maps of the lower and upper sequences show their distribution and thicknesses, and can be used to infer depositional processes.

4.2 Seismic Cross-Sections

The following seven seismic cross-sections show the important features and relationships of the two sequences. Figure

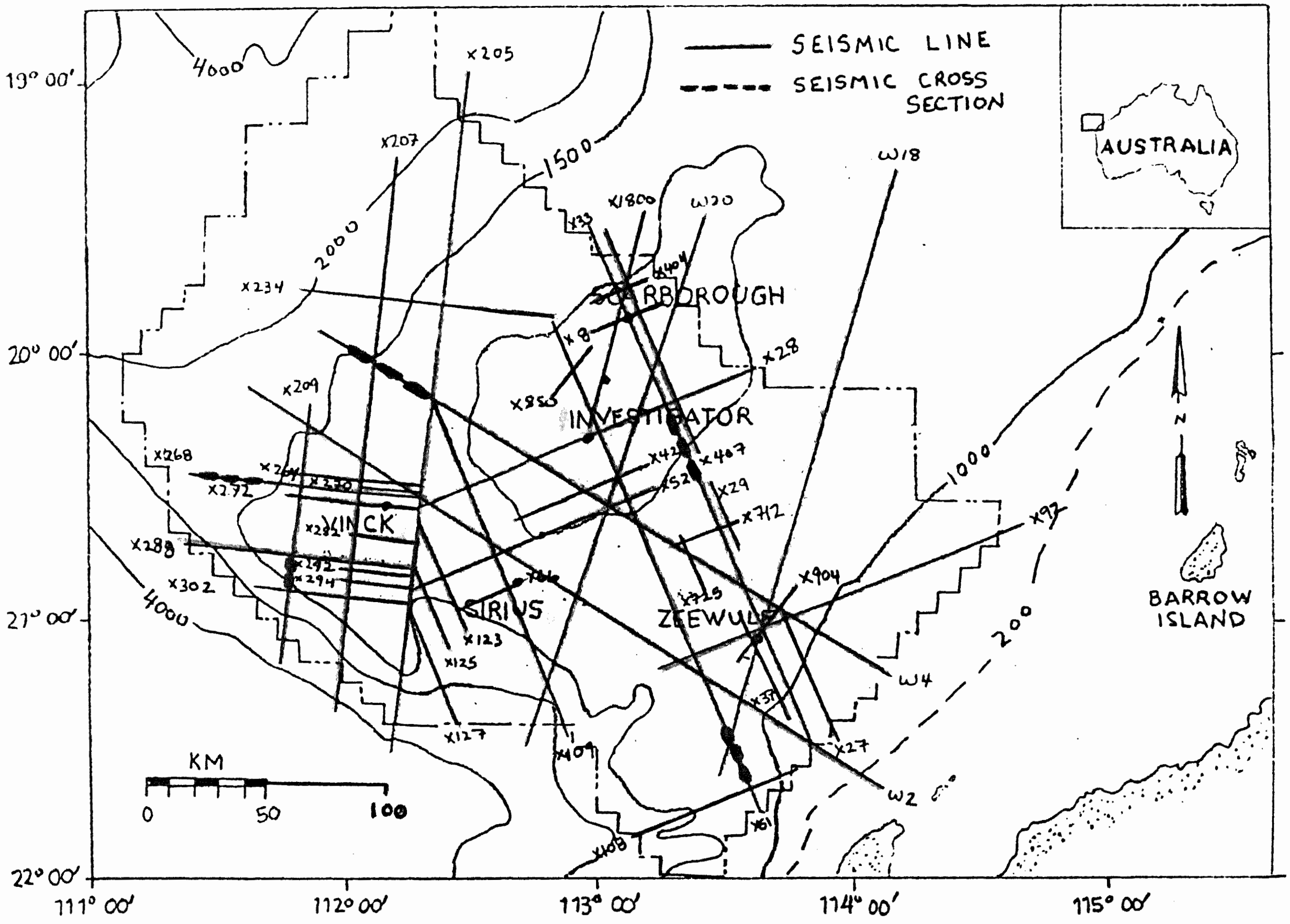

FIGURE 4.1-Seismic line and cross-section location map.

4.2 shows the erosional truncation of the upper sequence on a topographic high in the southeastern part of the study area. The internal reflections of the upper sequence show coastal onlap and erosional truncation of the upper strata, and the strata below the upper sequence also show erosional truncation.

Figure 4.3 shows the erosional truncation of both the upper and lower sequence between shotpoints 3100 and 2940. This occurs on a topographic high in the southwestern part of the study area. The internal reflections of both sequences show erosional truncation against the same reflector. Diffractions in the record at shotpoint 3050 result from reflector terminations against the vertical fault surface.

In the western part of the area, line X78A-268 shows the lower sequence downlapping at the base of a topographic high of volcanic origin (Fig. 4.4). The upper sequence appears to downlap on the top of the high and on the lower sequence. The upper sequence shows toplap rather than erosional truncation. Diffractions in the record result from reflector terminations such as downlap and faulting.

Figure 4.5 shows the lower sequence shelf break. The point of maximum curvature represents the position of the ancient shoreline for this prograding delta. Within the lower sequence, the internal reflectors show downlap and toplap, and the whole unit disappears by shotpoint 5400 where the lower boundary terminates in a toplap relationship. The upper sequence shows onlap and downlap onto the lower sequence shelf, and it thins to the south.

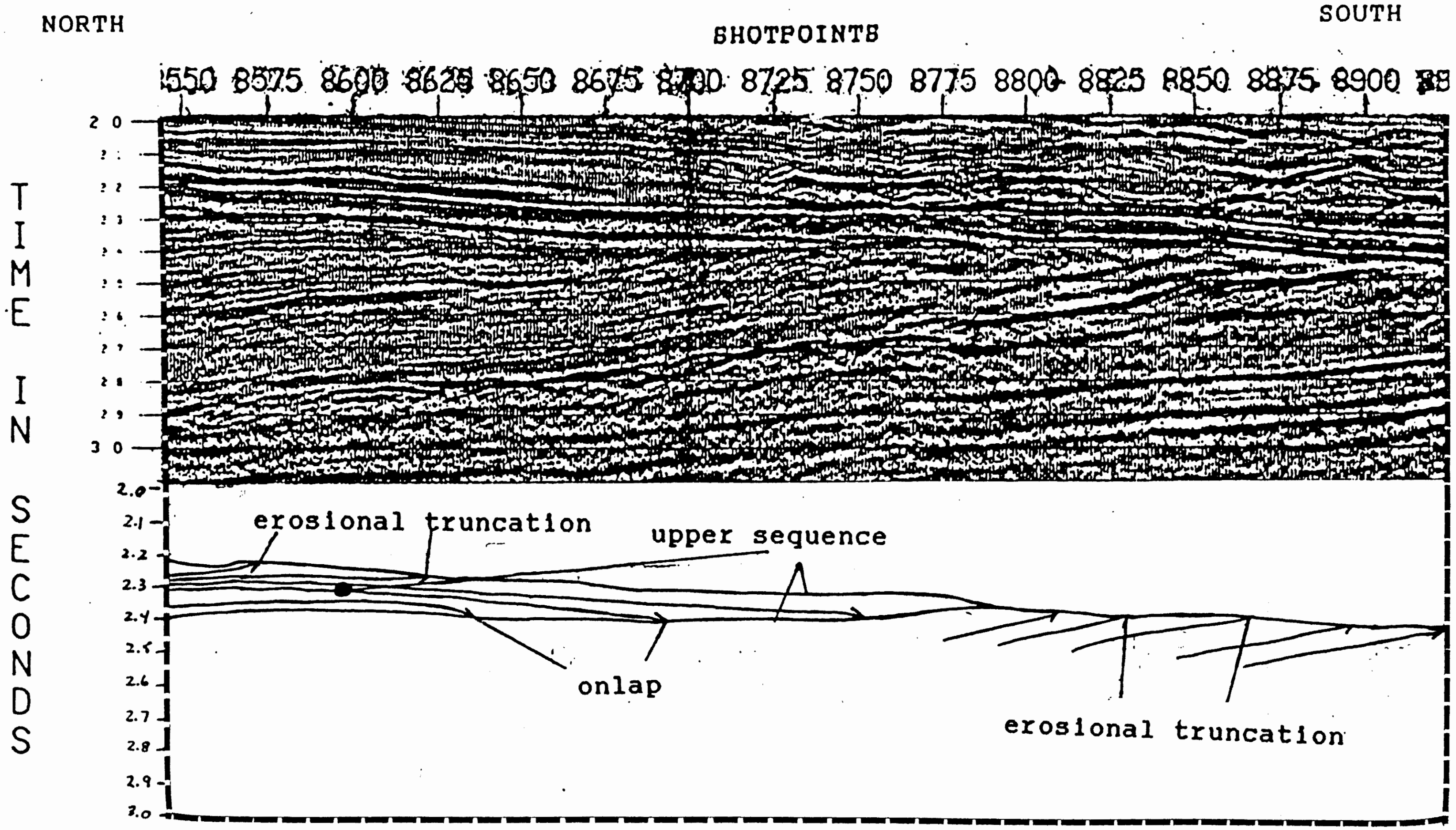

FIGURE 4.2-Line X78A-51. Erosional truncation of the upper sequence in the south eastern part of the study area.

