SOUTHEAST GEORGIA EMBAYMENT

HIGH-RESOLUTION SEISMIC-REFLECTION SURVEY

by

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ABSTRACT

A high-resolution seismic survey of the offshore part of the Southeast Georgia Embayment on about a 20 km spacing was completed in 1976. A stratigraphic analyses of the data shows that the largest controlling factor in the depositional history of the shelf has been the Gulf Stream. These currents have shifted back and forth across the shelf, at times incising into shelf sediments, and at all times blocking much of the accumulation of Cenozoic sediments seaward of the Florida-Hatteras Slope. In the southern region the Gulf Stream maintained its present position since Miocene time, blocking the accumulation of Pliocene and younger rocks on the Plateau. Northward, in the middle, region the currents turned slightly to the northeast. The inner portion of the Blake Plateau has been scoured of sediments since the Paleocene in this area, and scouring has also occurred on the shelf from time to time. In the northern part of the survey area a more easterly flow of the Gulf Stream has allowed Eocene and younger rocks to be deposited on the Plateau. Line drawings and a geologic map show the distribution of the various Cretaceous and Cenozoic units.

A number of potential environmental hazards or constraints to petroleum development seen in the reflection data are identified. Besides current scour and erosion features, these include gravity faults on the slope, a slump, faulting on the inner Blake Plateau, the shelf edge reef, and deep water reefs on the Blake Plateau.

INTRODUCTION

During June and July of 1976, the U.S. Geological Survey conducted a high-resolution seismic-reflection survey of the offshore part of the Southeast Georgia Embayment. The embayment is an east-plunging depression recessed in the Coastal Plain between the Peninsular Arch of Florida and the Cape Fear Arch of North Carolina (Figure 1). The embayment opens seaward onto the Blake Plateau Trough.

Data were collected on the Continental Shelf, Florida-Hatteras Slope, and western portion of the Blake Plateau between $29^{o}30'$ and $33^{o}31'$ N (Figure 2). This survey represents the most complete coverage of the Southeast Georgia Embayment to date, allowing a careful regional analysis of geologic hazards. In addition, the minisparker records have provided a much more detailed understanding of the Cenozoic development of the area.

A 600-joule minisparker was used to penetrate the first half-second of subbottom strata. The data were filtered between 280 and 1060 hertz. Excellent records were obtained in all areas except on the shallowest portions of the continental shelf, where the interference of bottom multiples prevented the positive identification of deeper reflecting horizons. An integrated navigation system was used. It included a Teledyne Loran C, Magnavox Satellite receiver, Sperry Mark 29 gyro, and a Chesapeake speed log integrated with a Hewlett Packard HP-21 MX, and a data acquisition computer with dual track magnetic tape recording. Range-Range Loran was the primary system. Hyperbolic Loran and the gyro were used as secondary systems. Reliable satellite fixes were generally within 150 m of either Range-Range or hyperbolic Loran positions.

This report deals with the analysis of minisparker records in terms of acoustic units. An acoustic unit, as observed on the minisparker

