31. SEISMIC STRATIGRAPHY OF THE SITE 766 AREA, WESTERN MARGIN OF THE EXMOUTH PLATEAU, AUSTRALIA[1]

Richard T. Buffler,[2] Philip Rowell,[2] and Neville Exon[3]

ABSTRACT

A grid of seismic reflection data was used to develop a seismic stratigraphic framework for the Site 766 area. Five seismic sequences were defined and correlated directly with the lithologic units drilled at Site 766. The results of the seismic stratigraphic analysis were used to summarize the geologic history of the site area plus discuss some of the more important regional relationships in the vicinity of the site area. A contour map on acoustic (volcanic) basement plus the wedge-shaped, onlap-fill geometry of the overlying Valanginian-Hauterivian (VH) sandstone/siltstone sequence suggest initial deposition in a deep-water (800-1000 m), asymmetrical rift basin along the western Exmouth Plateau. Although intruded by oceanic volcanics, basement below the site area may be a narrow zone of thin, rifted continental crust rather than true oceanic crust. The VH unit sediments were derived from shallow-water shelves and volcanic landmasses on the thermally uplifted adjacent plateau and possibly were fed into the basin through canyon systems to the south. During the Barremian (BA sequence) the site area and adjacent margins began to subside rapidly after the emplacement of oceanic crust in the Cuvier and Gascoyne basins, and only distal hemipelagic muds were deposited. From Aptian through Cenomanian time (AC sequence) the area continued to subside and received mainly pelagic sediments in a deep-water, open marine setting. Starved, open-marine conditions continued throughout the Late Cretaceous (UK sequence) and the Cenozoic (CZ sequence), with the final disappearance of clay taking place in the Campanian. Strong deep-sea current systems periodically swept the margin throughout the Cretaceous and Cenozoic, as indicated by the overall abbreviated sedimentary section drilled and the numerous erosional unconformities seen on the seismic sections.

INTRODUCTION

The specific location of Site 766 (originally designated Site EP2A) was proposed following an extensive site-survey cruise across the Exmouth Plateau in 1986 by the Australian Bureau of Mineral Resources (BMR) using the research vessel *Rig Seismic*. One leg of this cruise (Leg 55, 10 March through 10 April 1986) involved the collection of 1150 km of multifold seismic data along the western margin of the Exmouth Plateau (Fig. 1). These data include seven long regional lines (Lines 55/2,4,5,6,7,8, and 9), plus a detailed survey at designated site EP2A, located at the western ends of Lines 55/2 and 55/4 along the western margin of the Plateau (box, Fig. 1). Further details of this site-survey cruise are contained in a BMR cruise report (Exon and Williamson, 1988).

A primary objective of drilling at Site 766 was to understand better the early rift history of passive continental margins in general and, more specifically, the evolution of the western Exmouth Plateau margin. The site is located in a small rift basin at the foot of the southwestern escarpment of the plateau and presumably overlies the first oceanic-type crust emplaced during the initial rifting of the margin near the continent/ocean boundary (Fig. 2). Confirming the age of the volcanic basement at this location, as well as the paleowater depths, environments of deposition, and geologic history of the overlying sedimentary section, provide important data for testing subsidence and stretching models for the evolution of this continental margin.

Specific objectives of this study are three-fold: (1) to present a seismic stratigraphic framework for the Site 766 area that has been tied to the drilling results, (2) to present an interpretation for the local geologic history of the area based on the seismic stratigraphic analysis, and (3) to discuss how this local history relates to what is known about the geologic history of the surrounding areas. More details about the site objectives, the early interpretations of the site survey data, and the site selection process are contained in the "Seismic Stratigraphy" section of the "Site 766" chapter (Ludden, Gradstein, et al., 1990, p. 62–65).

DATA BASE AND SETTING

The seismic stratigraphic framework was developed using multifold seismic reflection data collected by the BMR in the site area. This survey consists of a 94-km grid of data covering an area approximately 30 × 45 km (Fig. 3). The lines include the western end of Line 55/2 plus five short line segments designated Lines 55/3A, B, C, D, and E. To the east, Line 55/3E becomes regional Line 55/4 (Figs. 1 and 3). Only the straight line segments of these lines were fully processed (solid lines). All of the processing was performed by scientists at BMR. Recording parameters, processing sequence, and display parameters for these lines are summarized in Table 1. The final sections presented here are displayed with automatic gain control (AGC) applied.

Additional single-fold seismic lines were collected during Leg 123 before and following the drilling of Site 766. The first (Line 2B) was collected during the approach to the site area and parallels Lines 55/4 and 55/3E (Fig. 3). Comparison of the monitor record for this line with Line 55/3E was used to select the exact place to drop the beacon for Site 766 (see "Seismic Stratigraphy" section, "Site 766" chapter, Ludden, Gradstein, et al., 1990). A second single-fold seismic line (Line 3) was collected while leaving the Site 766 area. This line consists of a short triangular survey south of the site area (A,B,C), followed by a crossing back over the actual site (Fig. 3). This line was placed so as to expand the seismic coverage in the area and to trace the stratigraphy of the site area farther to the south. Recording and processing parameters for these lines are summarized in Table 2.

The regional setting for Site 766 is shown on a bathymetric map of the entire western margin of the Exmouth Plateau, com-

[1] Gradstein, F. M., Ludden, J. N., et al., 1992. *Proc. ODP, Sci. Results*, 123: College Station, TX (Ocean Drilling Program).
[2] University of Texas at Austin, Institute for Geophysics and Department of Geological Sciences, 8701 Mopac Blvd., Austin, TX 78759, U.S.A.
[3] Australian Bureau of Mineral Resources, P. O. Box 378, Canberra 2601, Australia.

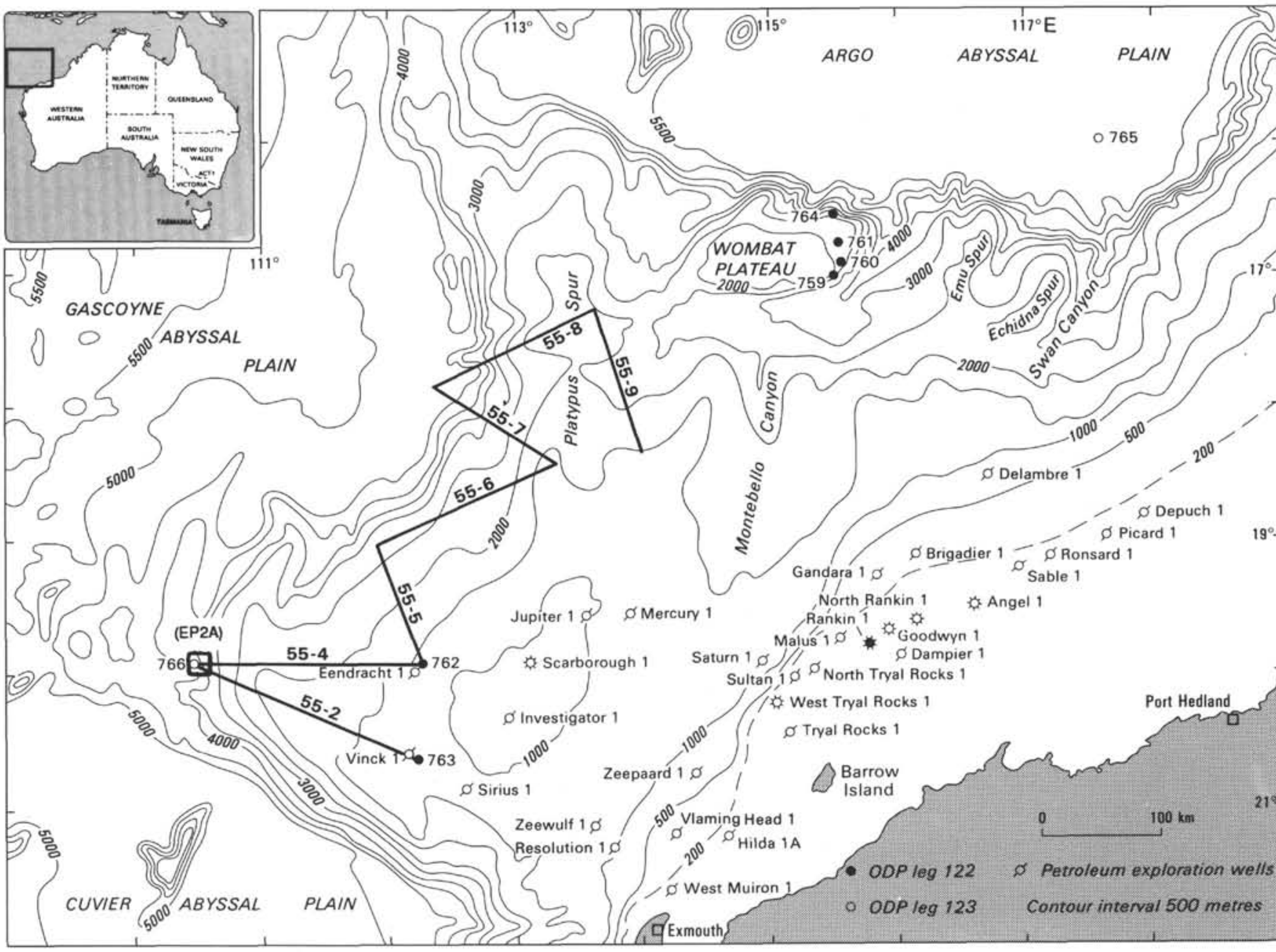


Figure 1. Map showing location of Sites 766 (EP2A), 762, and 763; long regional BMR seismic lines on the western Exmouth Plateau; and industry wells in the region.

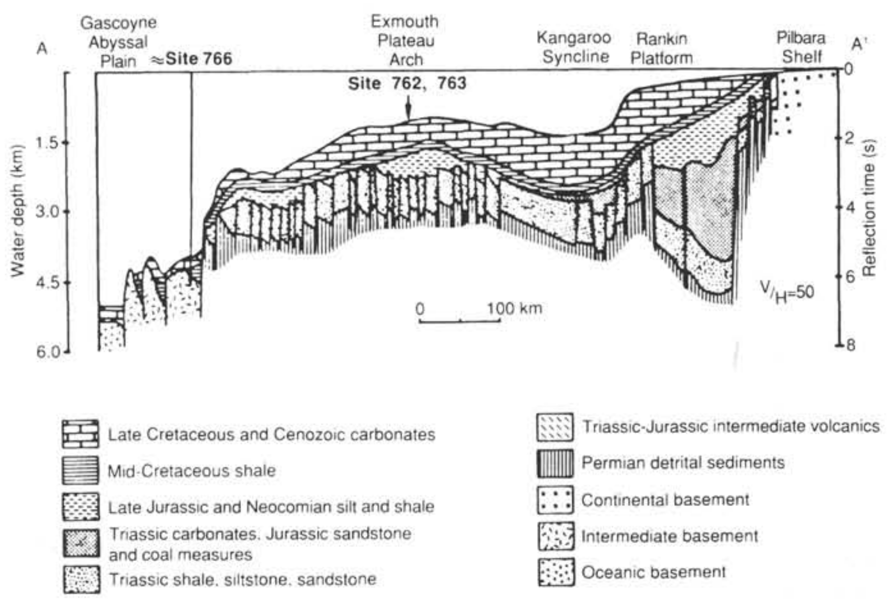


Figure 2. Schematic east-west geological cross section across the southern Exmouth Plateau showing location of Sites 766, 762, and 763 (modified from Ludden, Gradstein, et al., 1990).

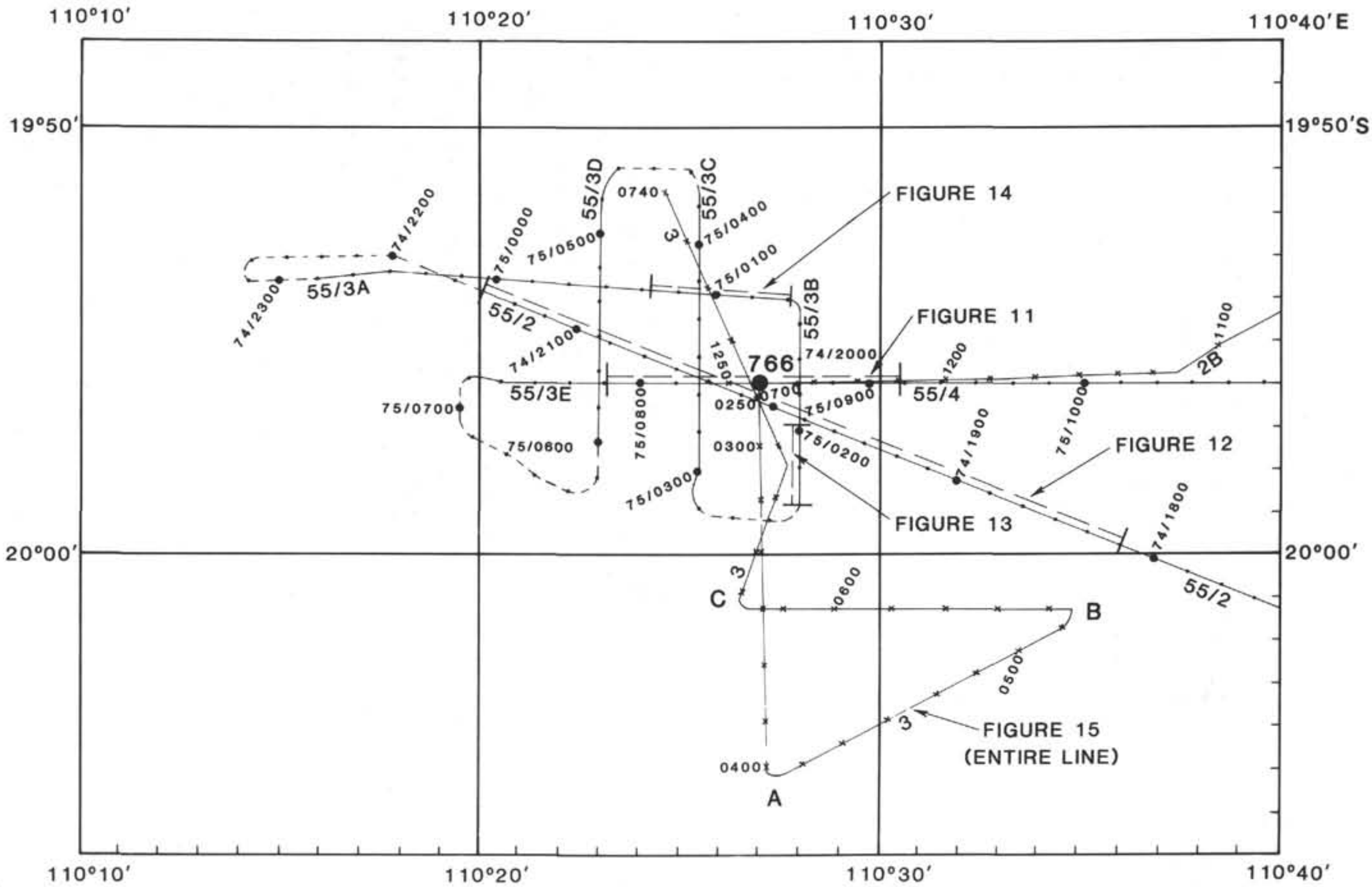


Figure 3. Track chart showing location of BMR multifold seismic data (Lines 55/2, 3A, 3B, 3C, 3D, 3E, and 4) and ODP single-fold Lines 2B and 3 in the Site 766 area. Solid lines are processed lines, while dashed represent unprocessed segments. Also shown are locations of Figures 11 through 15.