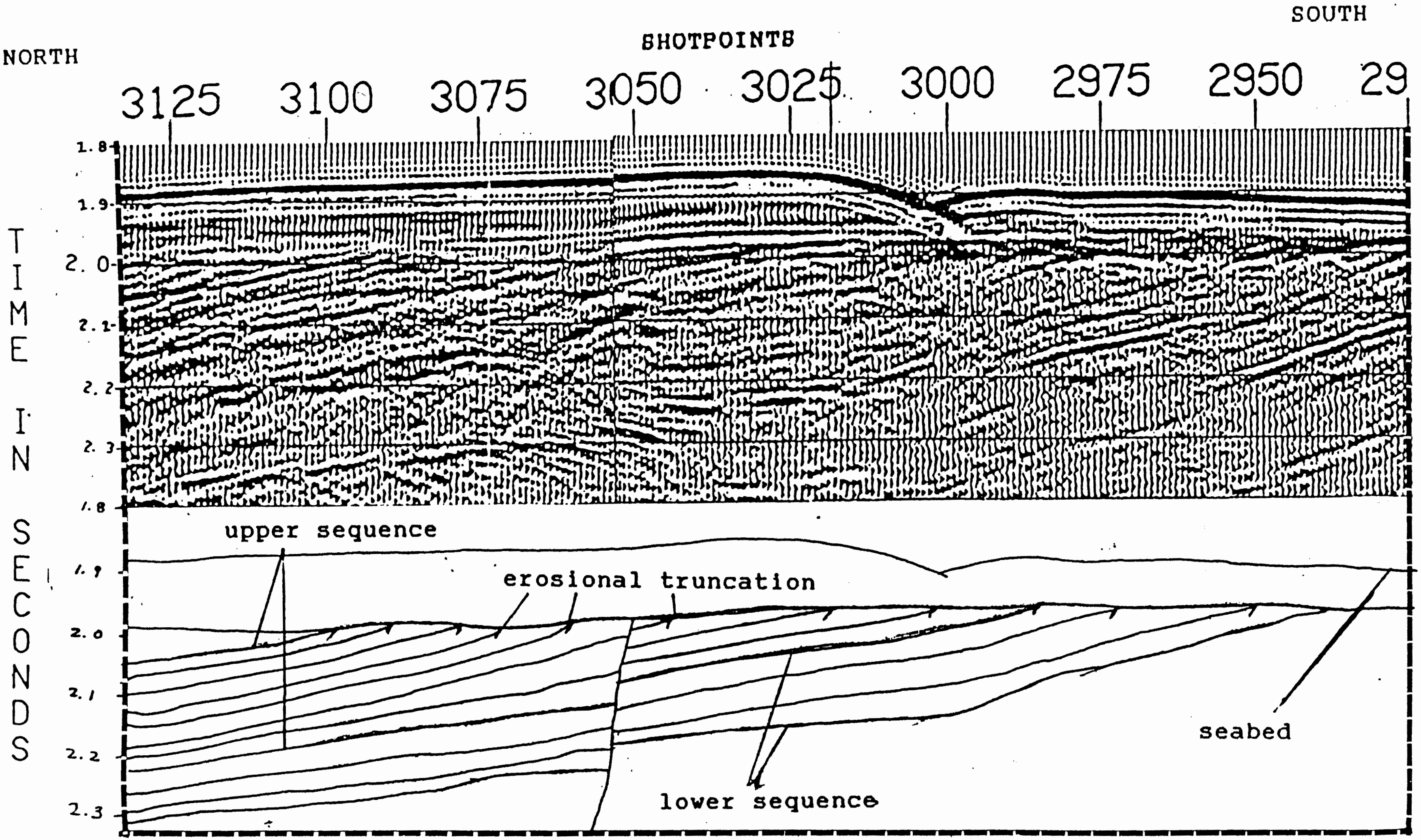

FIGURE 4.3-Line X78A-209. Erosional truncation of the upper and lower sequence in the southwestern part of the study area.

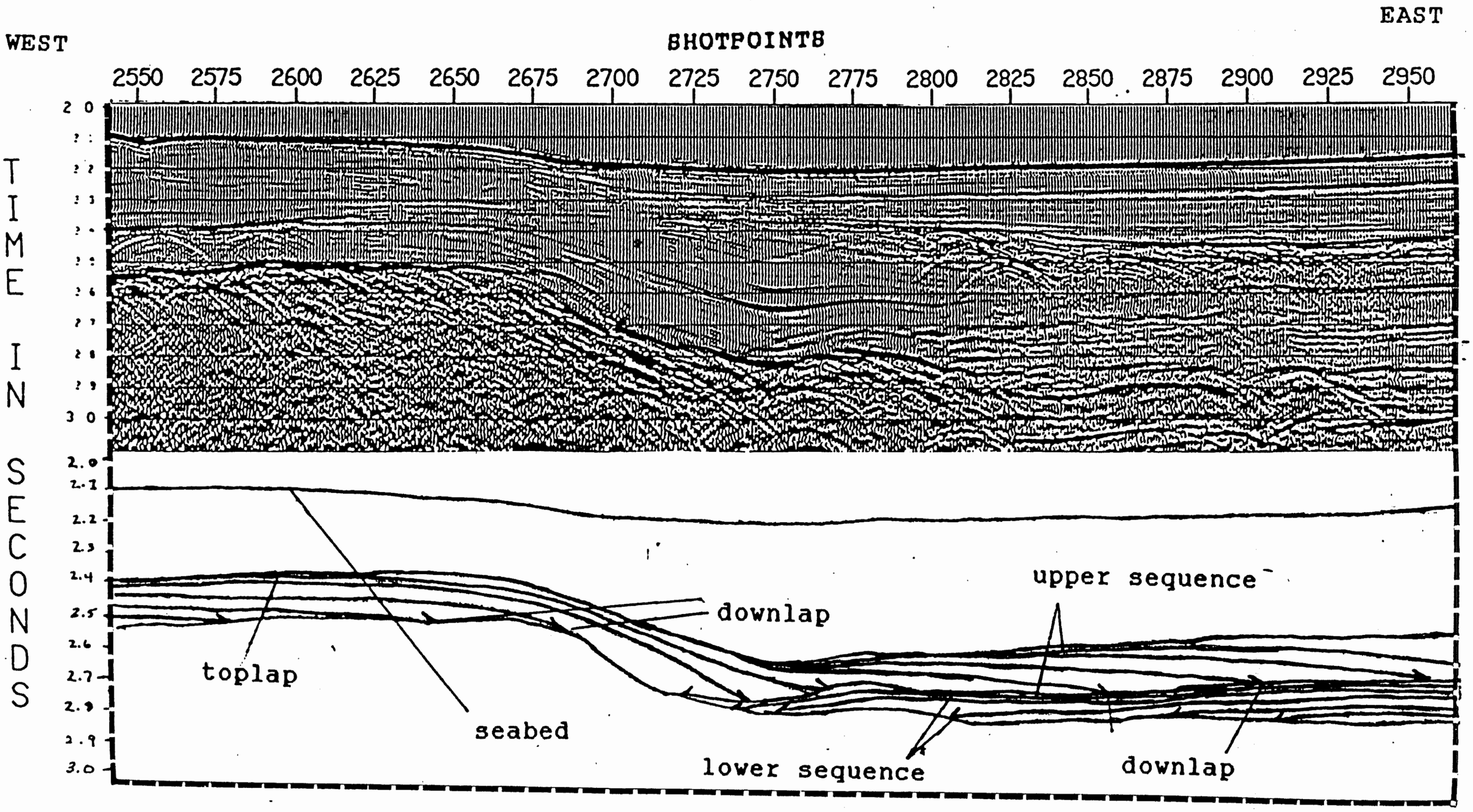

FIGURE 4.4-Line X78A-268. Westernmost sediment source of the upper sequence.

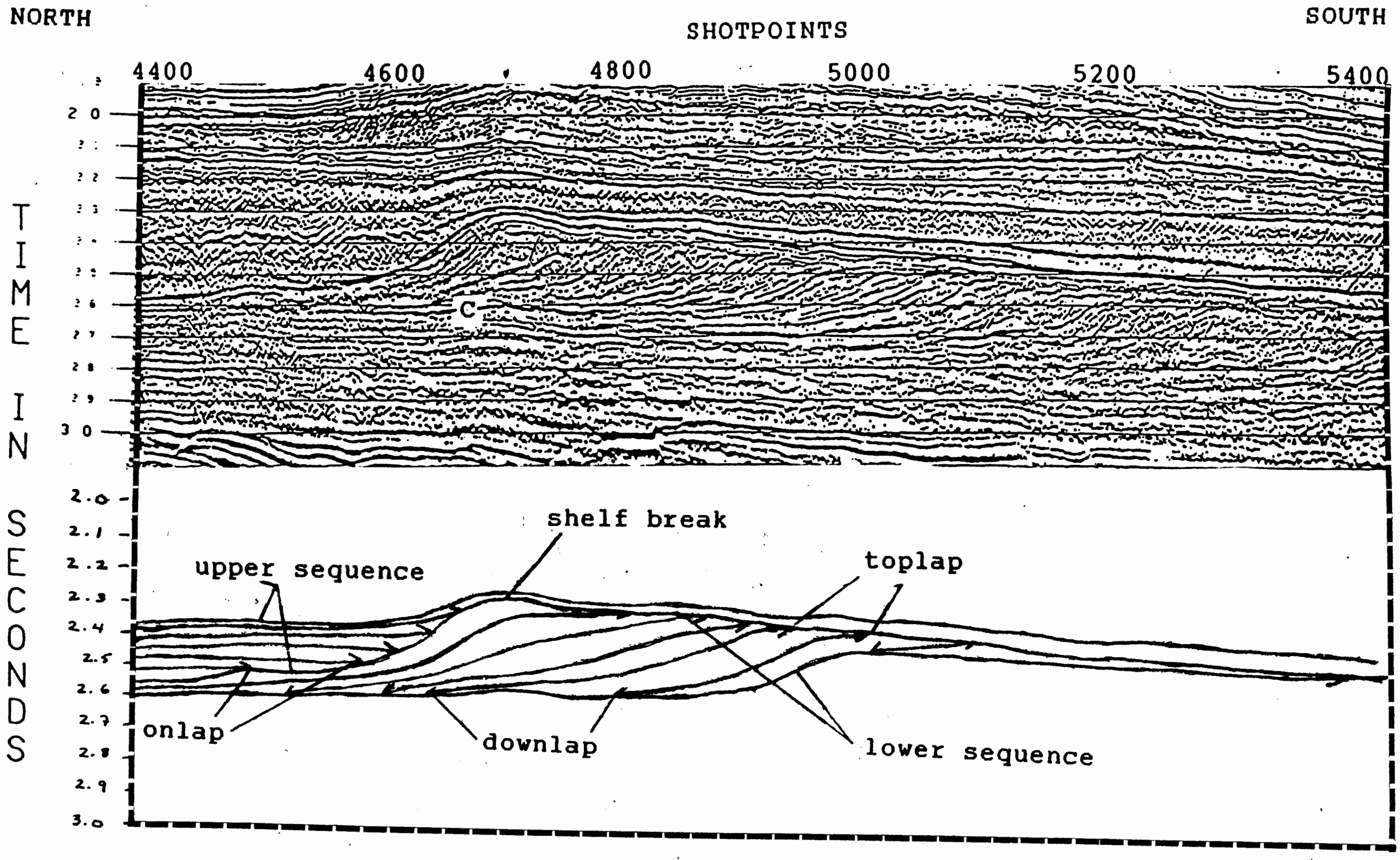

FIGURE 4.5-Line X78A-33. Lower sequence shelf break.

Figure 4.6 is a continuation of Figure 4.5. This section shows the upper sequence thickening again, and the appearance of a shelf break within this unit. The point of maximum curvature shows the ancient shoreline for this prograding delta. The internal reflectors show downlap onto the lower sequence boundary and concordance with the upper boundary.