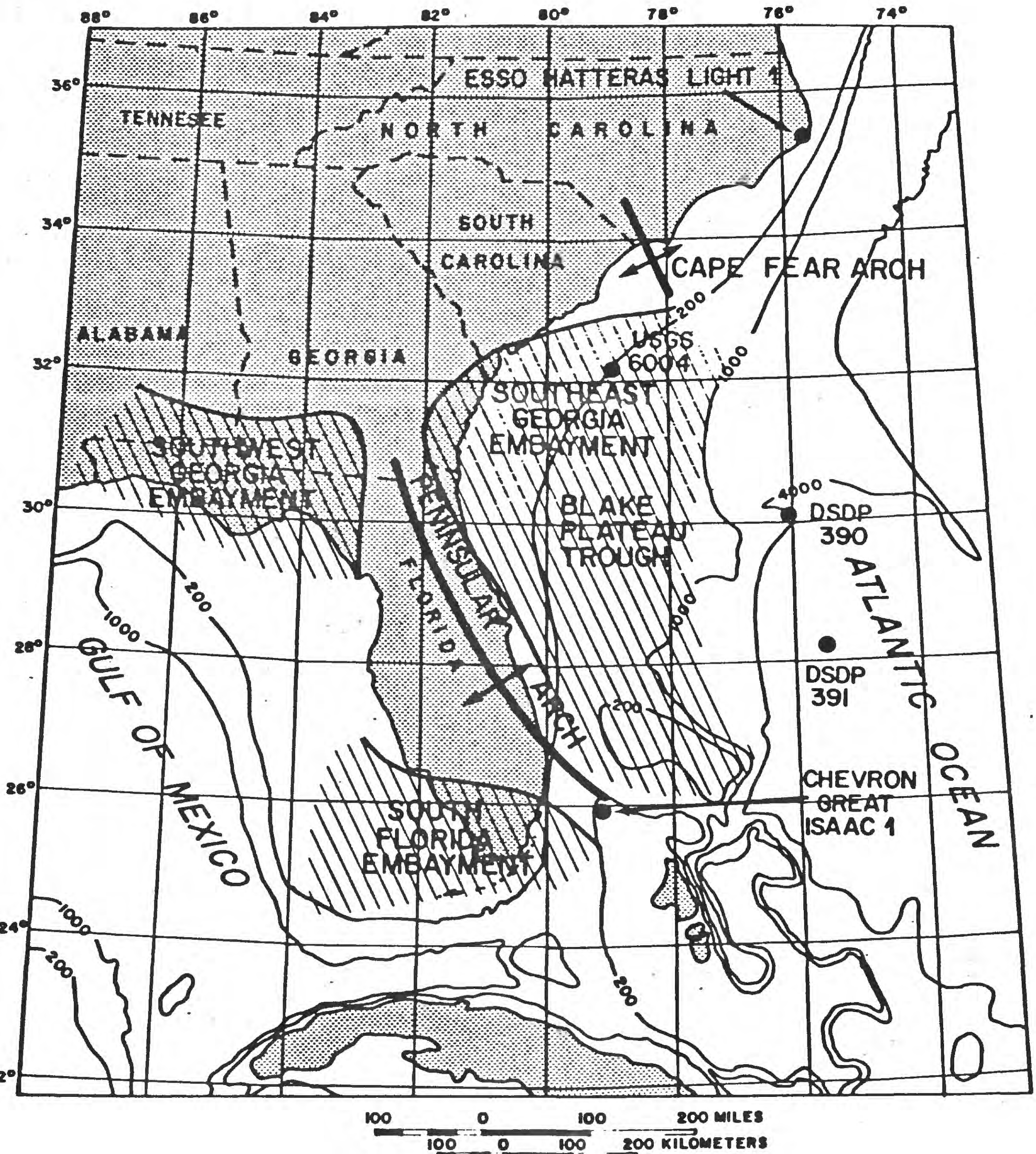

Figure 1

SOUTHEAST GEORGIA EMBAYMENT

from Dillon and others
(in press, Figure 1)