piled by Exon and Buffler (in press) (Fig. 4). The site lies at the foot of the southwestern escarpment of the plateau, at the head of a broad trough that opens to the southwest. Seismic data from the site area were used to map in more detail the local bathymetry (Fig. 5). In the eastern part of the area, the gently sloping western margin of the Exmouth Plateau drops off abruptly, forming a steep escarpment. Depths across the site area range from 3900 to 4100 m and confirm the broad trough opening to the southwest (Fig. 5). This local topography results mainly from differential erosion of the underlying sedimentary section, and indicates strong erosional currents through the area during the late Cenozoic. Several gentle erosional terraces step down from east to west across the central area. The local high in the northwest is an erosional remnant of late Cenozoic sediments (see below). The bathymetric high to the south, however, represents a regional westward projection of the structure of the Exmouth Plateau (Figs. 4 and 5), and probably is controlled by the underlying basement of the plateau (Exon and Buffler, in press).

SEISMIC STRATIGRAPHY

Seismic Sequences and Correlation With Hole 766

Five seismic sequences were defined initially as part of a preliminary seismic stratigraphic analysis of the Site 766 area (see "Seismic Stratigraphy" section in "Site 766" chapter, Ludden, Gradstein, et al., 1990). Further analysis of the seismic data suggests that these five sequences are still valid; thus, they have been kept for this study and are discussed in more detail below. Each unit originally designated with a number (1–5), is now designated with letters corresponding to their geologic ages, as determined from correlation with Hole 766.

Identification of the sequences and their boundaries followed the standard seismic stratigraphic analysis procedures first outlined by Vail et al. (1977). Sequence boundaries are marked by prominent reflections that can be traced across the study area and are characterized, in places, by disconformable relationships (erosional truncation below and onlap or downlap above). These boundaries correspond to unconformities or their correlative conformities (Vail et.al., 1977) and represent major vertical changes in sedimentation. The sequences themselves are characterized internally by various seismic facies, which can be interpreted in terms of their geology, based on the seismic character, drilling results, and regional setting. Some of the defined sequences have local unconformities within them. These surfaces, however, are not extensive enough to map regionally, and therefore, they are not used as sequence boundaries in this study.

The sequences and their boundaries have been interpreted to correlate with major lithologic units identified in Hole 766 (Figs. 6 and 7). The upper sequence correlates with the Cenozoic oozes of subunits IA and IB and is designated CZ. The next sequence correlates with the Upper Cretaceous oozes (lithologic subunits IIA and IIB) and is designated UK. The third sequence correlates with the Lower Cretaceous chalks (subunits IIC and IID) of Aptian through Cenomanian age and is designated AC. The fourth and fifth sequences correlate with the Barremian claystone (IIIA) and the Valanginian through Hauterivian sandstone/siltstone unit (IIIB) and are designated BA and VH, respectively. The top of volcanic basement drilled at Site 766 correlates with the regional

Table 1. Recording parameters, processing sequence, and display parameters for multifold seismic Lines 55/2 and 55/3.

Recording parameters

Vessel: *Rig Seismic*	Date recorded: March 1985
Ship's speed: 5.5 knots	Shot interval: 50 m
Source: 1 × 8.1 × 1.6 L guns	Source depth: 8 m
Group length: 50 m	Nominal cable depth: 10 m
No. of traces: 48	Leading trace: 1
CDP spacing: 25 m	Coverage: 24-fold
Near offset: 247 m	Maximum offset: 2597 m
Sample rate: 2 ms	Record length: 7500 ms
Data recording format - BMR SEGY 1600 BPI tape	

Processing sequence

1. Geometry definition
2. Reformat to DISCO internal format
3. Resample to 4 ms
4. Static correction applied
5. F-K shot records
6. Velocity analysis
7. Spike edit
8. Spherical divergence correction
9. Spike deconvolution 100 point operator
10. Normal moveout correction
11. Inside trace mute to attenuate multiple
12. Stack, 24-fold
13. Predictive deconvolution 50-point operator, 20 point gap
14. Time-gated bandpass filter:
    - WB to WB + 1500 ms — 15–60 Hz
    - WB + 3000 ms to end data — 8–35 Hz
15. AGC with 500 ms gate

Display parameters

Trace density: 15.7 traces/cm	Time scale: 10 cm/s
Polarity: Normal	Display gain: 0.75
Display date: December 1987	
Horizontal scale = 1:39.400 (1 cm = approximately 394 m)	

Note: These seismic data were processed at the Seismic Processing Center of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia, by I. Moxon and M. Swift.
Collected and processed by the Bureau of Mineral Resources (Australia), Geology and Geophysics Division of Marine Geoscience and Petroleum Geology, as part of an ODP site survey for Sites EP2A and EP2B.

Table 2. Recording and processing parameters for single-fold seismic lines in Site 766 study area collected aboard the *JOIDES Resolution*.

Recording parameters

Vessel: *JOIDES Resolution*
Date recorded: October 1988
Source: 2 × 80 in.^{3} water guns at 2000 psi
Shot interval: 13 s
Cable: 100 m, 60 hydrophones
Sample rate: 1 ms
Filter: 25–250 Hz
Data summed to one channel
Data recorded on 9-track tape on Masscomp 501 computer

Processing parameters

1. Trace edit
2. Seafloor mute
3. Bandpass filter (30–125 Hz)
4. 1-2-1 Trace mix
5. AGC with 500 ms gate

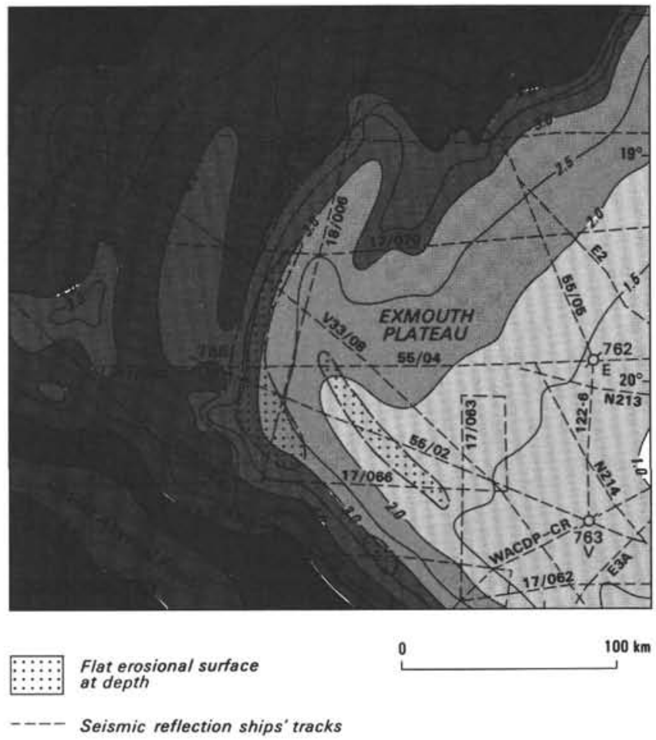


Figure 4. Map showing bathymetry of southwest margin of Exmouth Plateau (from Exon and Buffler, in press).

high-amplitude reflection at the base of the sedimentary section and is designated VB (Figs. 6 and 7).

This correlation was performed by converting the lithologic unit boundary depths to two-way traveltime, using the average interval velocities (Fig. 7) based on all the measurements for each unit taken from the cores on board the ship (see "Physical Properties" section, "Site 766" chapter, Ludden, Gradstein, et al., 1990). These times compare closely with the two-way traveltimes for the sequence boundaries taken from the seismic line at the drill site (Fig. 7), thus suggesting the correlation proposed.

This correlation was confirmed by two additional approaches. First, the depths of the lithological boundaries were converted to traveltime, using an empirical curve developed by Carlson et al. (1986) from DSDP data (Fig. 8). These times also correlate closely with the observed times from the seismic line (Figs. 7 and 8). Second, a series of two-way traveltime vs. depth curves was calculated from the RMS velocity information determined from velocity analyses conducted at various locations along the seismic lines surrounding the site. These RMS velocity data were generated during the processing of the seismic data. An envelope of these curves is shown in Figure 9. Plots of the depths to the lithology boundaries vs. two-way traveltime to the sequence boundaries (crosses) fall within this envelope, again supporting the original correlation.

The basement surface and each of the five sequences defined in the study area are discussed in more detail below. A contour map on the top of basement shows the overall structure of the area (Fig. 10). Several examples of the seismic data are shown to illustrate the seismic character of the sequences (Figs. 11 through 15). Isopach maps (in two-way traveltime) were drawn for each sequence to show the local changes in thickness (Figs. 16 through 20). Each of the sequences are discussed in terms of their local geologic history, as inferred from their seismic character, correlations with Hole 766, and regional setting.

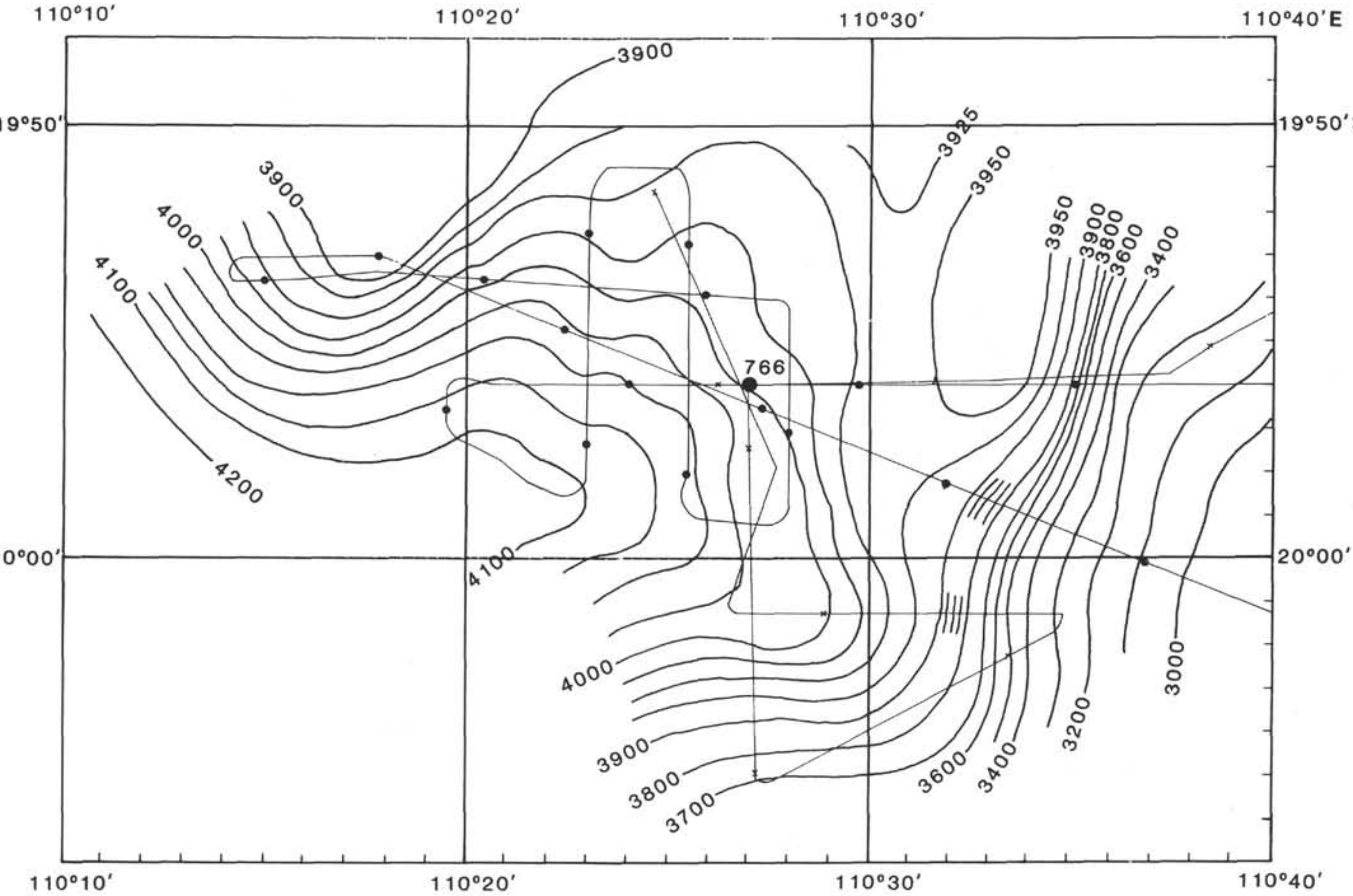


Figure 5. Bathymetry of Site 766 area, as determined from seismic lines. Contour interval 20 m between 3900 and 4100 m, 100 m elsewhere. Contours in western part of area from older BMR line (line location not shown).