Both sequences pinch out at distances of over 100 km north of the southern topographic highs. Figure 4.7 shows the lower sequence downlapping and pinching out on the Triassic fault blocks. Similarly, Figure 4.8 shows the upper sequence downlapping and pinching out on the lower sequence.

4.3 Isopach Map of the Lower Sequence

Figure 4.9 is an isopach map of the lower sequence showing the thickness of the sequence in two-way travel time in seconds. The eastern and central areas of the map have a broad arc of contours which shows a thick sediment accumulation. This arc represents the advancing depositional front of the lower sequence. The dark line along the zone of maximum sediment thickness is the shoreline of maximum progradation (shelf break). In the southern part of the study area is a circular zone of sediment accumulation. In the western part of the study area, and on the north side of the eroded zone, is a third accumulation of sediment. This sediment lies along the eroded zone. The northernmost contour shows the maximum depositional limit of the lower sequence. The isopach map indicates that the lower sequence begins 20-30 km south of the shoreline of maximum progradation.

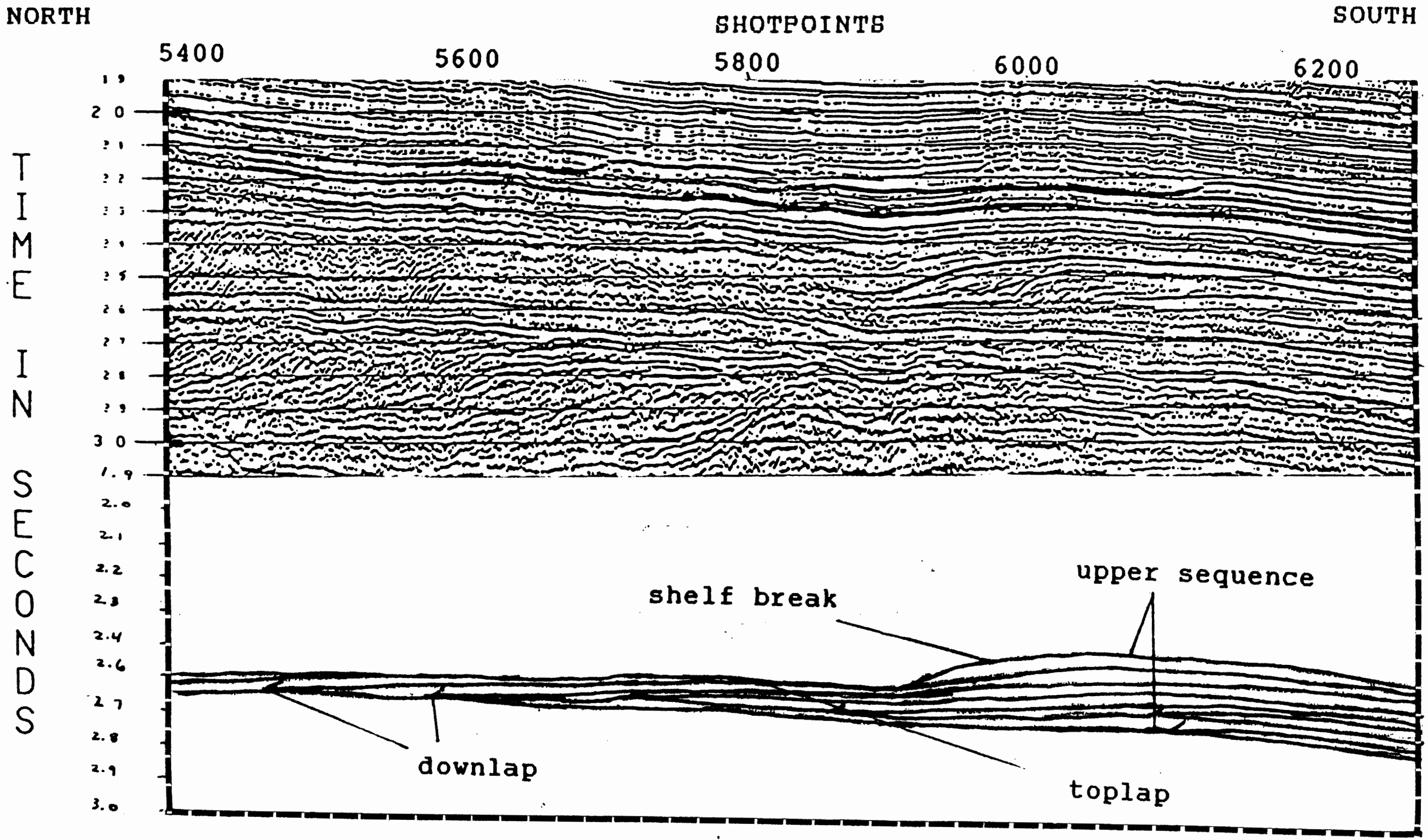

FIGURE 4.6-Line X78A-33. Upper sequence shelf break.

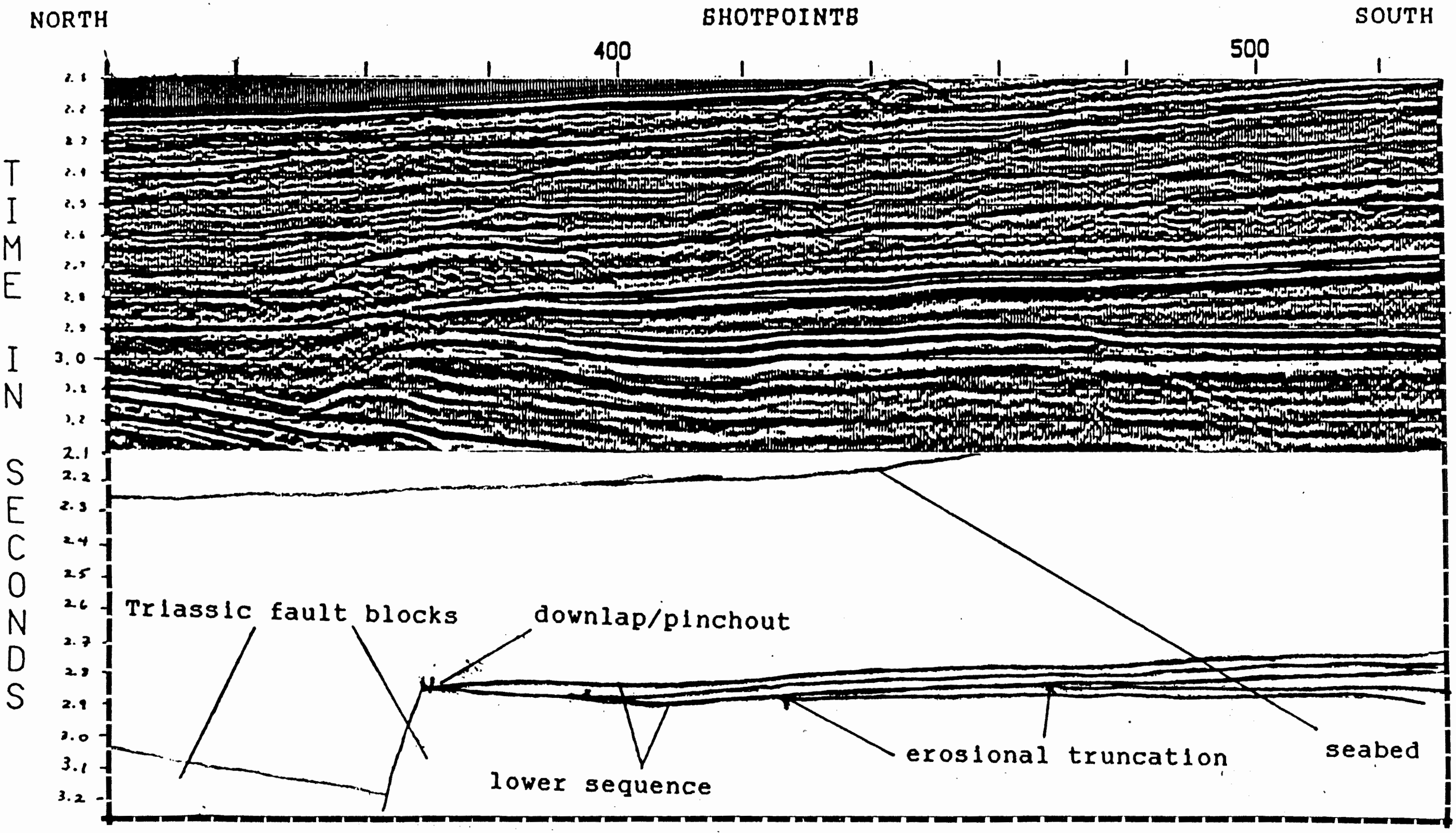

FIGURE 4.7-Line WAS-4. Downlap and pinch out of the lower sequence on the Triassic fault blocks.