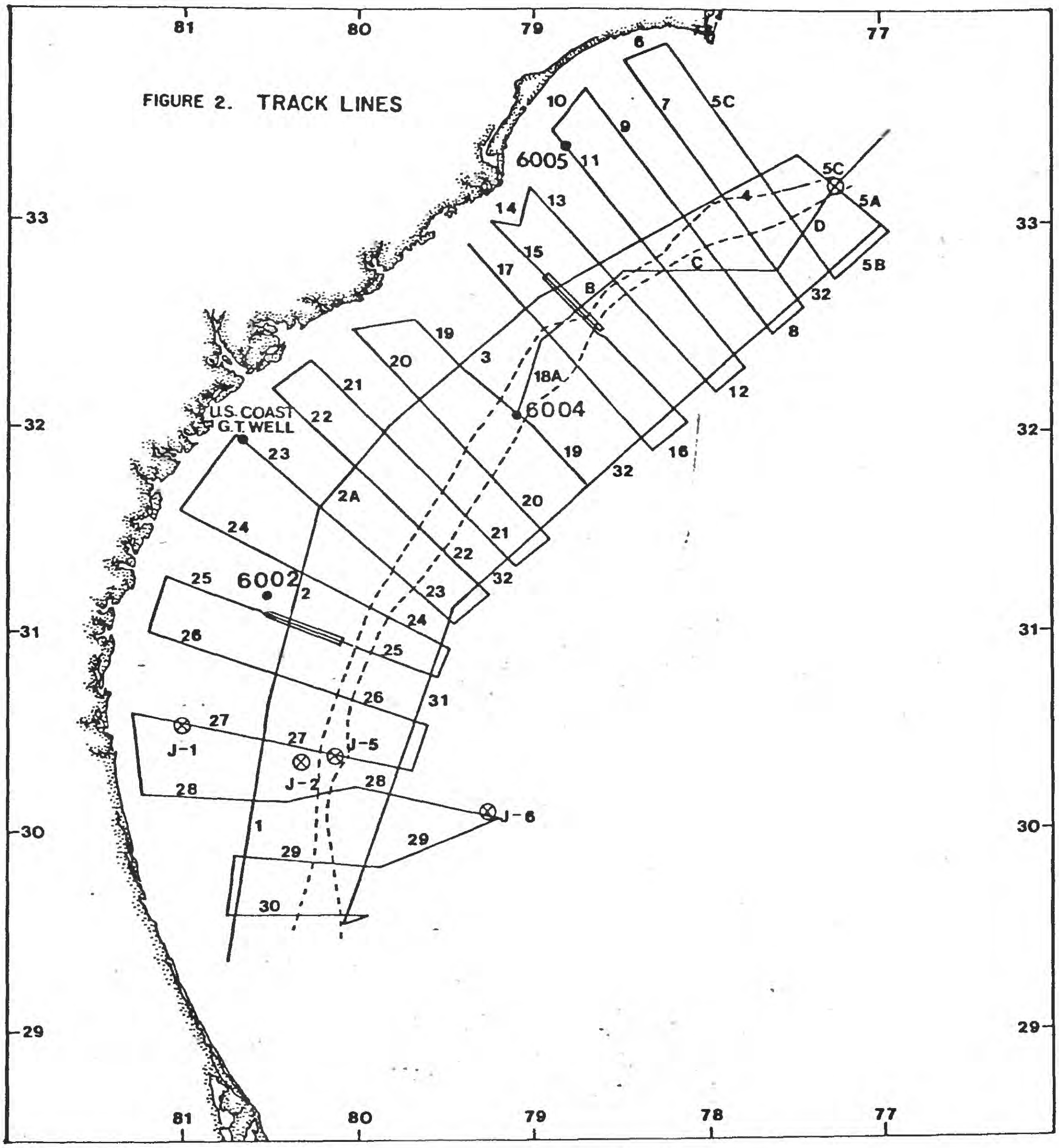
FIGURE 2. TRACK LINES
81
80
79
78
77
33
32
31
30
29
U.S. COAST G.T. WELL
6005
6004
6002
J-1
J-2
J-5
J-6
5A
5B
5C
18A
2A

records, is a relatively comformable sequence of related strata (Vail and others 1976). Each unit is separated from sequences above and below by unconformities or their correlative conformities. In most instances, the acoustic impedence contrast is larger between units than within units, showing on the record as a stronger reflector. Eight major acoustic units were identified within the study area. Reflections bounding these units were traced around the grid network of 21 NW-SE lines and 3 NE-SW tie lines. Geologic ages could be assigned to the acoustic units based on dated materials recovered at several drill sites and from published and unpublished descriptions of vibracores, piston cores, and dredge samples from the area. Depths to unconformities observed on the minisparker records were correlated with stratigraphic horizons established at drill sites by assuming seismic velocities between 1.5 and 1.8 km/sec. Once the age for a particular acoustic unit was established in this manner, the continuity and age equivalency of this unit were verified elsewhere on the grid network.

Tracings of reflections observed on the minisparker records were converted to true depth cross sections, assuming sound velocities of 1.5 km/sec in water and sediments. Approximate vertical exaggeration is X20 on the line drawings (Appendix B).

GEOLOGIC STUDIES IN THE SOUTHEAST GEORGIA EMBAYMENT

The continental margin in the Southeast Georgia Embayment differs from the typical shelf-slope-rise transition because of the presence of the Blake Plateau, which interrupts the slope at a depth of several hundred meters. The Continental Shelf and Florida-Hatteras Slope landward of the Blake Plateau consist of a gently southeasterly dipping sequence of Tertiary and Quaternary sediments that have upbuilt the

Shelf and outbuilt the Slope. Erosion has modified the Blake Plateau and the Florida-Hatteras Slope since early Cenozoic times. The Southeast Georgia Embayment lies in the transition zone between the calcareous province of Florida and the Bahamas and the clastic province north of Cape Hatteras. U.S. Geological Survey Open File Report 75-411 (Dillon and others 1975) summarizes the geology of this region. Several articles (Hersey and others 1959; Ewing and others 1966; Emery and Zarudzki 1967; and Uchupi 1967) discuss interpretations of seismic reflection records across the continental margin.