Volcanic Basement (VB)

The high-amplitude reflection seen on all the seismic lines (Figs. 11 through 15), at the base of the sedimentary section, was drilled at Site 766, where it corresponds to the top of a section of basaltic dikes and sills of oceanic composition. These igneous rocks intrude the basal part of sequence VH. This reflection, therefore, has been interpreted to represent the top of Lower Cretaceous volcanic basement throughout the study area west of the Exmouth Plateau. Beneath the adjacent plateau, however (e.g., Figs. 12 and 15), this surface may represent the top of older (latest Triassic-earliest Jurassic) volcanic rocks that are inferred to underlie much of the outer margin of the plateau (Exon and Buffler, in press).

A contour map in two-way traveltime on volcanic basement shows the overall structure of the region (Fig. 10). The smooth surface gently dipping to the west and underlying the western Exmouth Plateau (east end of Fig. 12) apparently represents an Early Cretaceous regional erosion surface beveling the older volcanic basement (Exon and Buffler, in press). The western margin of the plateau is highly faulted, and the basement surface steps down over 1000 m to the floor of the site area (Figs. 10 and 12). In the southern part of the area, a high-standing basement block extends westward from the plateau proper (Figs. 10 and 15) and influences the local bathymetry of the region (Fig. 5). The basement contour map and seismic data show a broad gentle synclinal trough that opens to the north (Figs. 10 through 12). Along the western margin of the trough, basement steps up gently across a series of small faults to a regional high (Figs. 10 and 12) before dropping off again into another basin (Figs. 2 and 10). Overall, the structure appears to represent an asymmetrical rift basin, with a steeply faulted east flank and a gently dipping west flank. The faulting apparently reflects the initial rifting that occurred during the breakup of the western and southern margins of the Exmouth Plateau to form the adjacent Cuvier and Gascoyne ocean basins.

Lying below the basement surface in places are some weak, intrabasement reflections (Fig. 15). Although these reflections might represent some type of multiple energy, their divergence in places from the basement surface suggests that they represent real reflections from a deeper surface. These reflections appear to rise toward the base of the adjacent plateau, which is inferred to be underlain by older Triassic-Jurassic volcanic rocks (Exon and Buffler, in press). Therefore, this deeper surface may represent a fragment of the older volcanic basement that collapsed or faulted down during the early rifting of the margin and was intruded by the younger, initial oceanic basalts of the Gascoyne Abyssal Plain drilled at Site 766.

Valanginian–Hauterivian Sequence (VH)

The Valanginian–Hauterivian sequence (VH) directly overlies basement in the central part of the site area. At the drill site, its upper boundary occurs at 5.695 (two-way traveltime) and its lower boundary at basement at 5.850 (Fig. 7). The sequence has a general wedge-shaped geometry, that thickens to the east along the base of the escarpment (Fig. 16). The thickest section (more than 300 ms) occurs in the structurally lowest part of the basin (Fig. 12 at 1910 hours; also, compare Fig. 10 with Fig. 16). The

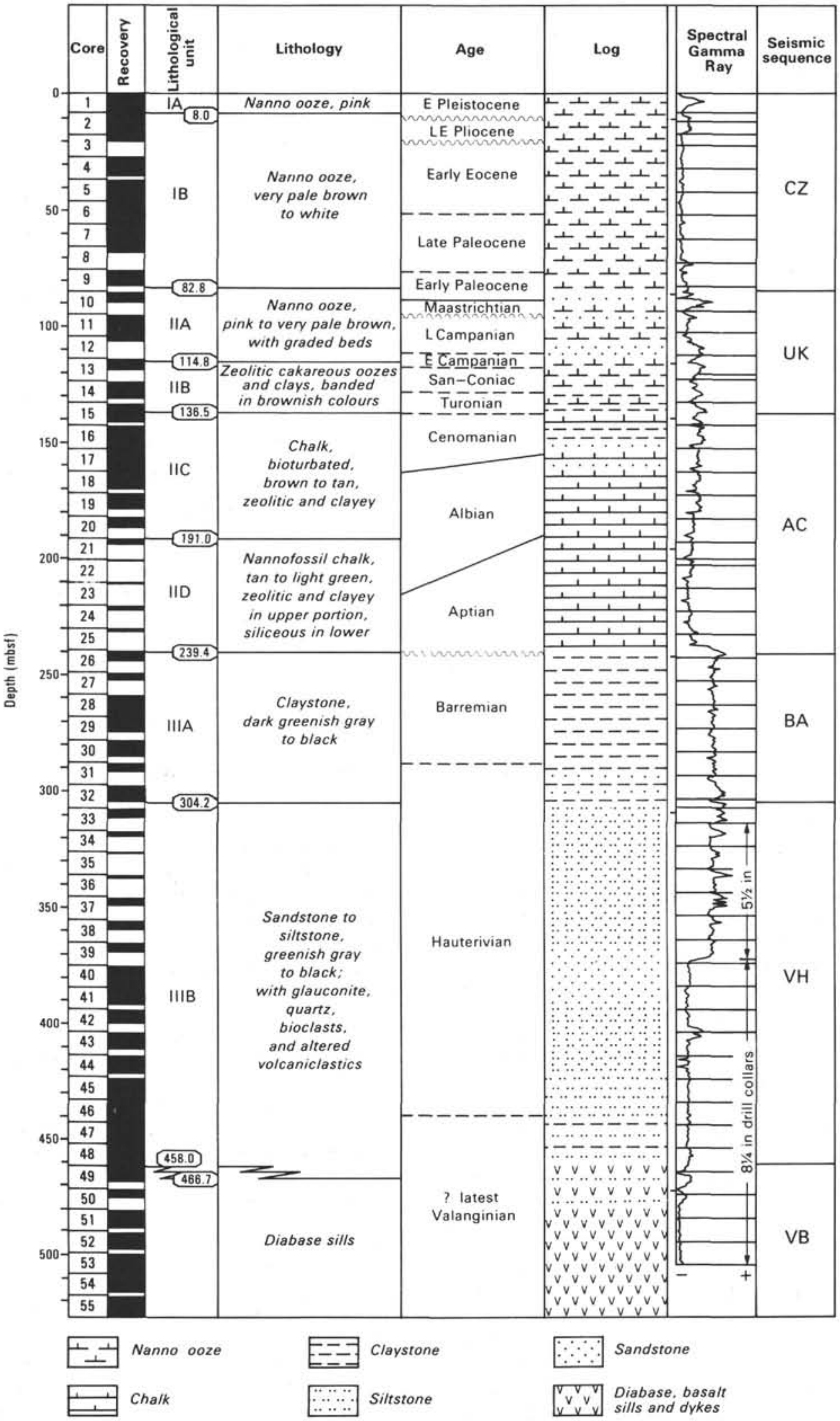
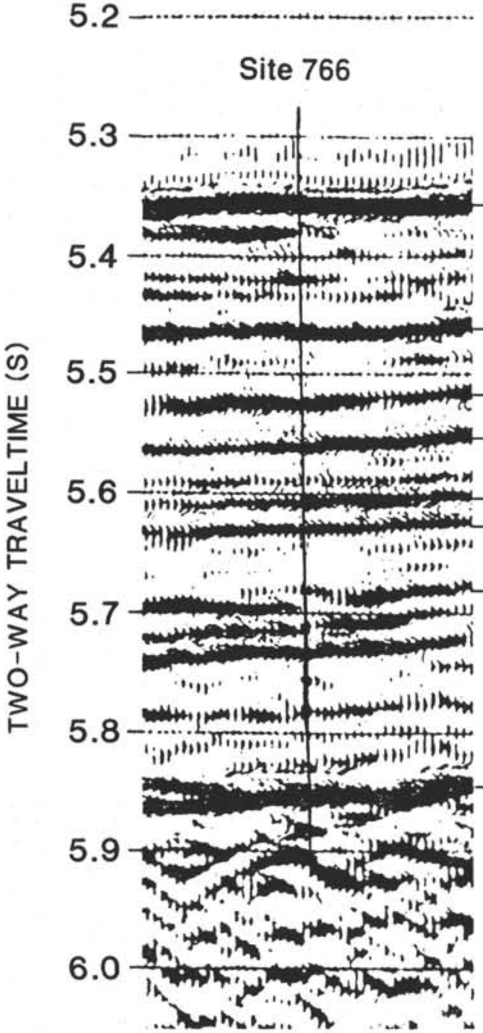


Figure 6. Schematic column showing lithologic units drilled at Site 766 and their correlation with seismic sequences.



	SEISMIC SEQUENCES	Δt (two way time) MEASURED FROM SEISMIC DATA (MSEC)	Δt (two way time) CALCULATED FROM MEASURED CORE VELOCITIES (MSEC)	INTERVAL VELOCITIES MEASURED FROM CORES (M/SEC)	LITHOLOGY UNITS	DEPTH (MBSF)
(5.360)						0
	CZ	105	108	1521	IA IB	
(5.465)						82.8
	UK	60	64	1629	IIA IIB	114.8
(5.525)						136.5
	AC	105	111	1613 1783 2168	IIC IID	191.0
(5.630)						239.4
	BA	65	71	1812	IIIA	
(5.695)						304.2
	VH	155	150	2065	IIIB	
(5.850)	VB					458.0

Figure 7. Correlation between portion of seismic Line 55/3E across Site 766 and lithologic units at Site 766. Interval velocities are from core measurements. Traveltimes to sequence boundaries on seismic line compare closely with traveltimes calculated for major lithology boundaries in core hole.

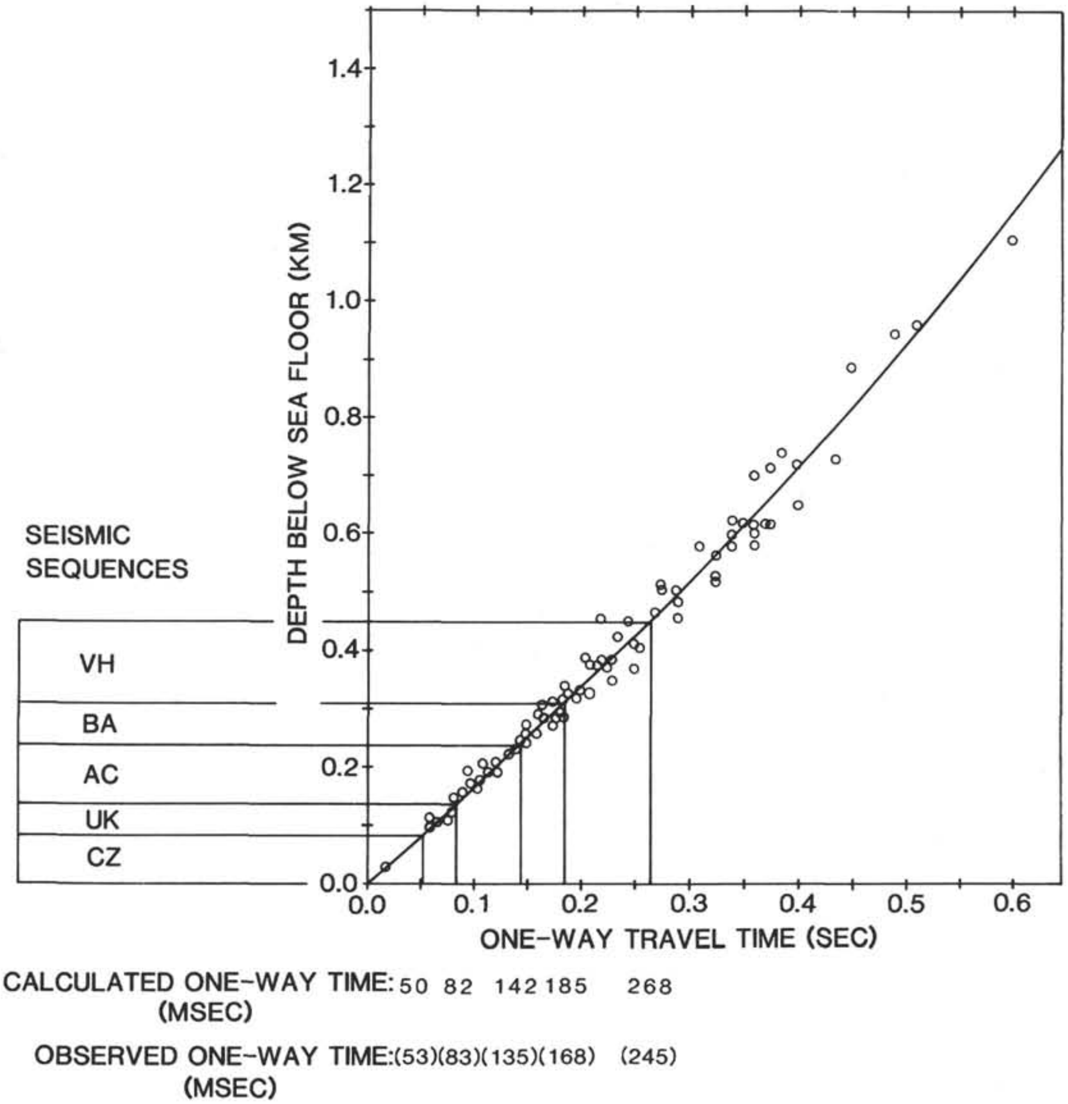


Figure 8. Graph showing correlation of lithologic unit boundaries with traveltimes determined from empirical curve of Carlson et al. (1986). These calculated traveltimes correlate closely with the observed traveltimes from seismic data at Site 766.

section is approximately 150 ms thick at Site 766. The sequence thins to the west, mainly by downlap or onlap onto the basement surface (Figs. 11 and 12). Along the western margin of the structural trough, the sequence pinches out against the faulted basement surface (Figs. 11, 12, and 14). The upper boundary is characterized by gentle truncation (Fig. 11).