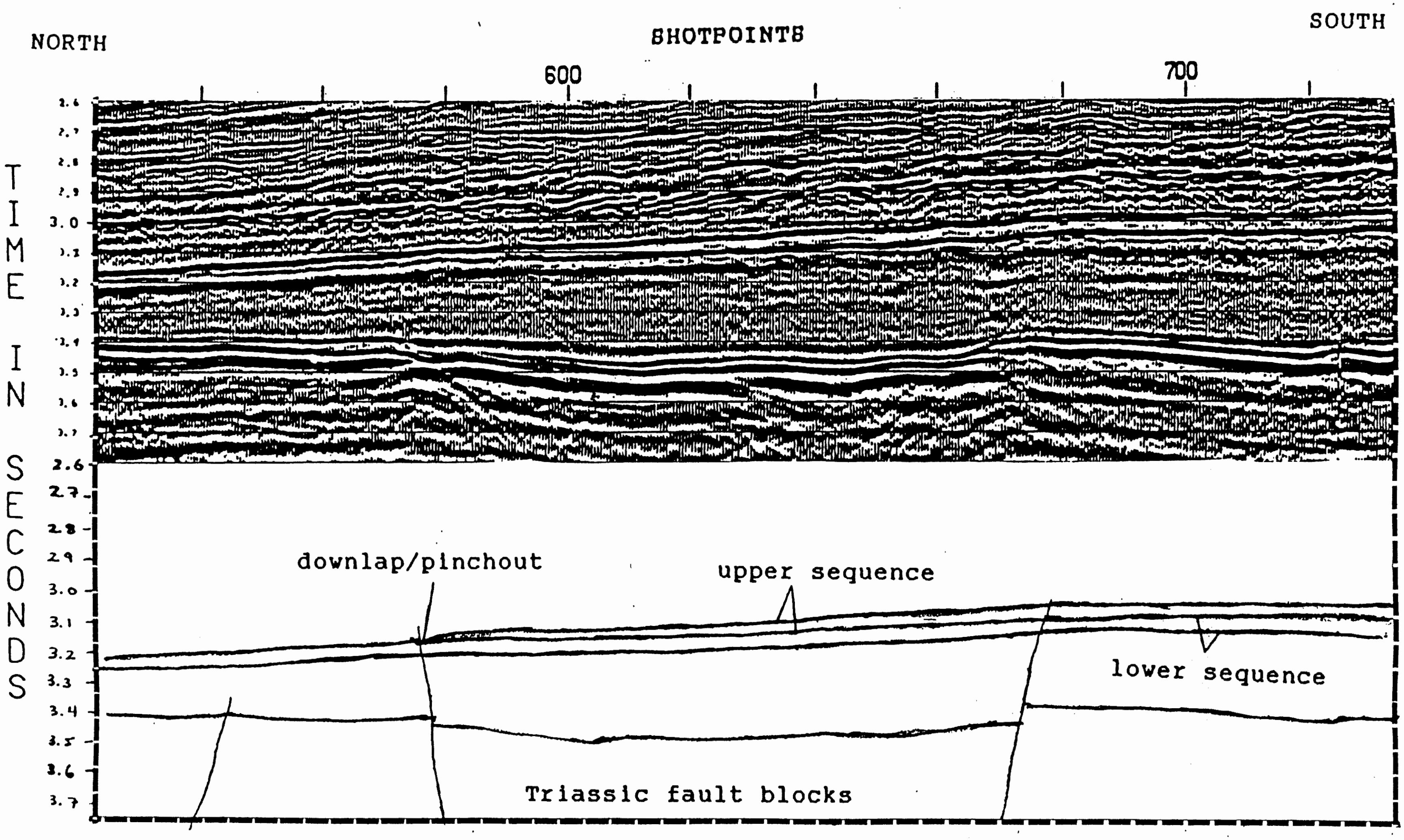

FIGURE 4.8-Line WAS-4. Downlap and pinch out of the upper sequence on the lower sequence.

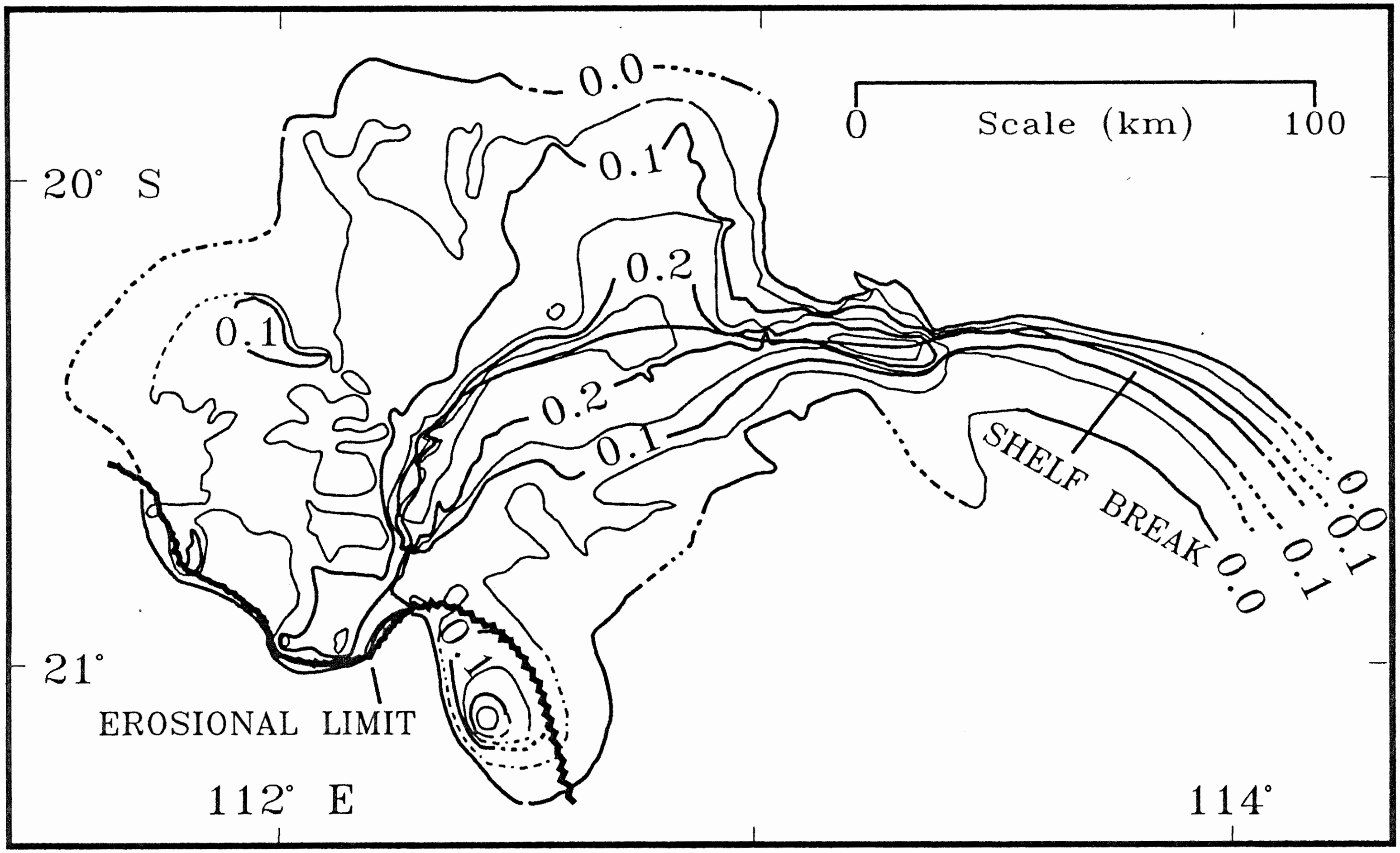

FIGURE 4.9-Isopach map of the lower sequence. Contours in seconds. Also shown is the shelf break and erosion limit.

Deposition thinned beyond this shoreline and terminated 40-50 km further north.

4.4 Structure Contour Map of the Middle Reflector

The middle reflector represents a temporal hiatus between the end of deposition of the lower sequence and the beginning of deposition of the upper sequence. A structure contour map of this surface (Fig. 4.10) shows post-depositional topography modified by tectonic processes. The tectonic processes include uplift and erosion.

The contour values in the central area of Figure 4.10 show two major structures. The northeast-southwest trending structure is a low amplitude anticline known as the Exmouth Plateau Arch, a post-depositional feature that acts as a structural hydrocarbon trap. The second major feature in the center of the diagram appears as an east-west trending dark line; it is the transgressed ancient shoreline of the lower sequence labelled shelf break.

The contour values in the southeast corner of the study area show a topographic high (Fig. 4.10). The dark northeast-southwest trending line on the high area shows the northwesternmost limit of erosion on this feature.

Contour values in the southwestern part of the study area show two topographic highs and two lows (Fig. 4.10). Between the two highs there is one topographic low where two-way travel times of more than 2.50 sec occur. Just to the east of the southernmost high there is a deep topographic low where two-way travel times

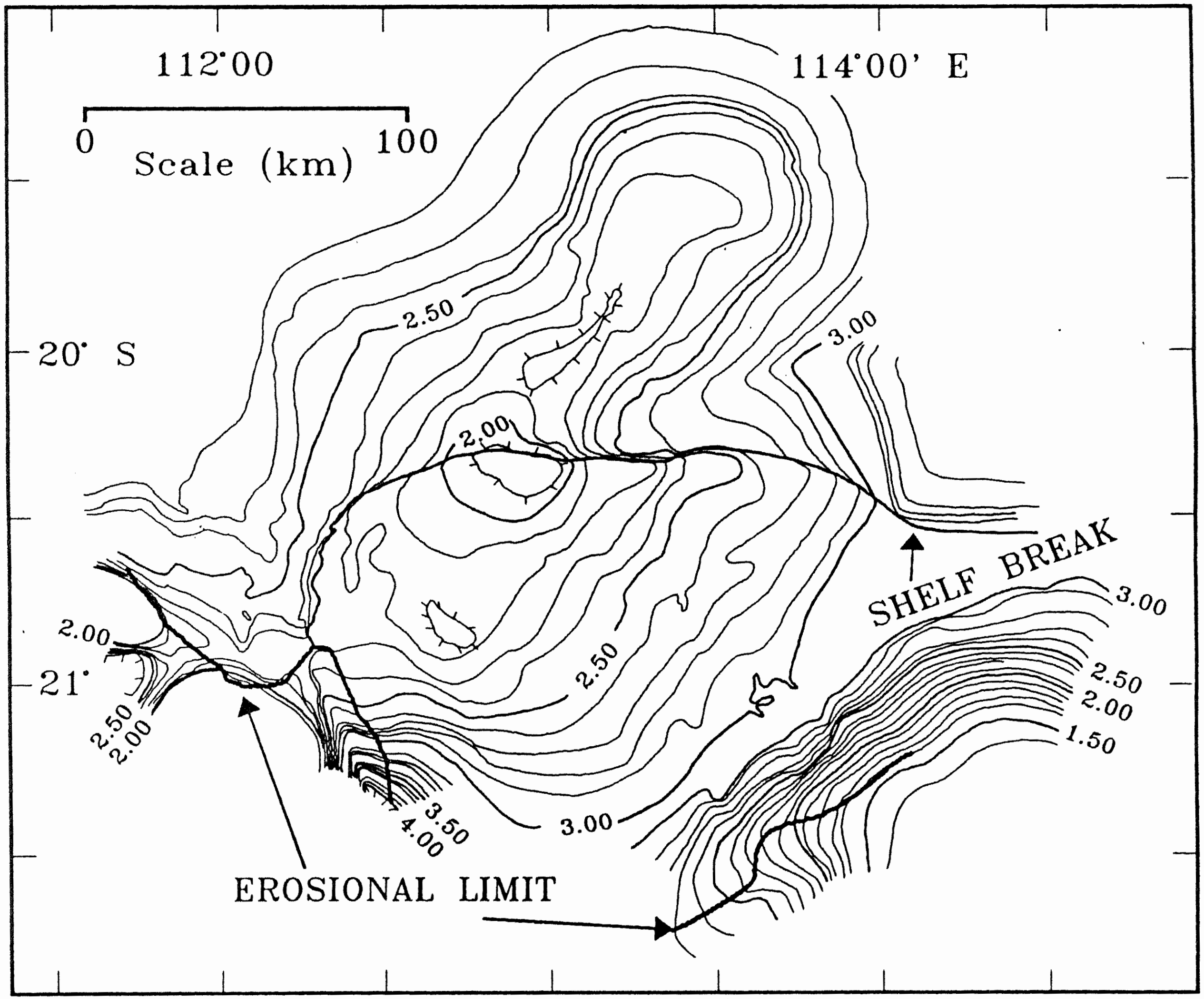

FIGURE 4.10-Structural contour map of the middle reflector. Contours in seconds. Also shown is the lower sequence shelf break and erosion limit of this surface.

of greater than 4.00 sec occur. The dark northwest-southeast trending line in this area is the northeasternmost erosional limit in this area. The lower sequence shelf is absent in the southwestern part of the area because of erosion.