Many hundreds of wells drilled onshore in Florida, Georgia, and South and North Carolina have provided detailed information on the structure and stratigraphy of the sediments and rocks underlying the Atlantic Coastal Plain. McCollum and Herrick (1964) have reported on the stratigraphy of a drill hole in 17 m of water on the continental shelf at 31°56′53.5" N, 80°41′00" W. In 1965, six holes were drilled east of Jacksonville, Florida by the Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) Program. However, until the summer of 1976, no drill sites were available on the main part of the Continental Shelf in the embayment. The JOIDES holes (Figure 2) revealed a continuity in age and lithologic character of the onshore and offshore sequences at the south end of the embayment (Bunce and others 1965; Schlee 1977). The three United States Geological Survey (U.S.G.S.) Atlantic Continental Margin Coring Project Holes (AMCOR) (6002, 6004, and 6005) (Figure 2) drilled in the embayment have provided dating control for the major acoustic units observed on the minisparker records (Hathaway and others 1976). Furthermore, these sediments have provided samples for determining the geotechnical and engineering properties of the materials and information useful in determining paleodepositional environments. Due to the anchoring requirements of the D/V GLOMAR CONCEPTION, this drilling program was limited to a maximum of 305 m of penetration at a maximum water depth of 460 m. Other information available for the offshore areas came from piston and vibracores, grab and dredge samples, and from CALDRILL C-5 drill hole, located on line 5A.

DISCUSSION OF DATA

General Description

Acoustic penetration up to 0.5 second two-way time (375 m) was obtained from the Blake Plateau on the high-resolution seismic records. Less penetration was observed beneath the Continental Shelf and Florida-Hatteras Slope due to interference of bottom multiples. The pulse length of the minisparker system usually obscures the uppermost 5 to 7.5 m of the section, and commonly prevents a detailed look at the Holocene section on the Shelf and Slope. On the Blake Plateau the presence of Holocene sediments could not be documented in the profiles, although bottom cores from this area usually include a thin Holocene sequence (Pilkey 1977, personal communication).

Bottom topography on the Continental Shelf is generally smooth. Irregularities arise from buried or partially buried algal and coral reefs, sand waves, wave-cut terraces, and other erosional and constructional features associated with changes in sea level during Quaternary time. Such bottom irregularities have been discussed by Stetson and others (1962), Uchupi and Tagg (1966), and Pilkey and others (1971). Examples of these various features are presented in Appendix A (photographs 2, 3, 4, 6, 10, 12, 13, 15, 17, 19 and 20). The approximate 30 km spacing between the NW-SE track lines does not permit good correlation between tracks, but pronounced features such as shelf edge reefs and large erosional herms can be traced between the lines. There is good correlation between the features observed on the two sets of closely spaced lines (15, 15A, and 15B; and 25, 25A, and 25B). Subbottom reflections can be traced for long distances beneath the shelf. Buried erosional valleys, as much as 75 m deep and 4 km wide, are common on the shelf. In general, the NW-SE cross-shelf lines show seaward-dipping Tertiary and Quaternary beds, often in the form of foreset bedding near the shelf edge. Most of the Tertiary units pinch-out beneath the Quaternary veneer north of 32^{o} and northwest of the present shelf break. The subaerial exposure of a large portion of the shelf during the Pleistocene resulted in the removal of some older units. In addition, the acoustic pattern of Pleistocene and Pliocene sediment in the southern portion of the embayment suggests that these sediments were deposited primarily on the slope. For these reasons, as well as minor amounts of recent sediment accumulation, older Tertiary units are close to the present sea floor. In the embayment, several unconformities occur beneath the shelf. The U.S.G.S. AMCOR holes (6002, 6004, and 6005) provide ages for the sediments above and below them, and in most cases, it is relatively easy to trace these acoustic units from line to line. However, north of 32^{o} the shelf has undergone extensive erosion which makes the tracing more difficult. As a result of the cut and fill stratigraphy, the units are discontinuous and complicated by apparent dip reversals and chaotic bedding. It is possible that age assignments of some of these units may change as more cores become available in this area.

The most distinctive features on the Florida-Hatteras Slope are reefs, two major faults on line 29, and a major slump on line 19. No submarine canyons were observed.

The Southeast Georgia Embayment can be divided into southern, middle and northern regions, based upon the structure and age of the Cenozoic outcrops (Figure 3). In the southern region (lines 23-30), a seaward-dipping wedge of Paleocene, Eocene, Oligocene, and Miocene sediments lie on the Upper Cretaceous sequence. The middle region (lines 16-22) is characterized by outcrops of Paleocene and Cretaceous sediments on the Plateau. The northern region (lines 5A-15) contains a thin sequence of Paleocene to Holocene sediments separated by unconformities. Extensive erosion is obvious in all three regions.