Over much of the central area, the sequence is characterized by a thin upper zone of continuous to discontinuous high-amplitude reflections (Figs. 7 and 13). These are underlain by a thicker zone of moderately continuous to discontinuous, low to moderate amplitude reflections (Figs. 7, 11, 12 and 13). To the west as the unit thins and steps up over basement faults, a notable change occurs in seismic character to a more discontinuous facies (Fig. 14). In places, small basement faults appear to extend upward from the basement (Fig. 10) into the lower part of the unit (Fig. 11).

The VH sequence correlates with the thick wedge of upper Valanginian through Hauterivian sandstones and siltstones (lithologic subunit IIIB) that overlie and are intruded by the volcanic dikes and sills of the basement (Figs. 6 and 7). The group of higher-amplitude reflections at the top of the sequence probably represents the more mixed, sandy upper part of the unit, while the lower-amplitude, less-continuous lower part of the sequence probably represents the lower, more uniform siltstone part of the unit. The internal sedimentary structures in Subunit IIIB cores suggest deposition by gravity transport mechanisms, possibly grain-flow deposition (Ludden, Gradstein, et al., 1990). The downlap and onlap relations at the base and the internal seismic character tend to support this interpretation.

The notable lateral facies change to the west, above the faulted basement, probably represents a real geologic change. One possibility is that it represents a change from mass-gravity deposition in the deeper part of the rift basin to more distal pelagic deposition over the higher basement block above the turbidite plain. Alternatively, this facies may represent local gravity-flow deposits coming off the adjacent basement block to the west, or it simply might represent disruption of the section by small-scale faulting.

This unit apparently represents syn-rift sediments filling an asymmetrical basin formed during the initial rifting of the western Exmouth Plateau margin. Early sedimentation was coeval with

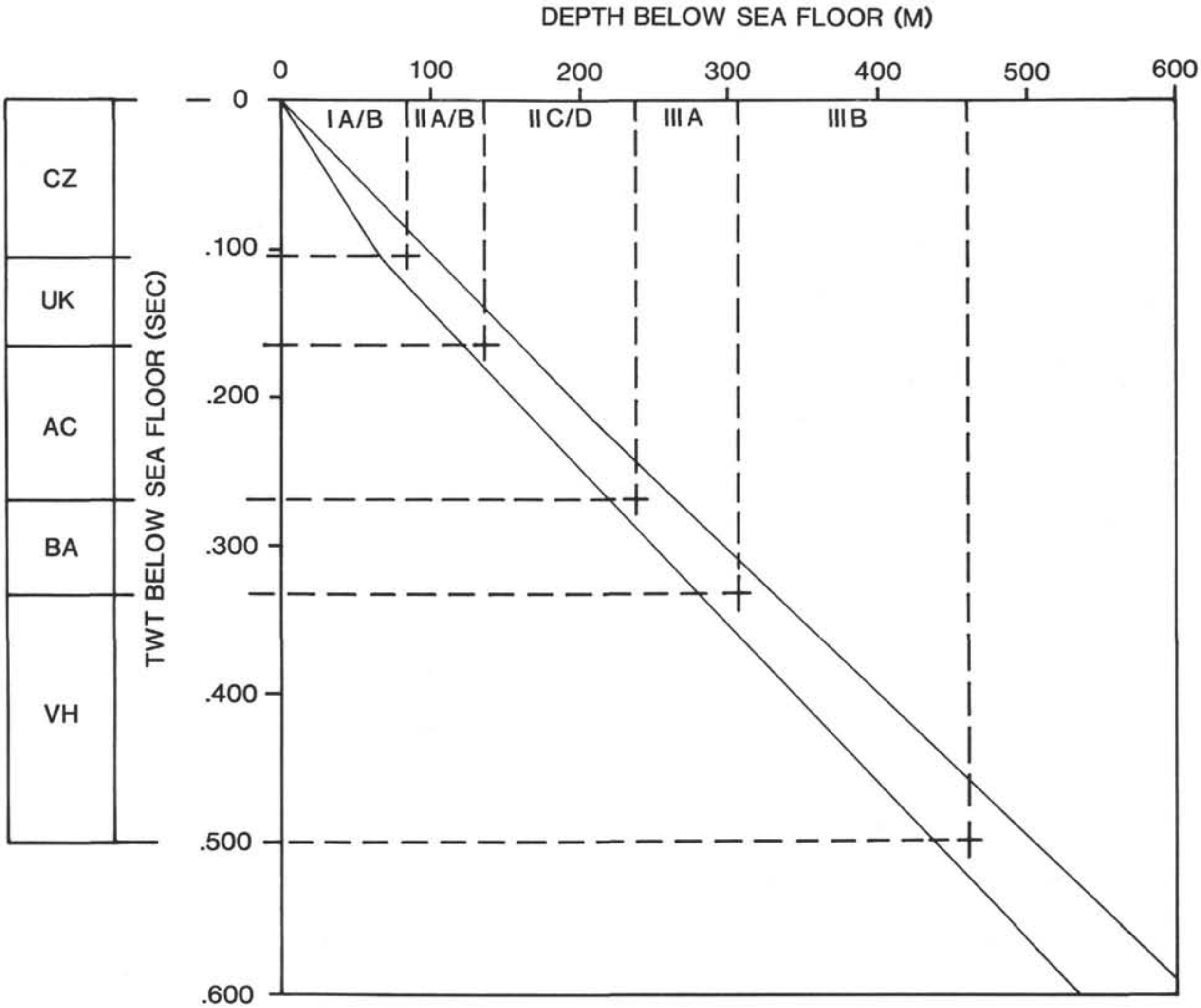


Figure 9. Plot showing envelope of two-way traveltime vs. depth curves calculated from the RMS velocity information generated during the processing of the BMR multifold seismic data in the vicinity of the site. A plot of the depths to the lithology boundaries vs. two-way traveltime to the seismic sequence boundaries (crosses) falls within this envelope, thus supporting the correlation.

the early emplacement of oceanic basalts, as indicated by the intrusive relations at the basal contact observed at the drill site. Faulting also continued during early sedimentation. The sedimentary structures of the unit suggest deposition in a deeper water setting, but exactly how deep is unknown. Preliminary subsidence modeling at the well site suggests an initial depth of water of about 800 m (Ludden , Gradstein, et al., 1990). This is approximately equivalent to its present depth below the adjacent plateau surface (1000 m), which may approximate the original relief along the faulted margin. The sediments in the unit are composed of abundant shallow-water material (glauconite, shallow-water organisms, etc.); thus, a nearby shallow shelf must have been the source of the sands and silts. Abundant volcanic material suggests erosion of a nearby volcanic terrane. Palynomorphs in the sediments suggest a landmass nearby and contain reworked Permian, Triassic, and Berriasian forms (A. McMinn, pers. comm., 1989).

The unit onlaps and thins abruptly along the base of the fault-controlled escarpment to the east and no canyons are apparent here, which suggests lateral filling of the basin. A possible canyon system occurs to the southeast between the two faulted basement highs (A and B, Fig. 15). Here, a thick section interpreted as equivalent to the VH unit (0410–0440, Fig. 15) may represent canyon fill in a depositional setting higher than the main part of the unit, suggesting a possible feeder system for the unit from the southeast. Possibly, a shallow shelf overlying a volcanic landmass lay just to the south and east and was the source of the sediments that filled this initial deep-water rift basin along the plateau margin. This unit is discussed further in the "Discussion" section (this chapter).

Barremian Sequence (BA)

The Barremian sequence (BA) has a relatively uniform thickness (40–60 ms) across most of the entire study area (Fig. 17). At the drill site, it extends from 5.630 down to 5.695 (two-way traveltime) (Fig. 7). The sequence onlaps and pinches out along the escarpments to the east and southeast (Figs. 12, 15, and 17). To the west it oversteps the VH unit and drapes up over the basement topography (Fig. 12). Farther west, it is absent due to erosion or nondeposition (Fig. 17). Internally, the sequence is characterized by low-amplitude reflections (almost transparent) over most of the area (Figs. 7, 11, 13, and 14). The lower boundary is a prominent unconformity characterized by truncation below and subtle onlap above (Fig. 11). The upper boundary has some local truncation and, in places, has an irregular erosional surface (Fig. 11). Over the western basement high, the local thickness

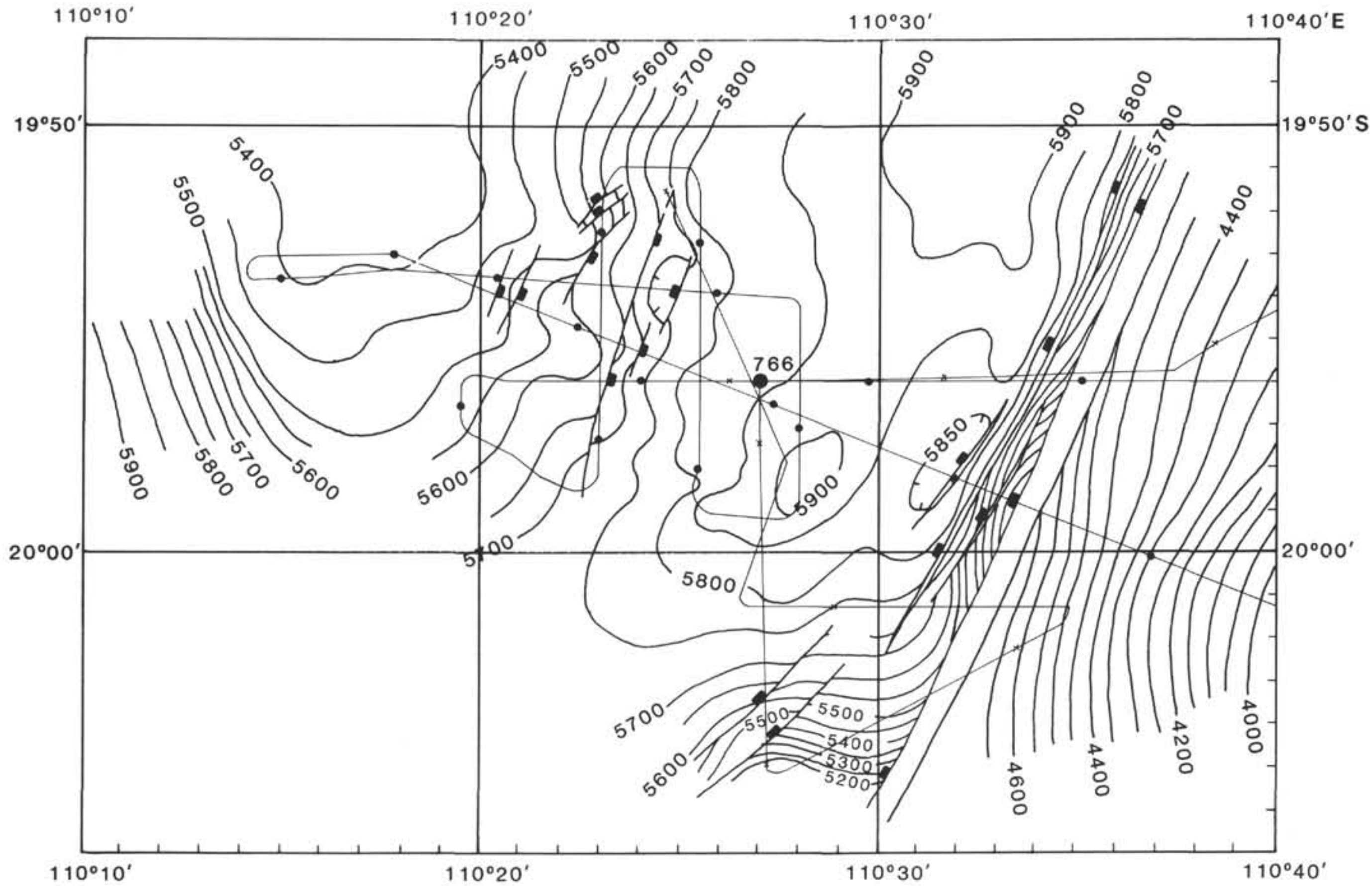


Figure 10. Depth to volcanic basement in two-way traveltime. Inferred faults hatched on downthrown side.

variations are controlled by small-scale faulting in the basement (Figs. 12 and 17).