4.5 Isopach Map of the Upper Sequence

The northernmost contours in the isopach map of the upper sequence (Fig. 4.11) shows the farthest depositional limit of the sediments. In the center of the study area the contours show an area of thick sediment over 0.2 sec (200 m) thick that is not proximal to any topographic highs (Figure 4.11). To the southeast of this sediment, the contours indicate a second thick deposit of sediment (Fig. 4.11). This second deposit occurs between a shelf break to the north and a line of erosion to the south. This line represents the northwesternmost erosional limit of the upper sequence. The contour lines between the sediment deposit in the center and the southeast of the study area connect. These contours show the path of sediment dispersal from the southern topographic high first to the northeast then they change direction to the northwest.

Three thick packages of sediment appear in the southwestern part of the study area (Fig. 4.11). The two southernmost packages show erosion of their upper strata and they occur adjacent to a topographic high which appears in Figure 4.10. The third westernmost package of sediment shows no erosion of its upper strata and does not correlate with any depositional buildup of the lower sequence.

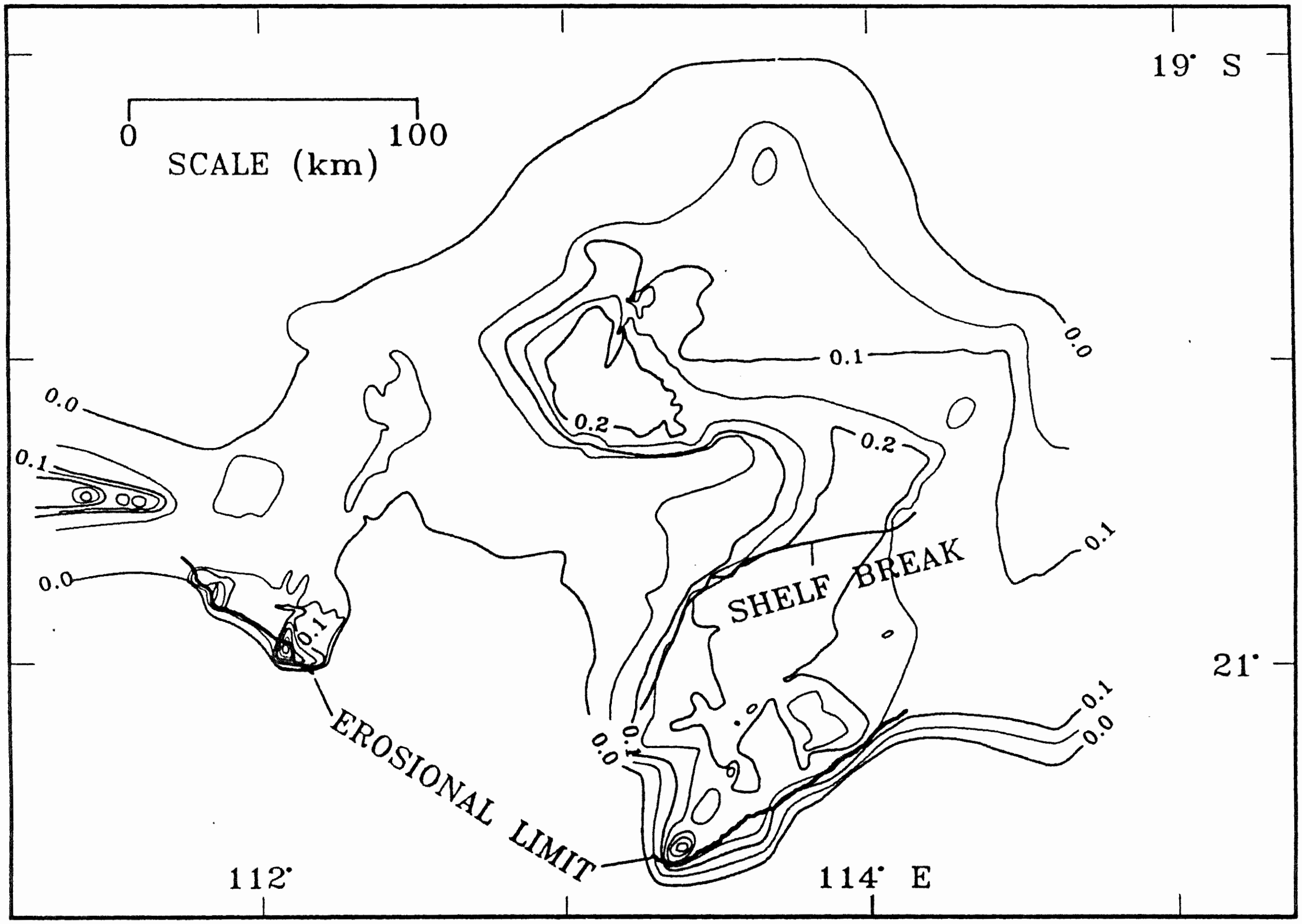

FIGURE 4.11-Isopach map of the upper sequence. Contours in seconds. Also shown is the shelf break and erosion limit.

4.6 Summary

The isopach maps show two deltaic sequences at the top of the Barrow Group. The lower, older sequence covers an area roughly 120 x 150 Km, and has a continental shelf which forms an arc roughly 100 Km long. The upper, younger sequence covers an area roughly 180 x 150 Km, and has a shelf break which rests upon the lower sequence. In the central part of the study area these two shelves occur roughly 50 Km apart but converge towards the east. The isopach maps also show erosion of both sequences in the southeastern and southwestern areas of the study area. The zones of erosion indicate uplift of the sequences above sea-level. In addition, a thick package of sediment occurs in the western part of the upper sequence.

The structure contour map of the middle reflector which divides the two sequences shows topographic highs and lows. Topographic highs appear in the southwestern and southeastern areas of the map where erosion occurs. The lower sequence continental shelf appears on the structure map but disappears at the erosional boundary in the southwest.

The seismic cross-sections present the eroded topographic highs in the south, the uneroded topographic high in the west, both shelf breaks, and the sequence progradation limits. The cross-sections show that both topographic highs in the south experienced uplift after the deposition of both sequences. The westernmost topographic high appeared after deposition of the lower sequence. The lower sequence shelf break shows internal downlap and toplap while the upper sequence onlaps it. The upper sequence shelf break shows downlap and concordance of its internal reflectors. Both sequences pinch out in the northern part of the study area and is therefore their progradational limit.

CHAPTER 5: WELL CORRELATION

5.1 Introduction

This chapter discusses data from five wells drilled on the Exmouth Plateau: Scarborough-1, Zeewulf-1, Investigator-1, Vinck-1, and Sirius-1 (Fig. 5.1). Data from these wells show dinoflagellate assemblage zones and lithostratigraphy, and enable the calculation of depths to sequence boundaries. The depth and dinoflagellate information in each well enables seismic sequence and boundary correlation between each of the five wells. The importance of the lithologic data appears in the discussion chapter.

5.2 Correlation

Correlating sequence boundaries on seismic profiles with boundaries in well data involves converting their depths to one-way-time. Seismic profiles show depth to reflections in two-way travel time which may be converted to one-way travel time by dividing the original value by two. Boundary depths in meters in the well data can be converted to one-way travel times from time vs. depth curves. To generate these curves, a receiver in the well measures the time it takes for a seismic wave to reach it at a known depth. This process is repeated at successive depths in the well to create a graph. For a given depth in meters on the depth-axis, a time-intercept on the curve for the depth value gives the boundary depth in seconds. These calculated times in each well can be compared with one-way-time values from seismic profiles (Tables 5.1-5.5).

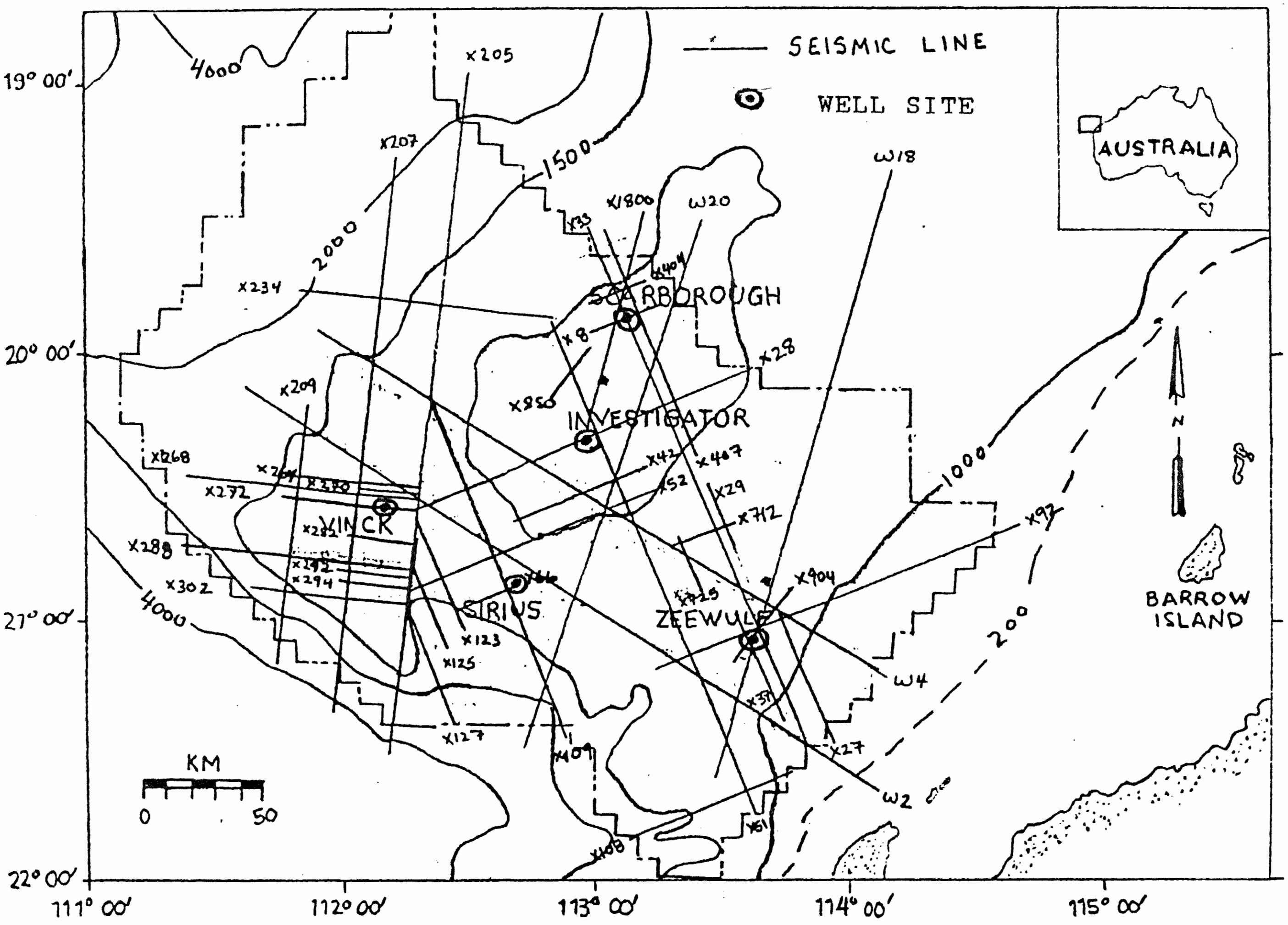

FIGURE 5.1-Well site location map.