Beneath the slope and plateau in the vicinity of lines 12-18, the Paleocene is shallower than to the north or south and is exposed by erosion. This is along the basement high associated with the Cape Fear Arch. The bathymetry of the Plateau also shows a high in this area. To the north (lines 5a-13) older Tertiary sediments were deposited and these have been capped by Pliocene and Pleistocene sediments. These are the only exposures of these younger sediments on the Plateau. As to the south, the Gulf Stream has formed a barrier to their transport further from shore. This deposition of young sediments may have occurred because the structural barrier associated with the Cape Fear Arch impedes and deflects the flow of the Gulf Stream. This causes it to lose some of its power to erode as deeply as to the south, at the same time allowing deposition.

The seismic data demonstrate that during the Cenozoic the Continental Shelf, Slope and Blake Plateau formed in an area where dynamic equilibrium had been established between sediment supply and erosional activity.

Appendices B, C, and D are intended for use with the description of

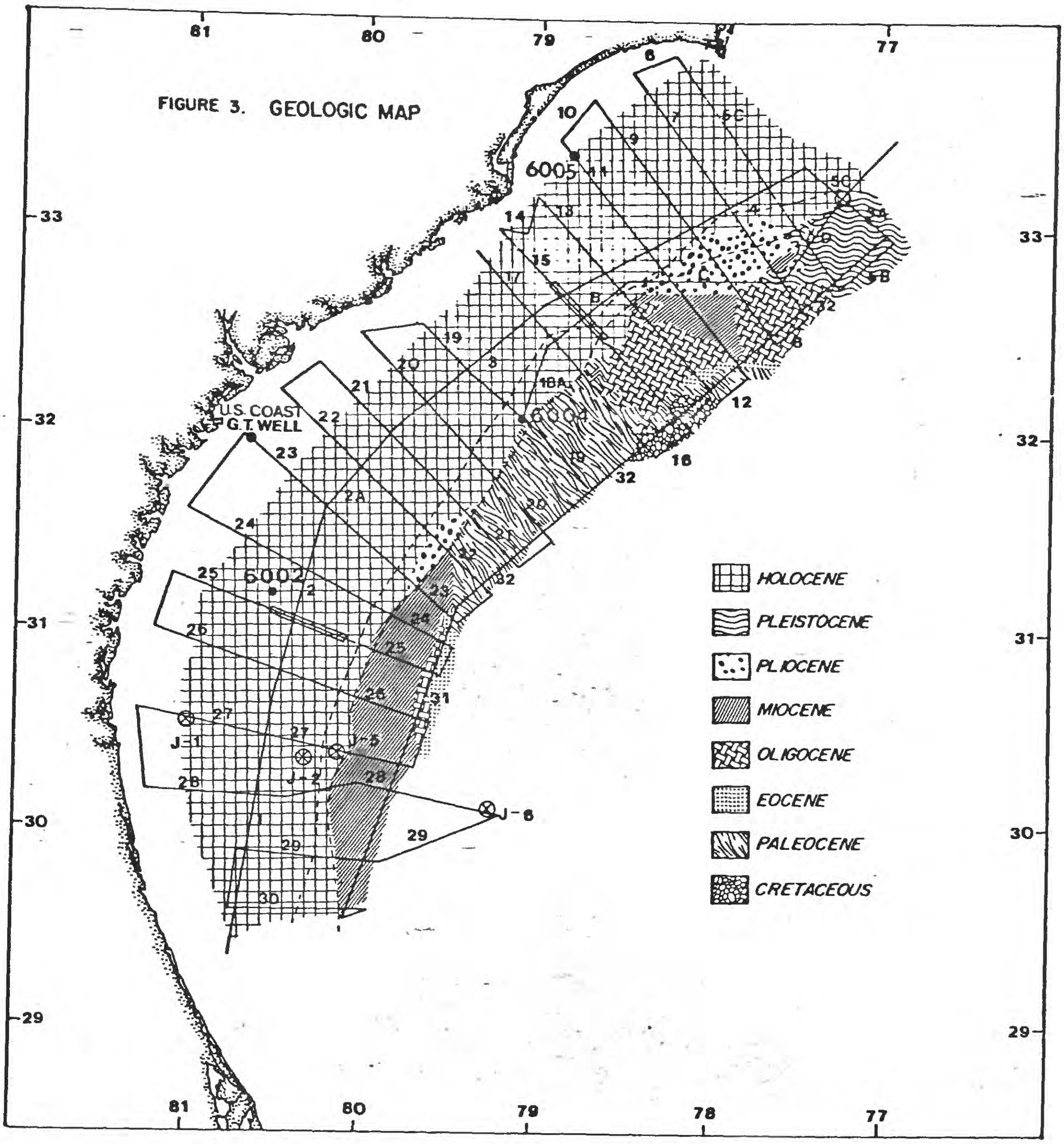
FIGURE 3. GEOLOGIC MAP
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
U.S. COAST G.T. WELL
6005
6004
6002
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29