At Hole 766, the BA sequence corresponds to the Barremian claystone subunit IIIA (Figs. 6 and 7). The almost transparent seismic facies of this sequence fits well with the uniform nature of the rocks. The unconformity at the top of the sequence corresponds with an unconformity identified at the drill site between the Barremian and the Aptian. The lower boundary corresponds to the lithologic change from sandstone below to claystone above. Regionally, this change probably reflects two causes: (1) overall thermal subsidence of the outer plateau and adjacent margins, following emplacement of the adjacent oceanic crust in the Cuvier and Gascoyne basins; and (2) a long-term rise in sea level at this time (Haq et al., 1987). Both of these effects might tend to have drowned out the local shallow-water sources along the outer plateau that were feeding the VH sequence. Thus, the basin became more isolated and received only hemipelagic muds being transported across the plateau from more distal sources to the east, off northwestern Australia. These muds filled in the main basin and also draped up over the adjacent basement high to the west, filling small, still locally active fault basins. The onlap and pinch-out to the east may have been controlled by local contour current systems flowing along the base of the escarpment.

Aptian–Cenomanian Sequence (AC)

The Aptian–Cenomanian sequence is more complex than the older sequences and extends across most of the study area. At the drill site, its upper boundary occurs at 5.525 (two-way traveltime) and its lower boundary at 5.630 (Fig. 7). The lower boundary is the Barremian/Aptian unconformity discussed above, which is characterized by local onlap and channel fill above (Fig. 11). The upper boundary is another prominent unconformity, which is characterized by onlap above and truncation below (Fig. 11) and corresponds to a break at the Cenomanian/Turonian boundary (Figs. 6 and 7). Internally, the sequence is characterized by alternating high- and low-amplitude, moderately continuous reflections (Figs. 7, 11 through 15). Several additional unconformities (characterized by local erosional truncation and onlap) can be identified within the sequence. These correspond to the two high-amplitude reflections at the drill site (Figs. 7 and 11). As these can be traced only locally within the seismic grid, they were not mapped as sequence boundaries.

The sequence is thickest through the central part of the study area (up to 120 ms, just over 100 m), thinning both to the east and west (Fig. 18). This trend is similar to that in the underlying unit, reflecting the continued influence of the overall basement structure in this rift basin. Thinning in the extreme west is by seafloor erosion, while to the east, the sequence pinches out along the base of the escarpment. A prominent thinning to 80 ms in the north-central part of the area (Fig. 18) is due to erosional truncation by the upper unconformable boundary (Figs. 11 and 12).

The AC sequence is equivalent to the Aptian through Cenomanian chalks that make up lithologic Subunits IIC and IID. Evidently, by Aptian time, the area had become completely isolated from any major terrigenous source. The sediments indicate a deep-water, open-marine setting that was receiving dominantly pelagic sediments, with only a minor background of clay. Strong erosional currents evidently swept the area periodically, as indicated by the several erosional unconformities within the sequence and marking the sequence boundaries, particularly at the top at the Cenomanian/Turonian boundary.

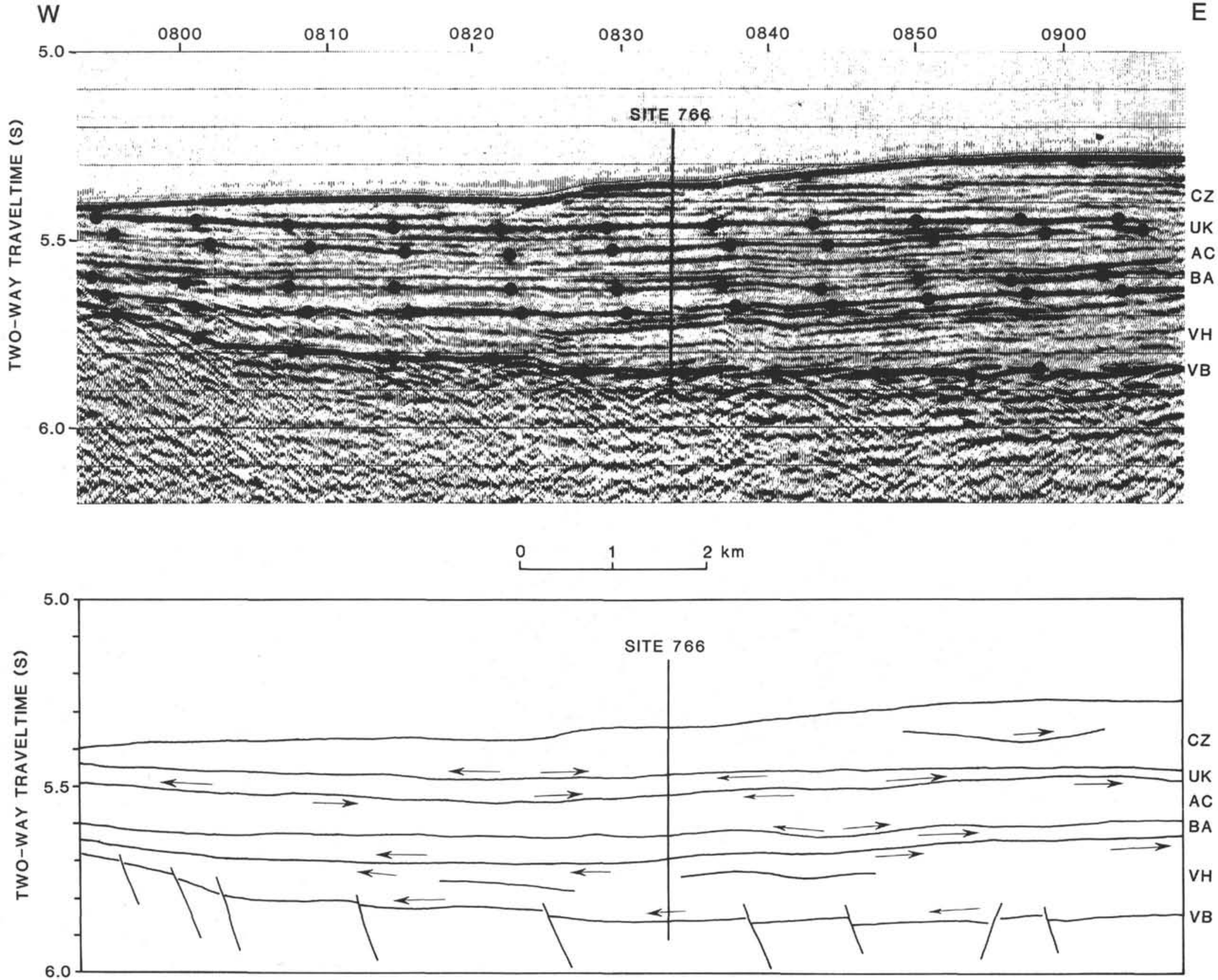


Figure 11. BMR multifold seismic Line 55/3E showing sequences in Site 766 area. Line drawing shows unconformable relationships at sequence boundaries (arrows). See Figure 3 for location.

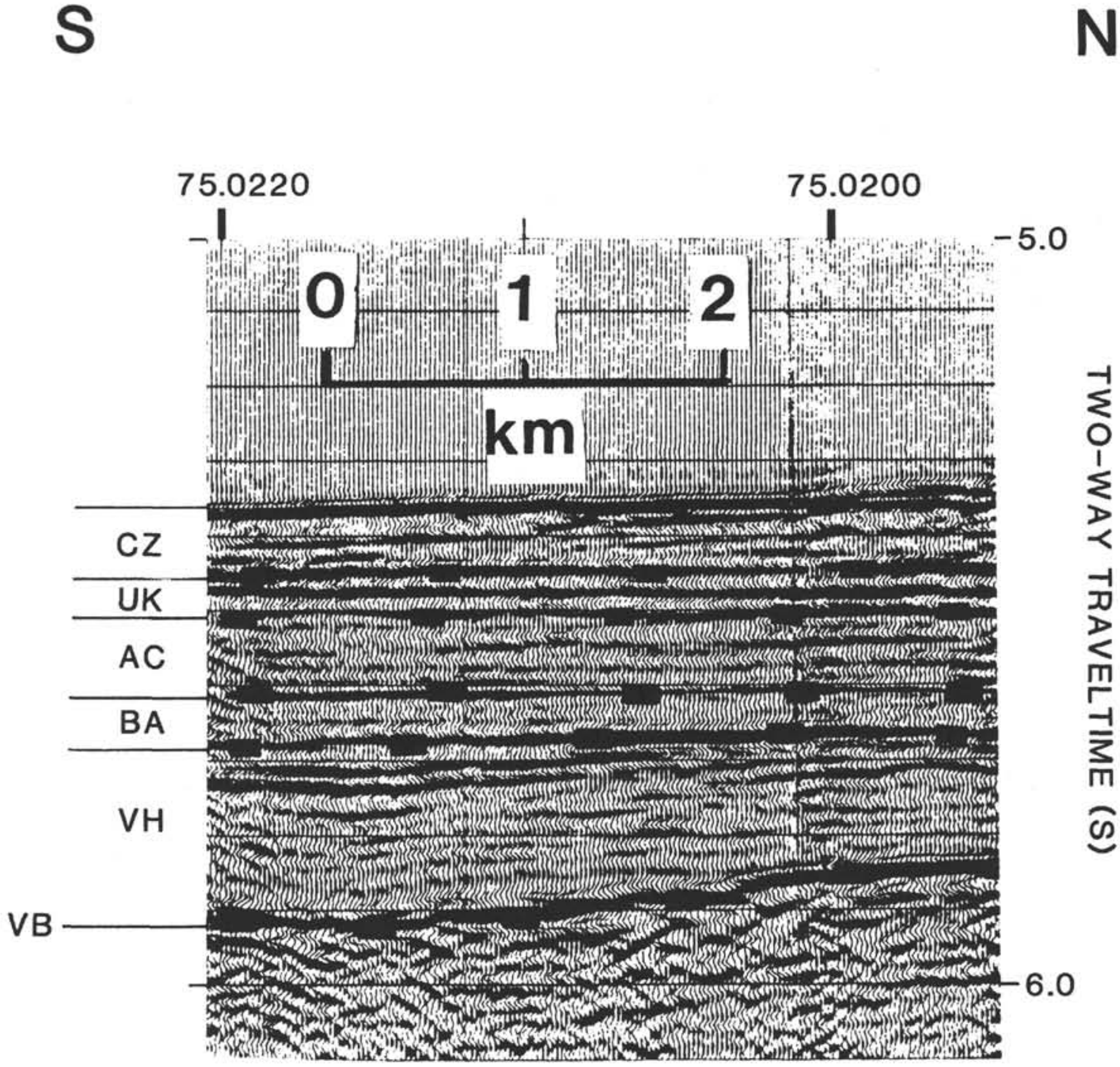


Figure 13. Portion of BMR multifold seismic Line 55/3B showing detailed seismic facies of seismic sequences. See Figure 3 for location.

Upper Cretaceous Sequence (UK)

The Upper Cretaceous sequence (UK) extends from 5.456 to 5.525 (two-way traveltime) at the drill site (Fig. 7). Its lower boundary corresponds to the prominent Cenomanian-Turonian unconformity discussed above, while its upper boundary is another prominent unconformity that is characterized by onlap above and truncation below (Fig. 11). This unconformity correlates with the top of lithologic subunit IIA, which actually corresponds to a break in the Paleocene. Thus, the upper part of the unit may be, in part, early Cenozoic in age. Internally, the sequence is characterized by moderately continuous, high- to low-amplitude reflections (Figs. 7, 11 through 15). The sequence is thickest in the central part of the basin, as well as to the northwest, where it fills in the erosional low along the lower boundary surface (Fig. 19). To the west, the sequence outcrops and is truncated by seafloor erosion, while to the east, the sequence has been truncated by Cenozoic erosion (Fig. 19).

The UK sequence correlates with the Upper Cretaceous oozes and thin, graded sequences of lithologic subunits IIA and IIB. Relatively starved, deep-water, open-marine conditions persisted in the study area throughout the Late Cretaceous. Strong erosional bottom currents probably continued to be active throughout the area during this time, as indicated by the erosional surfaces at the top and bottom of the sequence and by the abbreviated section in the drill hole. The onlap fill relationships of the unit support the partial deposition of the sequence by currents.