ZEEWULF-1

TIME (MA)	EPOCH	UNIT	SUBSEA DEPTH (m)	SUBSEA DEPTH (CALC.) (SEC)	SUBSEA DEPTH (MEAS.) (SEC)	DINO. ASSEM. ZONE	LITHOLOGY
121	-					3a	
	V						
122	A					-------	
	L	grn					
123	A	----	2433	1.384	1.385	3b	---------
	N						
124	G	U				-------	coarse
	I	P					quartzose
125	N	P				3c	sandstone
	I	E					to silt,
126	A	R					claystone
	N						
127		pink				-------	
		----	2620	1.449	1.500	4a	---------
128	-					i-ii	
	B					-------	
129	E					4a	
	R					iii-iv	
130	R					-------	
	I						
131	A						
	S					4b	
132	I						
	A						
133	N						

134	-						

TABLE 5.1- Stratigraphic table of well Zeewulf-1.

INVESTIGATOR-1

TIME (MA)	EPOCH	UNIT	SUBSEA DEPTH (m)	SUBSEA DEPTH (CALC.) (SEC)	SUBSEA DEPTH (MEAS.) (SEC)	DINO. ASSEM. ZONE	LITHOLOGY
121	-	----	1482	0.898	0.905	3a	----------
	V	gren				-------	siltstone
122	A						and clay-
	L					3b	stone and
123	A	U					carbonate
	N	P					
124	G	P				-------	
	I	E					
125	N	R					
	I					3c	
126	A						
	N						
127		pink				-------	
		----	1502	0.908	0.915	4a	----------
128	-	L				i-ii	sandstone
	B	O				-------	siltstone
129	E	W.				4a	claystone
	R	----	*1760		1.010	iii-iv	----------
130	R	oran				-------	
	I						
131	A					4b	
	S						
132	I						
	A						
133	N						

134	-					4c	

TABLE 5.2- Stratigraphic table for well Investigator-1.

* depth value in meters calculated from seismic data because lithologic boundary unclear

VINCK-1

TIME (MA)	EPOCH	UNIT	SUBSEA DEPTH (m)	SUBSEA DEPTH (CALC.) (SEC)	SUBSEA DEPTH (MEAS.) (SEC)	DINO. ASSEM. ZONE	LITHOLOGY
121	-	gren				3a	
	V	----	1985	1.235	1.241	-------	----------
122	A						calcar-
	L					3b	eous grey
123	A						brown
	N	U					siltstone
124	G	P				-------	
	I	P					
125	N	E				3c	
	I	R					
126	A						
	N						
127		pink				-------	
		----	2004	1.243	1.250	4a	----------
128	-	L				i-ii	quartzose
	B	O				-------	medium gr
129	E	W.				4a	sandstone
	R	----	*2090		1.285	iii-iv	----------
130	R	oran				-------	
	I						
131	A					4b	
	S						
132	I						
	A						
133	N						

134	-						

TABLE 5.3- Stratigraphic table for well Vinck-1.

* depth value in meters calculated from seismic data because lithologic boundary unclear

SCARBOROUGH-1

TIME (MA)	EPOCH	UNIT	SUBSEA DEPTH (m)	SUBSEA DEPTH (CALC.) (SEC)	SUBSEA DEPTH (MEAS.) (SEC)	DINO. ASSEM. ZONE	LITHOLOGY
121	-	----	1667	0.970	0.975	3a	---------
	V	gren					
122	A					------	
	L	U					
123	A	P				3b	argilla-
	N	P					ceous,
124	G	E				------	calcar-
	I	R					eous
125	N						claystone
	I					3c	
126	A						
	N						
127						------	
						4a	
128	-					i-ii	
	B	pink				------	
129	E	----	1785	1.030	1.040	4a	---------
	R					iii-iv	
130	R					------	
	I						
131	A					4b	
	S						
132	I						
	A						
133	N						

134	-						

Table 5.4- Stratigraphic Table for well Scarborough-1.

SIRIUS-1

TIME (MA)	EPOCH	UNIT	SUBSEA DEPTH (m)	SUBSEA DEPTH (CALC.) (SEC)	SUBSEA DEPTH (MEAS.) (SEC)	DINO. ASSEM. ZONE	LITHOLOGY
121	-					3a	
	V					-------	
122	A						
	L					3b	
123	A						
	N						
124	G					-------	
	I						
125	N						
	I					3c	
126	A						
	N						
127		pink				-------	
		----	1665	1.037	1.040	4a	---------
128	-	L				i-ii	massive
	B	O				-------	sandstone
129	E	W.				4a	siltstone
	R	----	*1695		1.050	iii-iv	---------
130	R	oran				-------	
	I						
131	A						
	S						
132	I					4b	
	A						
133	N						

134	-						
						4c	

TABLE 5.5- Stratigraphic table for well Sirius-1.

* depth value in meters calculated from seismic data because lithologic boundary unclear

Dinoflagellate assemblage zones in well data show the relative time at which sequence depositional events occur. Assemblage zones appear at one discrete time, and disappear at a later time. When a sequence forms, its boundaries approximate time lines because all strata above a boundary are younger than the strata below. Because sequence boundaries and assemblage zone boundaries are time lines, they cannot cross each other. As a result, these zones are useful correlation tools; correlating a sequence with the same assembly zone in every well indicates correct boundary mapping. These zones can also show absolute time because they correlate with dated magnetic reversals.

5.3 Well Data

5.3.1 The Upper Sequence

The upper sequence appears in four of the five wells used for this work: Scarborough-1, Zeewulf-1, Investigator-1, and Vinck-1 (Fig. 5.1). Geophysical well log data show the depth to lithostratigraphic boundaries in the wells in meters and may be correlated with the upper (green) and lower (pink) sequence boundaries. Boundary depths in meters in each well convert to one-way travel times using the time vs. depth curve previously described (Appendix A). The sequence boundaries in time on seismic profile data show close matches to the calculated time values from all four wells (Tables 5.1-5.4).

Boundary depths for the upper sequence correlate closely with two dinoflagellate assemblage zones. The green boundary occurs between the base of Systematophora Areolata (3c) and the top of Phoberocysta Burgeri (3a) assemblage zones (Helby 1987) (Tables 5.1-5.4). The upper and lower absolute ages for the upper boundary are approximately 121.5 Ma and 127 Ma (Valanginian) respectively using the time scale of Haq et al. (1987). The pink boundary occurs within the boundaries of the Egmontodinium Torynum (4a i-ii) assemblage. The upper and lower absolute ages for the lower boundary are approximately 127 Ma and 129 Ma (Berriasian), respectively (Haq et al. 1987). The presence of these dinoflagellate assemblage zones in each well enables confirmation and correlation of the upper sequence between each well (Tables 5.1-5.4).

The lithologic data from Scarborough-1, Zeewulf-1, Investigator-1, and Vinck-1 show sedimentologic variations between each well for the upper sequence. Zeewulf-1 shows a coarse sandstone, silt, and claystone assemblage (Table 5.1) while Investigator-1 shows a combination of siltstone and claystone in the upper sequence (Table 5.2). Vinck-1 has predominantly a siltstone lithology (Table 5.3) and Scarborough-1 shows only claystone (Table 5.4). These results show a decreasing grain size trend to the northwest.

5.3.2 The Lower Sequence

The lower sequence appears in three of the wells used for this work. These wells are : Investigator-1, Vinck-1, and Sirius-1 (Fig. 5.1). Geophysical well-log data show the depth to lithostratigraphic boundaries in the wells in meters and may be correlated with the upper boundary (pink) and the lower boundary (orange). Boundary depths in meters in each well convert to one-way travel times using the time vs. depth curve previously described (Appendix A). The lithostratigraphic upper boundary in time for all three wells correlates closely with the lithostratigraphic upper boundary in one-way time on seismic profiles (Tables 5.2, 5.3, and 5.5). The depth to the lower boundary of the lower sequence does not appear in previously interpreted well data. The depth in one-way time of the lower boundary on seismic profiles converts to a depth in meters on the time vs. depth curves (Appendix A). This depth in meters appears in the unit column of Tables 5.2, 5.3, and 5.5.

The upper boundary for the lower sequence occurs within one dinoflagellate assembly zone. This zone is the Batioladinum Reticulatum (4a iii-iv) dinoflagellate assemblage zone (Helby 1987) (Tables 5.2, 5.3, and 5.5). The upper and lower time limits for this boundary are 129 Ma and 131 Ma (Berriasian) respectively (Haq et al. 1987). The presence of this assemblage zone in the three wells enables correlation of the lower sequence between each well (Tables 5.2, 5.3, and 5.5).

The lithology data from Investigator-1, Vinck-1, and Sirius-1 show a variation of clastic grain size between each well. Investigator-1 shows a sandstone, siltstone, and claystone lithology for the lower sequence (Table 5.2). In Vinck-1, a thin medium-grained sandstone approximately 20 m thick predominates within the lower unit (Table. 5.3). A massive sandstone body exists in the lower unit at Sirius-1 (Table. 5.5). These data indicate a fining trend in a northwest direction.

5.4 Results

The lithostratigraphic boundary choices from geophysical well-logs show a precise correlation with the seismic sequence boundaries. An error of +/-10 m (+-0.010 sec) corresponds to less than the width of a seismic reflector and is considered negligible (Boyd pers. comm.). All depth correlations are within this interval of error.