Cenozoic Sequence (CZ)

The Cenozoic sequence (CZ) represents the rest of the sedimentary section lying above the prominent Paleocene erosional unconformity discussed above. At the drill site it extends from 5.360 to 5.465 (two-way traveltime) (Fig. 7). The eroded seafloor forms the upper boundary. Internally, the sequence consists of alternating, continuous to discontinuous, high- to low-amplitude reflections. Several irregular and disconformable surfaces occur within the sequence and probably represent local erosional unconformities. The sequence is thickest in the central and eastern part of the area, where it has been better preserved and fills erosional channels (Fig. 20). It thins considerably to the southwest due to erosion and nondeposition at the seafloor and, finally, is truncated entirely at the seafloor (Fig. 20). An erosional remnant has been preserved to the west as an isopach thick (Fig. 20). Differential erosion of the various Cenozoic rocks produced a series of ter-

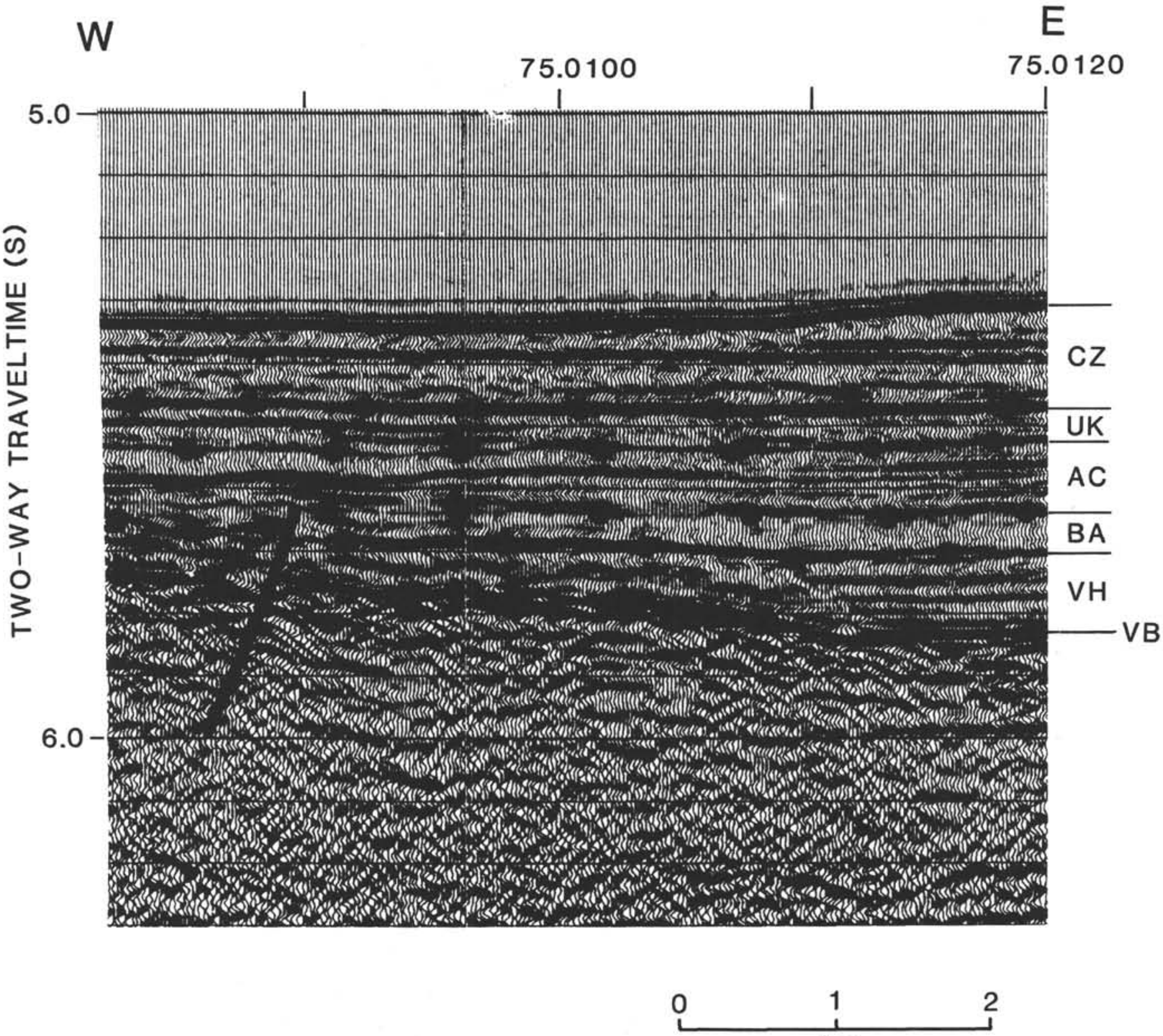


Figure 14. Portion of BMR multifold seismic Line 55/3 showing lateral facies change in VH sequence. See Figure 3 for location.

races across the area, as well as the high to the west, as indicated by the bathymetry map (Fig. 5).

The CZ sequence correlates with the Cenozoic oozes drilled at Site 766. Most of the section consists of Paleocene–Eocene rocks. A large hiatus occurs between these rocks and the overlying Pliocene section, but it is not clear which of the Cenozoic unconformities in the seismic data this represents. Deep-water, open-marine pelagic sedimentation, with some current deposition, persisted at this site throughout the Cenozoic. As with the older sequences, deposition was punctuated by intense erosion by deep sea currents.

DISCUSSION OF REGIONAL RELATIONSHIPS

Various aspects of the geologic history interpreted at the Site 766 area discussed above relate to the regional tectonic setting and geologic history around the site area. A few of these aspects are discussed briefly next.

Nature of Crust at Site 766

Previous studies in the area suggest that Site 766 was drilled on the earliest formed oceanic crust of the Gascoyne Abyssal Plain. For example, Veevers et al. (1985) mapped and modeled the continent/ocean boundary (COB) at the edge of the Exmouth Plateau based on magnetic data. Fullerton et al. (1989) also defined the COB at the edge of the plateau from magnetic data and identified the oldest magnetic anomaly running approximately through the site area as M-10 (late Valanginian). This age corresponds closely with the age of the oldest sediments cut by oceanic volcanic intrusions at Site 766, where (possibly) even anomaly M-11 was identified in cores (Ludden, Gradstein, et al., 1990). In addition, mapping of the area using a broad grid of seismic reflection data also suggests that the COB occurs along the outer margin of the Exmouth Plateau (Exon and Buffler, in press).

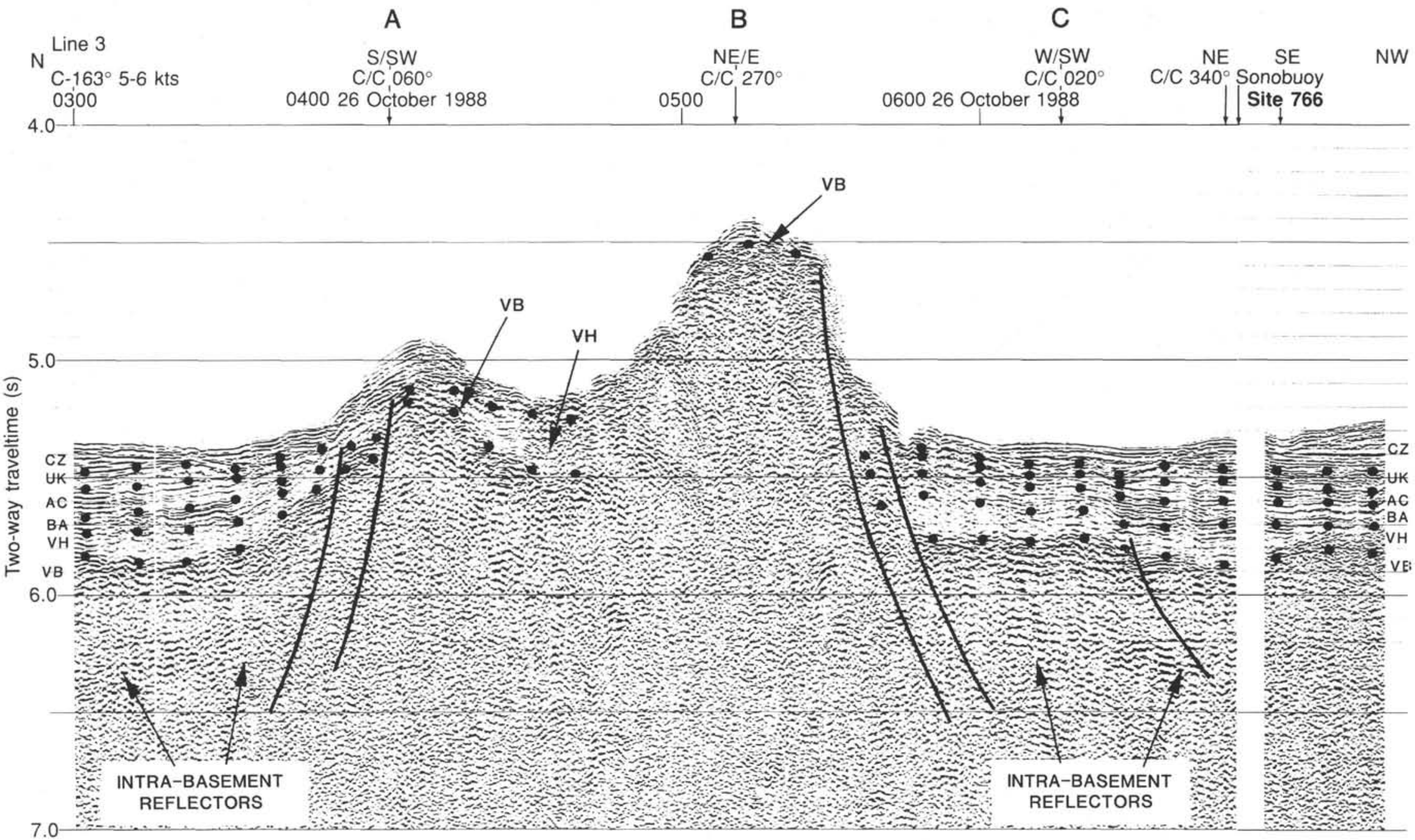


Figure 15. ODP single-fold seismic Line 3 across southern part of study area. See Figure 3 for location.

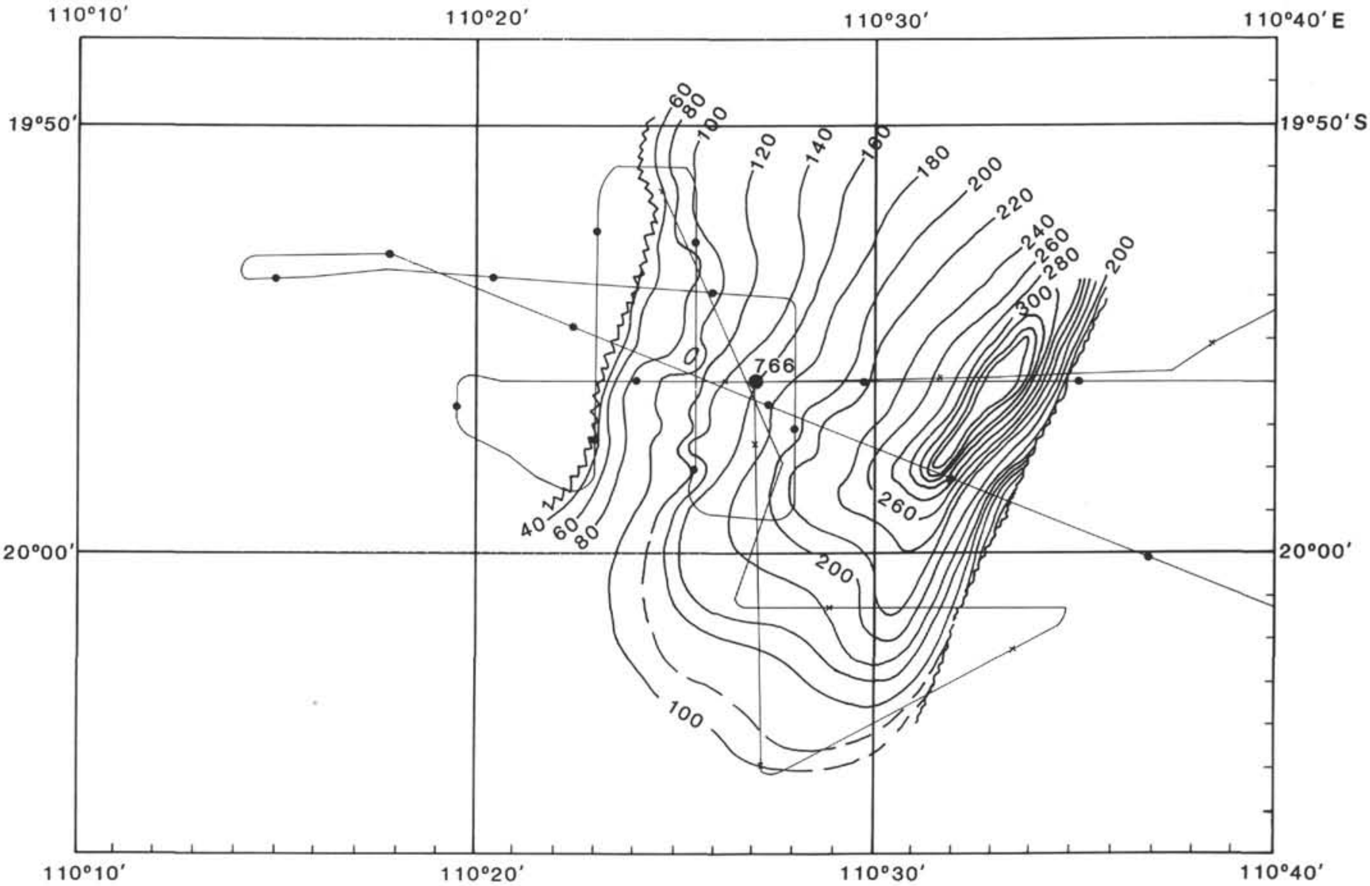


Figure 16. Isopach map (in two-way traveltime) of Valanginian–Hauterivian (VH) sequence. Contour interval = 20 ms.

Despite these studies and the fact that oceanic basaltic rocks were drilled at Site 766, several lines of evidence suggest that the crust below the site area is not true oceanic crust, but may be part of a narrow zone of rifted intermediate or very thin transitional crust lying between the previously thinned continental block of the Exmouth Plateau (20 km thick) and the adjacent Gascoyne oceanic crust. First of all, the depths to basement mapped in the study area (Fig. 10) and in the surrounding regions (Exon and Buffler, in press) are shallower (approximately 4500 m) than depths to which Cretaceous oceanic crust might have subsided. Depths between 5 and 6 km occur under the adjacent deeper ocean basins (Gascoyne and Cuvier abyssal plains). The shallower basement depths suggest a somewhat thicker crust below the site area. Furthermore, preliminary decompacted burial curves for Site 766 (Ludden, Gradstein, et al., 1990) project back to an initial water depth of approximately 800 m, not the 2200 to 2500 m expected for normal oceanic crust. Again, this suggests a thicker crust that never subsided to normal oceanic depths.

As discussed earlier, the site area is underlain by possible deeper intrabasement reflections that rise up toward the base of the westward projection of the adjacent Exmouth Plateau. Regional seismic studies by Exon and Buffler (in press) interpret the outer plateau basement to consist of latest Triassic-earliest Jurassic volcanic rocks. Perhaps the deeper reflections under the site area represent fragments of this older crust that simply collapsed or had been downfaulted along listric normal faults during the initial rifting process, forming a series of half-grabens. Such normal faults have been interpreted along the eastern part of the study area, at the steep escarpment (Fig. 10). This regional relationship is shown schematically in Figure 2. At the same time as the faulting and rifting, the older volcanics were injected and intruded by the initial oceanic magmas, which form the basement in the site area and were drilled at Site 766. Thus, the area of shallower crust might represent a narrow zone of true transitional crust, i.e., rifted continental crust that has been intruded during the latest rifting stage just prior to the emplacement of true oceanic crust. This type of crust would be too buoyant to subside to true oceanic depths.

The major problem with this scenario is explaining the magnetic anomalies, interpreted to be seafloor spreading anomalies, which begin at the edge of the plateau and extend over the site area and the area of inferred transitional crust (Veevers et al., 1985: Fullerton et al., 1989). As mentioned above, anomaly M-10 extends approximately through the site area. Perhaps enough margin-parallel oceanic rocks were intruded along the initial rifts to produce the anomaly pattern observed. Intrusion of oceanic volcanics along the margin is further supported by the occurrence of several small magnetic anomalies present on profiles at the outer plateau just landward of the escarpment in the site area (Veevers et al., 1985: Buffler, 1990).

Farther west of the site area is a large, anomalously high (less than 3.5 km) bathymetric rise area (Fig. 4), which is underlain by relatively shallow basement. This area overlies younger oceanic crust, as identified by magnetic anomalies (M-6 to M-8), and has been interpreted as a large volcanic pile (Exon and Buffler, in press). It occurs adjacent to the projection of the Cape Fracture Zone and may represent a major volcanic outpouring along a leaky fracture zone during the formation of the oceanic crust. Alternatively, it may represent a younger volcanic pile extruded later onto older crust. Similarly interpreted volcanic piles or rises occur in

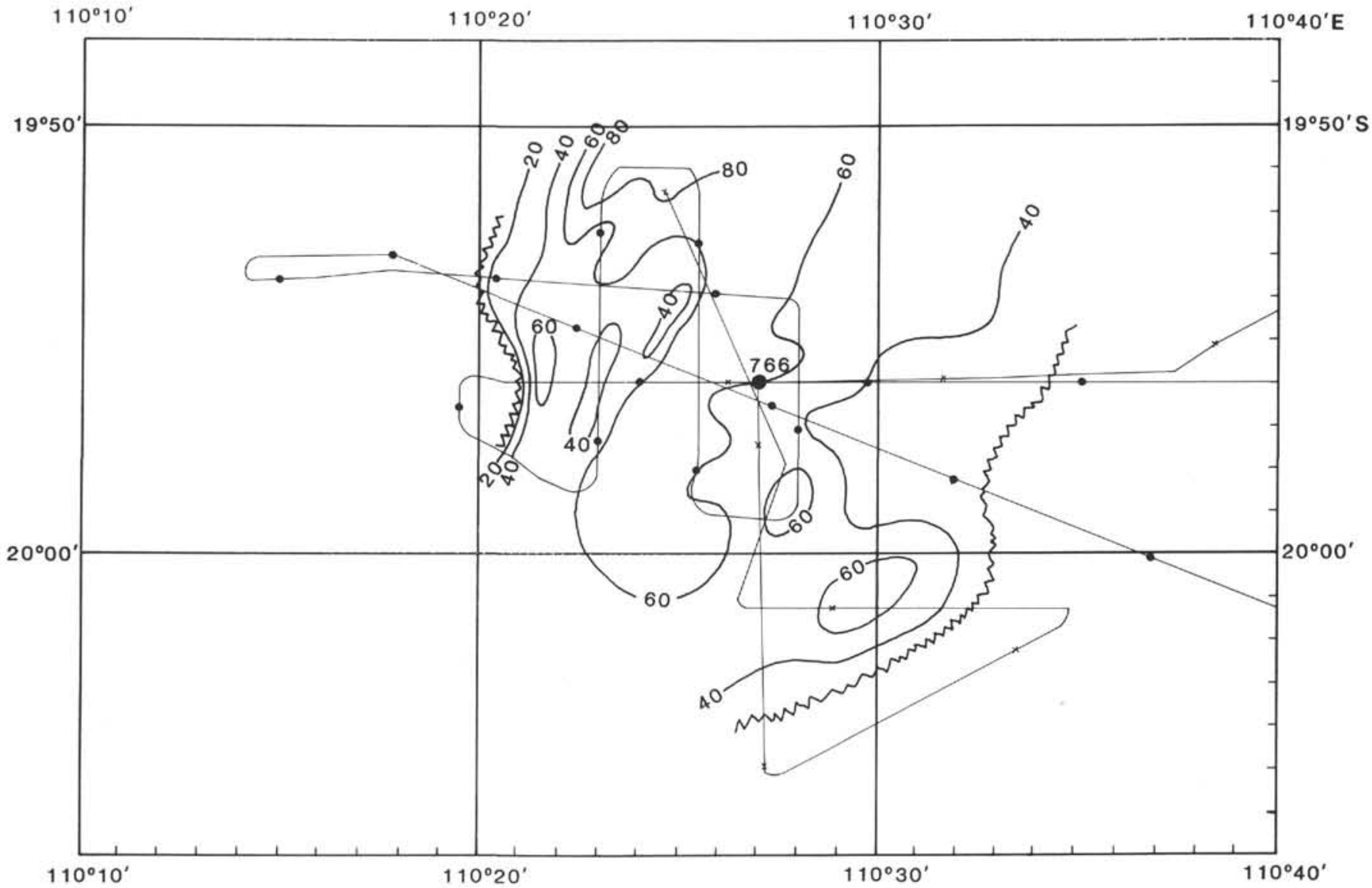


Figure 17. Isopach map (in two-way traveltime) of Barremian (BA) sequence. Contour interval = 20 ms.

similar settings farther to the north, along the northwest margin of the Exmouth Plateau (e.g., Joey and Roo rises, Veevers, 1984).

Regional Setting and Origin of the VH Sequence and Related Rocks

The VH seismic sequence (lithologic Subunit IIIB), which consists entirely of siltstone and sandstone, is interpreted as having been deposited in a relatively deep-water rift-basin setting along the outer margin of the Exmouth Plateau. This interpretation is based on several lines of evidence. First, the sedimentary structures in the cores suggest deposition by gravity flow mechanisms, most likely grain flow, based on the massive and uniform nature of the rocks (Ludden, Gradstein, et al., 1990). Faunal evidence is inconclusive. Second, preliminary decompacted burial curves show an initial water depth of approximately 800 m (Ludden, Gradstein, et al., 1990). A similar water depth also can be inferred from the relief along the faulted margin of the basin, i.e., from the outer edge of the plateau to the bottom of the basin (approximately 1000 m). This relief is thought to be close to the original relief. The unit is inferred as synrift in nature because it onlaps and fills the faulted basement. In addition, the unit itself is faulted and the basal section is intruded by oceanic volcanics. These relationships suggest that the major faulting, formation of the rift basin, and establishment of a deep-water setting mainly took place just prior to deposition of the sequence.

The composition of the VH unit (volcanic sands with abundant glauconite and shallow-water carbonate debris) indicates a shallow-water source area nearby. This source area probably consisted of a series of volcanic islands or small landmasses, surrounded by shallow shelves along the western edge of the Exmouth Plateau. Results from a preliminary study of spores in the VH unit (A. McMinn, pers. comm., 1989) are indicative of nearby landmasses. This interpretation is further supported by a study of the regional seismic data by Exon and Buffler (in press), who demonstrated that the western Exmouth was high and being eroded during the Neocomian. On the adjacent plateau, a thick wedge of sediment, equivalent to the early Neocomian Barrow Group farther to the east, onlaps and fills in an irregular surface on the top of the inferred Triassic–Jurassic volcanic rocks that formed the basement of the outer plateau. Evidently, this volcanic terrane was the local source for the VH unit. There is no equivalent of this unit at Site 766, as it was deposited prior to the rifting. In addition, the upper part of the volcanic sequence is planated, in places, by prominent erosion surfaces, suggesting erosion at wave-base. Thus, both the volcanic basement, as well as the older Barrow Group equivalent, may have been the source of the volcanic sands within the VH unit.

As discussed earlier, the most likely conduit for the sediments entering the deep basin is to the southeast, at the intersection of the eastern escarpment with the westward extension of the plateau. Here, a wedge of sediment, interpreted as equivalent of the VH unit (Fig. 15, between A and B), occurs higher than the basin floor and has been interpreted as filling a canyon system. As no obvious canyons have been recognized along the eastern escarpment, this is a possible entry point for the sediments filling the basin.

A local source for sediments during this time also is supported by the seismic stratigraphy of the post-Barrow, Lower Cretaceous sedimentary section on the adjacent plateau (Exon and Buffler, in

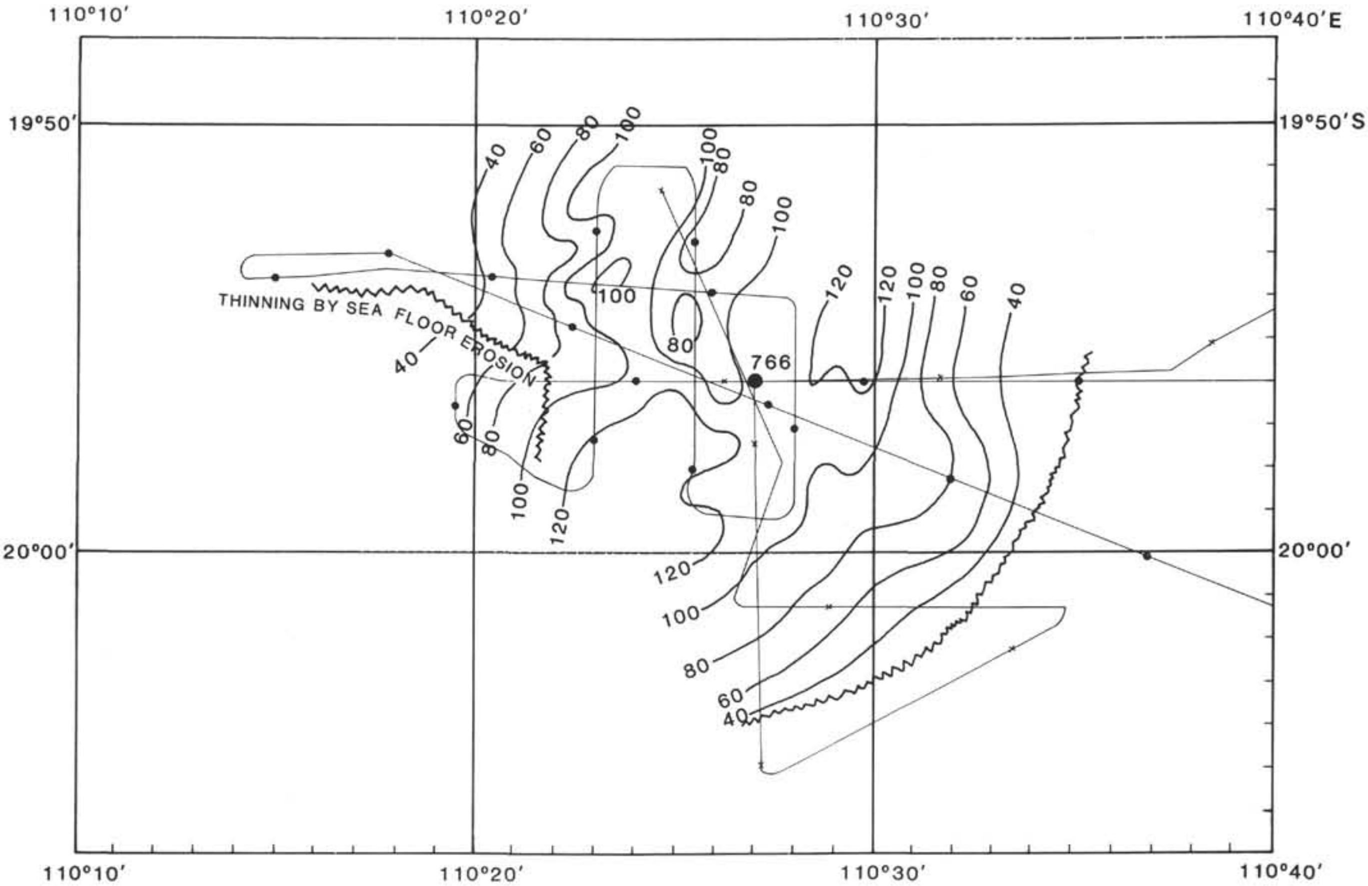


Figure 18. Isopach map (in two-way traveltime) of Aptian–Cenomanian (AC) sequence. Contour interval = 20 ms.

press). Here, the lower part of this section consists of a thick wedge that progrades and thins eastward, away from the volcanic high along the outer plateau. This locally derived wedge is inferred to be the equivalent of the VH unit in the adjacent basin.

It is not clear why the outer plateau was elevated, but it may have been because of thermal uplift of the margin just prior to and during initial rifting and seafloor spreading in the Gascoyne ocean basin (Exon and Buffler, in press). In addition, the area along the Cape Range Fracture Zone (CRFZ) to the southeast also had been uplifted at about the same time, again probably because of thermal upwelling just prior to and during the rifting and opening of the Cuvier ocean basin (Exon and Buffler, in press). At the time of deposition of the VH unit, the Cuvier ocean basin was just opening and "Greater India" was moving past the study area just to the south. The completion of the passage of "Greater India" past the study area and a major ridge jump at anomaly M-5 time (Fullerton et al., 1989) occurs at about the same time as the shutting off of the coarse clastics of the VH unit and the deposition of the overlying claystones of the BA unit. This suggests that the area had begun to subside rapidly due to the emplacement of adjacent oceanic crust; thus drowning the local source areas and cutting off the supply of coarse clastics.