The dinoflagellate assemblage zone data show that both sequences appear within their respective assemblage zone in each well. The only exception to this is the pink reflector in Scarborough-1. In this well the pink reflector appears 15 m below the dinozone in which it appears in other wells. This situation may result from several sources of error. One possible source of error is that both the well-log and seismic sequence boundary choices are incorrect. A second source of error could be incorrect choice of the dinoflagellate assemblage zone boundary. A third possibility is the occurrence of a 15 m thick stratigraphic unit containing dinoflagellates but too thin and lacking in impedance contrast to be resolved on seismic data. It is important to note, however, that the velocity sample intervals in the well data average between 50 and 100 m. Consequently, data between the points on the time vs. depth graph are extrapolated and this can cause errors in correlating well and seismic data. Except for this one correlation problem, the remaining well data show that the chosen seismic sequence boundaries match closely.

CHAPTER 6: DISCUSSION AND CONCLUSIONS

6.1 Introduction

This chapter discusses the results from the isopach and structural maps, seismic cross-sections, and well data of the two youngest sequences of the Barrow Group. Important implications for paleogeography, sediment dispersal patterns, depositional environments, and tectonic evolution result from this work.

6.2 Sediment Sources

Four topographic highs occur in the study area (Fig. 6.1). The southeastern high on the structural contour map closely corresponds with an area of maximum sediment deposition on the upper and lower sequence isopach map. Erosion truncated part of the sequence by uplift and subaerial exposure. None of the internal reflectors shows coastal onlap near the surface and, therefore, erosion removed the source area. Erosion did not penetrate to the depth of the lower sequence because there was only minor uplift in this area. Thus, the southeastern topographic high generated sediment for both sequences and the erosional unconformity is a post-depositional event.

The second and third topographic highs occur together in the southwestern part of the study area. This area has alternating topographic highs and lows in a northwest-trending line. This topography parallels the nearby Cape Range Fracture Zone. During the rifting of Gondwanaland in the early Cretaceous, this area was a zone of transtension and transpression resulting from strike-slip movement along the transform fault. Zones of

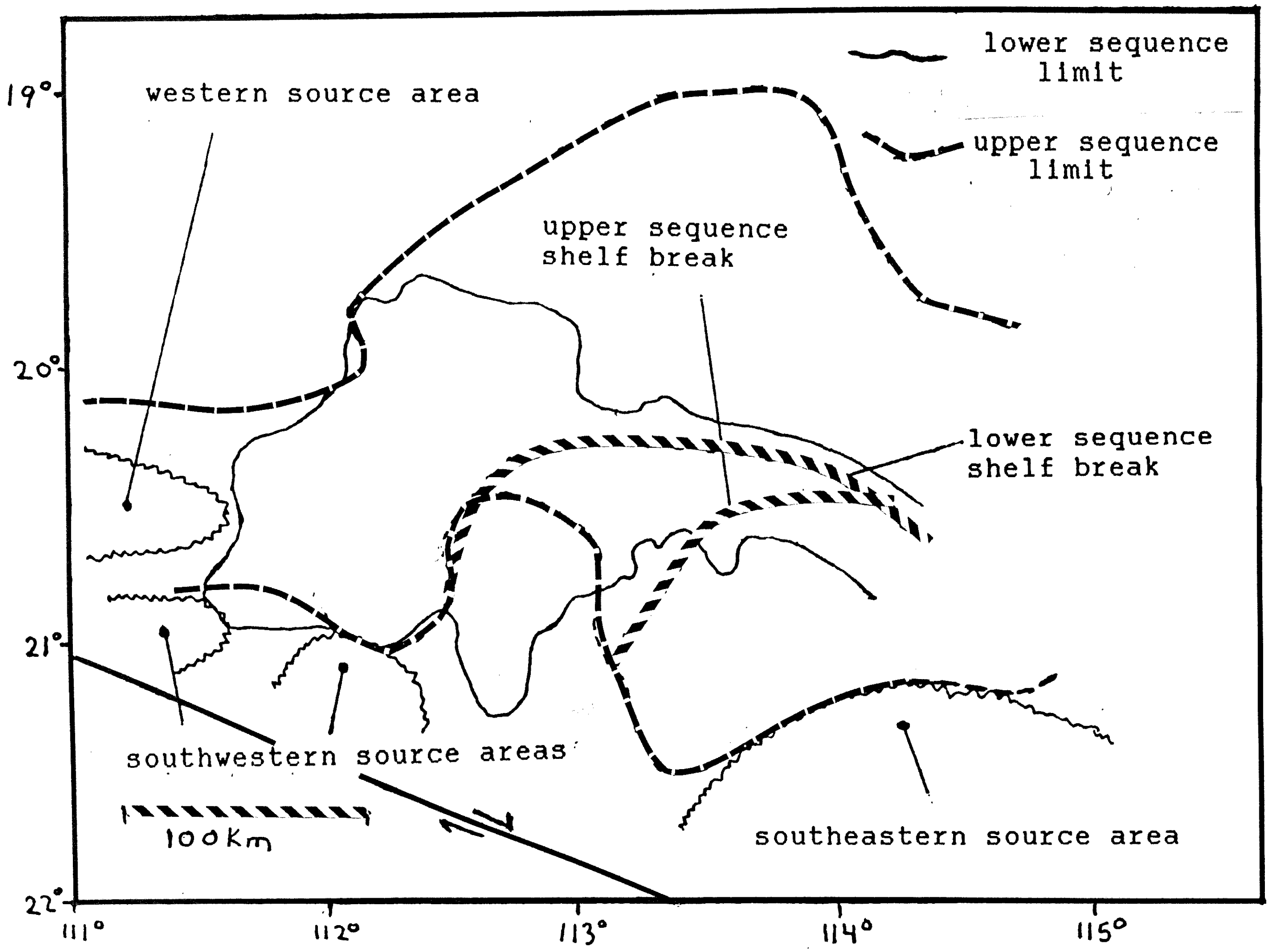

FIGURE 6.1-Map of the upper and lower sequences. Includes both shelf breaks and sediment source areas.

transtension and transpression create topographic highs and lows (Fig. 6.2), and the highs supply sediment to the adjacent lows. The presence of the erosional limit in the lows on the structural contour map indicates that the lows were once at the same elevation as the highs.

Seismic cross-sections of the southwestern high show erosional truncation of all reflectors in both seismic sequences. The structural contour map shows the lower sequence shelf break terminating at the erosional zone and this shows that erosion removed the western end of the shelf as well as the source area.

The fourth topographic high does not appear on the structural map because it formed after deposition of the lower sequence. This high generated sediment for the upper sequence which appears as a thick sediment package in the western study area. On seismic cross-sections this high feature shows a seismic signal response characteristic of volcanic rock. This high occurs to the east of the western plateau margin where Early Cretaceous rifting created new ocean floor. This uplift is analogous to the Atlantic mid-ocean ridge.

Seismic mapping of the lower sequence shows that no sediment originated from the western volcanic high. In contrast, seismic mapping of the upper sequence shows that the upper sequence downlaps onto the top of the volcanic high and the lower sequence nearby. Consequently, the volcanic high is post-lower sequence, but is pre-upper sequence, in relative age.

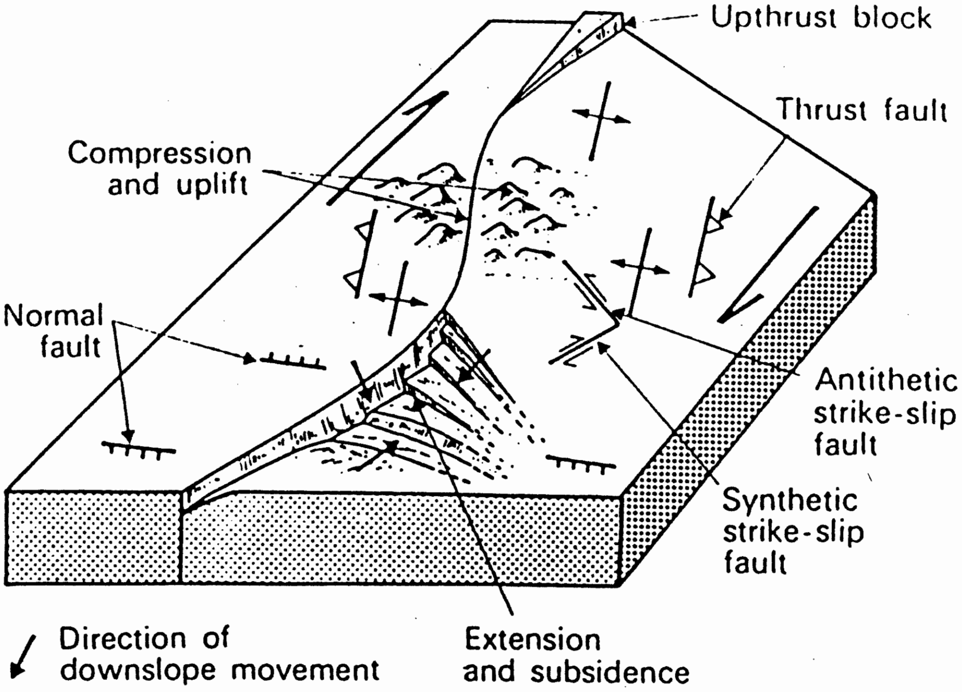

FIGURE 6.2-Block diagram illustrating the Ridge basin of California and how the curvature of the strike-slip fault may produce an extensional basin closely adjacent to compressional uplift, with superimposed tectonic pattern.

(from Reading 1986)

6.3 Sequence Deposition

Isopach data show that the lower sequence prograded about 60 Km to the northwest from two sources, then progradation stopped abruptly. Geophysical well data and reflector terminations show a relative sea-level rise flooded the lower sequence, creating an unconformity. Well data indicates an age for this sequence of Late Berriasian (127-129 Ma). Isopach maps and dinoflagellate data show that a continuing rise in relative sea-level permitted progradation of the upper sequence in the Early Valanginian. It prograded approximately 30 Km to the northwest from three sources. With progradation of the upper sequence, isopach maps show that the eastern part of its shelf overlapped the lower sequence shelf. Well data results show deposition of significant quantities of delta-derived silt and mud beyond the lower sequence shelf edge. The isopach map of the upper sequence shows that prevailing westerly ocean currents in the Tethys Sea transported sediment to a more northwesterly location. The sediment travelled along the isobaths, parallel to the shelf break of the lower sequence. Well and seismic data show a second relative sea-level rise occurred in the Late Valanginian (124-121 Ma) which flooded the upper sequence and terminated its progradation. After the second sea-level rise, erosion of the two southern source areas occurred. Seismic cross-sections show that the third, westernmost source area escaped erosion because of rapid subsidence and submergence below sea level. Its location away from the transform margin did not subject it to prolonged uplift.

6.4 Conclusions

-The Barrow Group shows two periods of regression terminated by two transgressions.

-The ages of the these events correlate to tectonic events on the margin such as rifting, breakup, seafloor spreading, and transform motion.

-The two youngest sequences of the Barrow Group show that deposition occurred in deltas, coastal plains, alluvial source areas, and offshore marine deposits.

-The structure contour map shows that the Exmouth Plateau Arch forms three structural domes near the large coastal sand bodies of the lower shelf break. These are prime exploration targets for petroleum accumulation.

-Directions and styles of sediment dispersal are shown by the progradational delta shelf breaks on the isopach maps. The lower sequence prograded simultaneously along a delta front 300 msec high (approximately 300 m) and 200 km long. The upper sequence prograded simultaneously along a delta front 200 msec high (approximately 200 m) and 120 km long.

-The source areas consist of four topographic highs in southern and western areas of the plateau. The southeastern high is 2 sec high (above 2 000 m) and at least 120 km long. The two southwestern highs are approximately 600 msec high (600 m). This uplifted area underwent more extensive erosion than the southeastern area and the original elevation is unknown because of the lack of data in the region. These two highs created about

100 km of coastline. The westernmost topographic high is 300 msec high (300 m) but the length of coastline is unknown.

-The isopach maps show information about currents and sediment dispersal directions beyond both shelf breaks. The lower sequence clearly shows a northwest progradation direction beyond the shelf break. The sediment dispersal from the southwestern high shows a northerly direction. The lower sequence shows a northwest direction of dispersion beyond the lower sequence shelf break. This direction results from westerly longshore currents. Sediment dispersion from the southwestern high shows a northerly direction, whereas sediment from the westernmost high shows an easterly direction. These dispersal directions result primarily from elevation changes derived from uplift on the Cape Range Fracture Zone and the western rift margin of the Exmouth Plateau.

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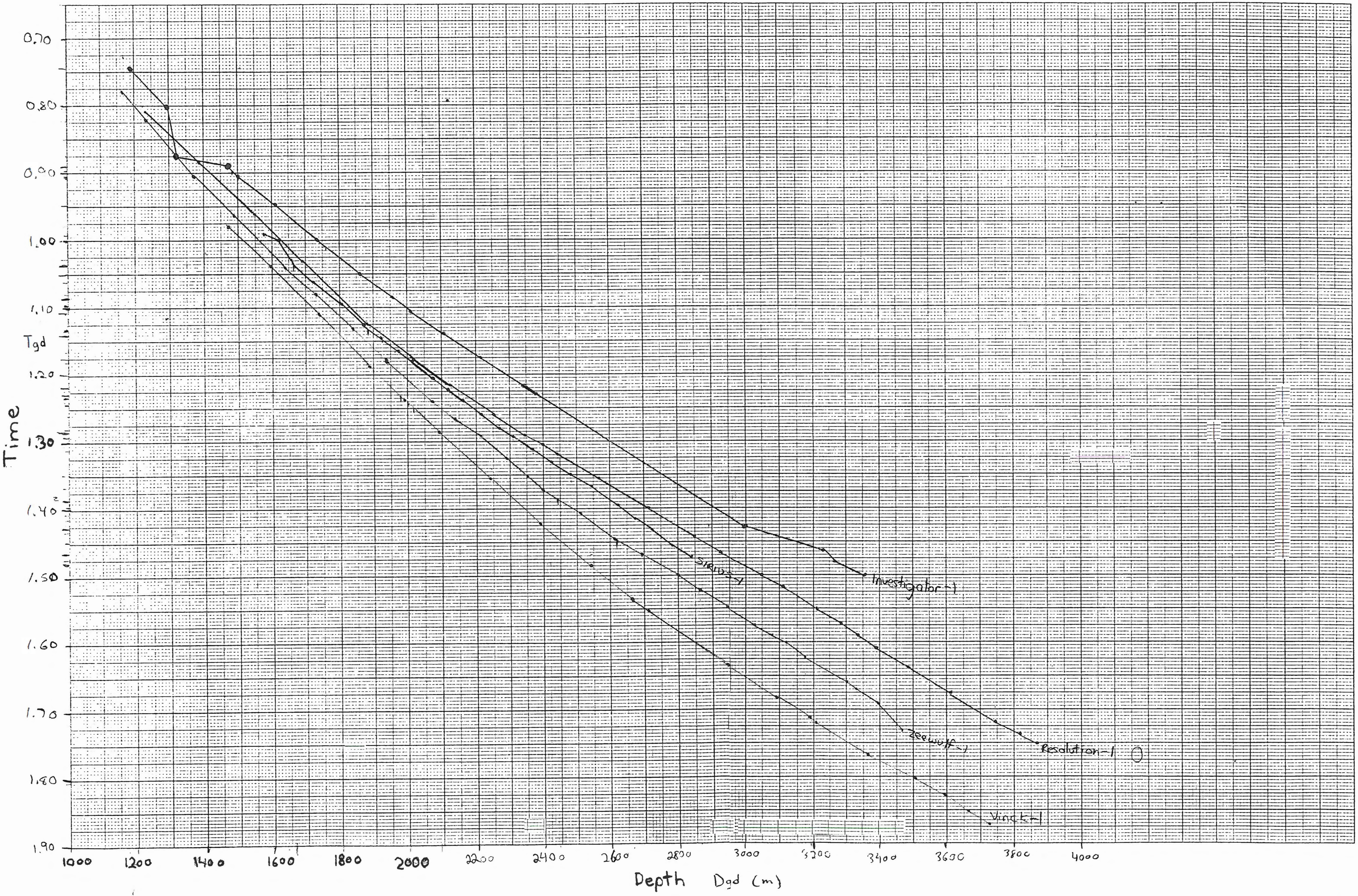
Appendix A

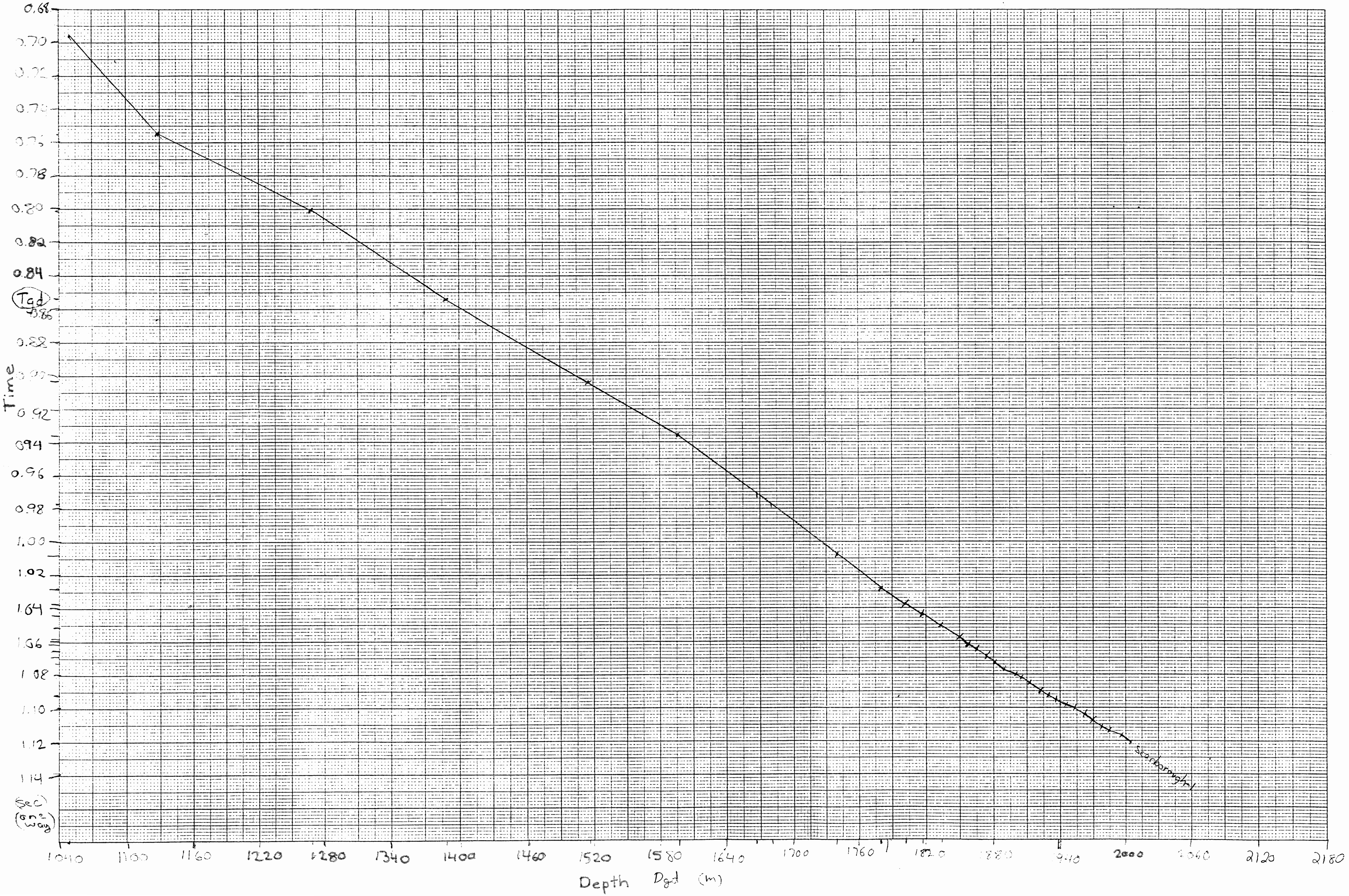
Time vs. depth curves for the well data in Chapter 5. They show the time in seconds that it takes a seismic disturbance to reach a given well depth in meters.

Appendix A



0.70
0.80
0.90
1.00
1.10
Tgd
1.20
Time
1.30
1.40
1.50
1.60
1.70
1.80
1.90
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
Depth Dgd (m)
Investigator-1
Sirius-1
Zeewulf-1
Resolution-1
Vinck-1

Appendix A


Time
Tad
(Sec)
(one way)
0.68
0.70
0.72
0.74
0.76
0.78
0.80
0.82
0.84
0.86
0.88
0.90
0.92
0.94
0.96
0.98
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1040
1100
1160
1220
1280
1340
1400
1460
1520
1580
1640
1700
1760
1820
1880
1940
2000
2060
2120
2180
Depth Dgd (m)
Scarborough-1