There is no unit equivalent to much of the VH unit at Sites 762 and 763 on the central plateau. This time period (early Valanginian to middle Hauterivian) is represented by a hiatus directly above the Barrow Group, with three dinoflagellate subzones missing that represent about 7 m.y. (Brenner, in press). As mentioned above, however, there may be a shallow-water equivalent of the VH unit on the adjacent outer plateau, where an eastward prograding wedge lies directly on the Barrow equivalent (Exon and Buffler, in press). It is not clear why there is no VH equivalent in the central plateau. The setting here presumably was still a relatively deep-water setting at the foot of the prograding clinoforms of the older Barrow delta sediments. It is unlikely that sea level fell far enough to expose the area to erosion. A deep-water setting is supported by the presence of equivalent age turbidites along the base of the Barrow Group farther to the east (Flagg turbidite sandstones), which are overlain by the transgressive Mardie-Birdrong glauconitic sandstones and the equivalent deeper-water Muderong shale (Boote and Kirk, 1989).

A possible explanation for the hiatus begins with a drop in sea level, during which the Flagg turbidites were deposited to the east. During this time apparently no sediments reached the central plateau. At the same time, the VH and equivalent shallow-water units had begun to be deposited along the outer plateau. This was then followed by a rise in sea level, which resulted in deposition of transgressive sands to the east, but caused a period of starvation or nondeposition (condensed interval) on the central plateau, i.e., the area was too deep and too distal from any terrigenous source. In addition, currents may have been sweeping the plateau, preventing deposition. On the sea-level curve of Haq et al. (1987), this should correspond to the 123.5 m.y. condensed section. This still leaves the question as to why the outer plateau remained high and a local source of sediments during the overall rise in sea level. This can be best explained by the continued thermal uplift of the margin, associated with the initial rifting and seafloor spreading, as well as movement of "Greater India" along the Cape Range Fracture Zone.

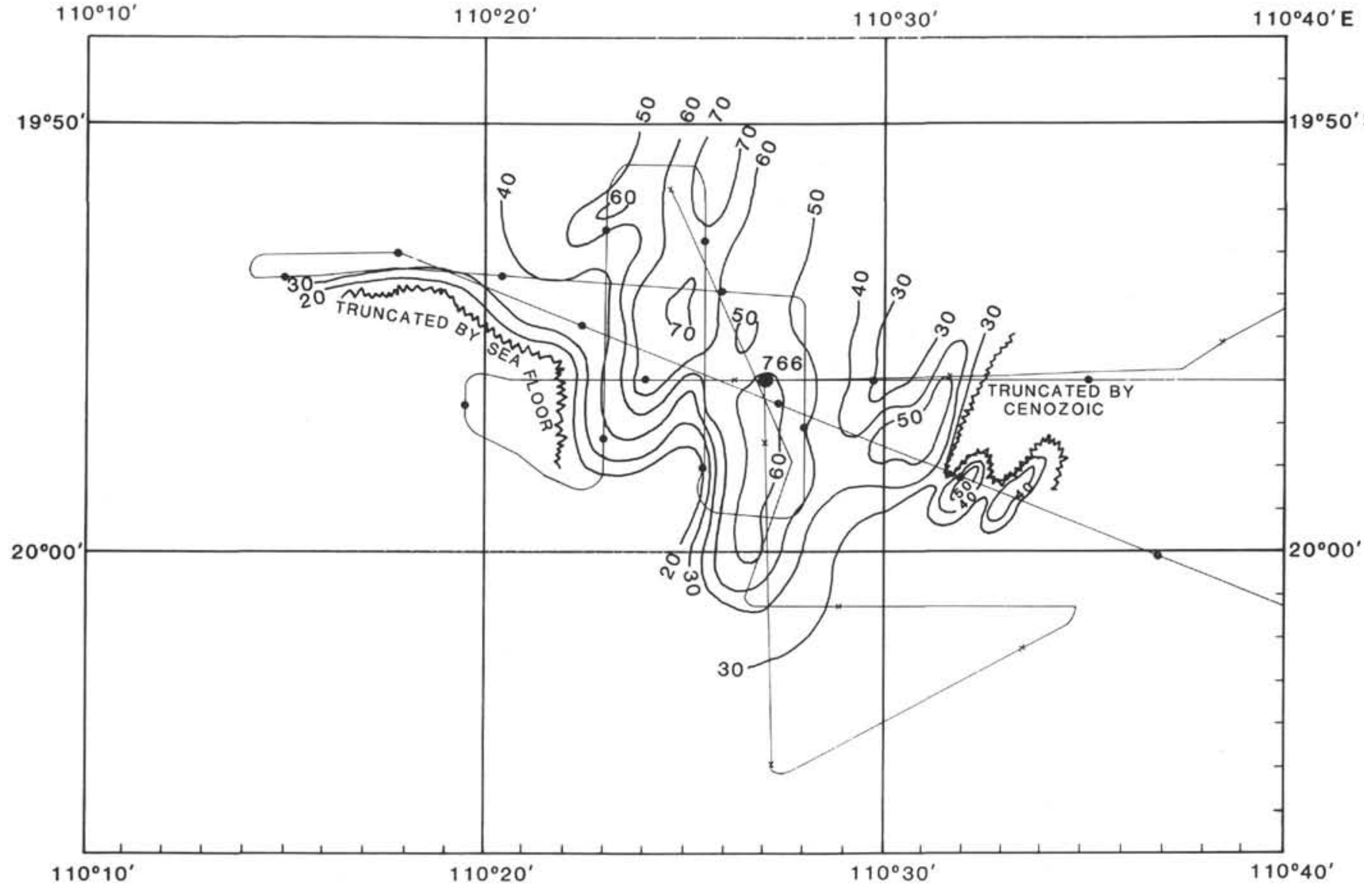


Figure 19. Isopach map (in two-way traveltime) of Upper Cretaceous (UK) sequence. Contour interval = 10 ms.

Late Hauterivian–Late Cretaceous Depositional Changes

Seismic studies and drilling results at Site 766 and the adjacent Exmouth Plateau (Sites 762 and 763) indicate both similarities and differences in the late Hauterivian through Late Cretaceous depositional history of the region. These similarities and differences can be expressed by the timing and distribution of two major depositional changes: (1) the reduction of major terrigenous influx and (2) the change to virtually clay-free sedimentation. At Site 766, major terrigenous influx disappears at the top of the Barremian claystone (seismic sequence BA) (Fig. 6), which is overlain by Aptian and younger chalks with minor clay. At Site 762, the major terrigenous influence disappears a little later, at mid-Aptian time at the top of the Muderong shale (Exon, et al., in press). Farther south at Site 763, the change occurs even later, between the mid-Aptian and mid-Albian. This progression in age apparently reflects the proximity to a southeasterly terrigenous source, as the plateau became more isolated by continued subsidence and long-term rise in sea level. The more distal site (766) became the first to be isolated, while Site 763 continued to receive significant influx the longest because it was nearer the source.

A background of terrigenous clay continued to be present in the younger, marly chalk section at all drill sites, representing the rest of the Lower Cretaceous and part of the Upper Cretaceous. Final disappearance of all terrigenous influx and deposition of almost pure, clay-free pelagic carbonates took place at about the same time throughout the region; early Campanian at Site 766 (Ludden, Gradstein, et al., 1990) and early Santonian at Sites 762 and 763 (Exon et al., in press), as well as throughout the plateau (Veevers and Johnstone, 1975). This change may be related to a major reorganization of oceanic circulation, perhaps caused by the breakup of Australia/Antarctica. However, this also may simply be due to the plateau having subsided and become too deep and too remote from any significant terrigenous source area.

Paleocurrents

Drilling at Site 766 indicates that this area along the base of the western Exmouth Plateau has been a site for deep-water deposition since Early Cretaceous time. The seismic stratigraphic study outlined above further indicates that strong bottom current systems have been active here for equally as long. Evidence for this is the numerous unconformities characterized by erosional truncation of reflections. These unconformities define major sequence boundaries, as well as occurring within the sequences themselves, and probably represent periods of intensified current action. In addition, present bathymetry is characterized by erosional terraces, benches, and remnants, suggesting that currents continued to be active through the late Cenozoic to Holocene.

The orientation of these erosional features is north-south, subparallel to the adjacent steep margin, which indicates a long-term flow parallel to and influenced by the margin. The swing in orientation to the southwest and the truncation of younger beds to the southwest suggest that these currents were deflected in that direction, probably as a result of the bathymetric and basement high that protrudes to the west, along the southern part of the study area. Many of the buried erosional channels in the Cretaceous section are onlap-filled by the overlying strata along the main axis of the basin, indicating deposition by less intense, nonerosional

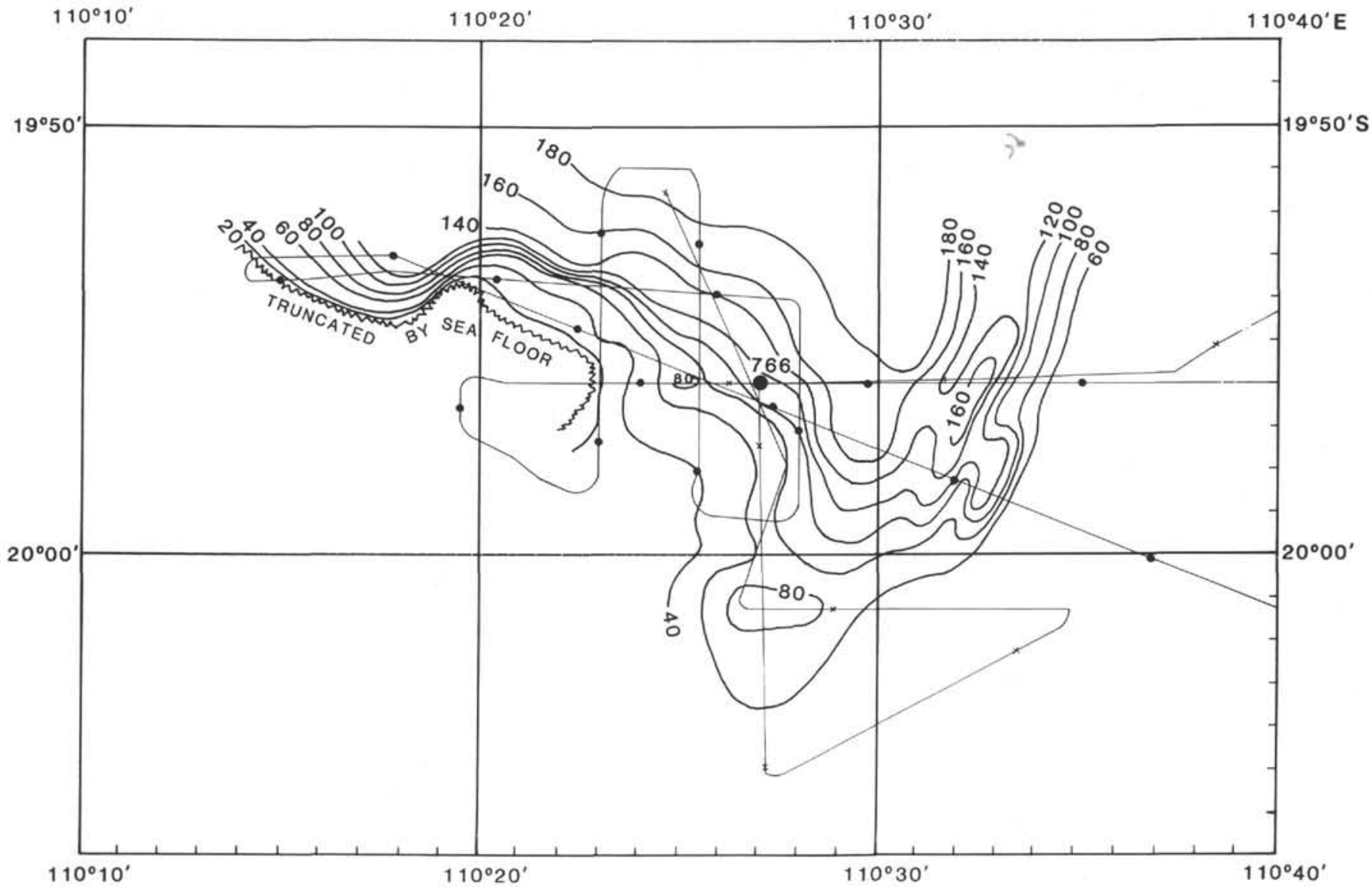


Figure 20. Isopach map (in two-way traveltime) of Cenozoic (CZ) sequence. Contour interval = 20 ms.

current systems, rather than strictly by pelagic drape. To the west, out of the axis of the currents, the units tend to drape up over the basement high. To the east, above the escarpment along the outer Exmouth Plateau, the Cretaceous and Cenozoic sections lying above the planated volcanic basement are abbreviated, indicating extensive current activity was concentrated in this area as well.

ACKNOWLEDGMENTS

We are grateful to the many members of the shipboard scientific parties of Legs 122 and 123 for their detailed work at Sites 762, 763, and 766 and for their helpful discussion regarding the seismic interpretation. We are particularly grateful to Paul Williamson of the BMR for his work with collecting, processing, and interpreting the site survey data, and to Ron Boyd and Tom Davies for their thoughtful reviews. Our appreciation goes to the BMR for permission to publish the BMR seismic data. N. Exon publishes with the permission of the Executive Director, Bureau of Mineral Resources, Canberra, Australia. Wayne Lloyd assisted with drafting of the figures. This is University of Texas Institute for Geophysics Contribution No. 835.

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Date of initial receipt: 4 June 1990
Date of acceptance: 22 May 1991
Ms 123B-138