the high-resolution profiles discussed in the following section. Maps of sediment distribution by age (Appendix C) form the basis of this report. The line drawing interpretations of the minisparker records appear as Appendix B. Appendix D presents the variations in sediment thickness and structure in each epoch of the Cenozoic.

Upper Cretaceous

Figure C-1 represents the inferred distribution of Upper Cretaceous sediments in the Southeast Georgia Embayment. This is based on the correlation of the depth to the top of the Upper Cretaceous recovered in U.S.G.S. AMCOR 6004 with the depth to the top of the appropriate acoustic unconformity on line 19. This deepest unconformity was traced throughout the embayment where possible, or inferred on the basis of the age of the overlying sequence. The assumed Upper Cretaceous sequence was observed in the southern region on lines 25 and 29 (Figures B-1 and B-2). It is presumably present throughout the area, but was not readily observed on all records. It is overlain by the Paleocene sequence throughout the southern region as drilled at Site J-6 (Figures B-1 through B-3). The Upper Cretaceous in the middle region was drilled at Site 6004 on line 19 and was extrapolated to lines 17-22 (Figures B-3 through B-5). Due to insufficient penetration on lines 20-22, it was not possible to observe internal stratification in the Upper Cretaceous sequence. An unconformity is observed within the Upper Cretaceous sequence on line 17. The lower unit consists of gently southeast--dipping strata, while the upper unit contains truncated foreset bedding. The thickness of this unit decreases to the southeast. The top of the Upper Cretaceous is too deep beneath most of the slope and all of the shelf to appear on the minisparker records. The Upper Cretaceous boundary was extrapolated from drill site 6004 on line 19 into the northern region (lines 5A-15), and was observed on all transects except line 5A, where the correlation was made from the tie line. The Upper Cretaceous is believed to crop out on the surface of the Blake Plateau (Figures B-5, B-10, and B-11) where it appears to dip gently northeastward.

Paleocene

Figure C-2 represents the inferred distribution of Paleocene sediments. Paleocene sediments were recovered by drilling at Sites 6004, 6005, J-6, and CALDRILL C-5 and thus related to the appropriate unconformities on minisparker lines 19, 11, 28, and 5A which passed through these drill sites. This unconformity was traced throughout the embayment where possible or inferred to be the top of the Paleocene on the basis of the age of the overlying sequence. In the southern region (lines 23-30), the Paleocene was observed to crop out on tie line 31, northeast of the crossing with line 24 (Figure B-2). Evidence of erosion is observed beneath the plateau on lines 23-26 (Figures B-2 and B-3). The middle region (lines 17-22) is characterized by the cropping out of southwest-dipping Paleocene sediments on the Blake Plateau. In addition, the highly eroded Paleocene sequence is very obvious beneath the shelf and slope on lines 17 and 19. The eroded appearance of the Paleocene beneath the shelf and slope differs greatly from that on the Blake Plateau. Beneath the shelf and slope the erosional features have resulted from the downcutting of streams into the Paleocene sediments during the subaerial exposure of this region during post-Paleocene, but pre-Miocene time. Although the track spacing is too great to be certain of correlations from one line to another, these stream channels on the shelf are thought to strike in a northeasterly direction parallel to the shelf edge. The appearance of the Paleocene sequence on the surface of the Blake Plateau reveals that erosion has truncated the gently southeasterly dipping beds and produced isolated outliers rising above its surface.

In the northern region (lines 5A-15), the Paleocene sequence was recovered at drill sites 6004 and 6005 and crops out on the southeastern ends of lines 13 and 15 and on tie line 32. It overlies the Upper Cretaceous and is present beneath the shelf, slope, and Blake Plateau. Whereas, evidence of severe erosion on the top of the Paleocene is absent, minor channels have been cut into it beneath the Plateau on lines 11 and 13, beneath the slope on line 7, and beneath the shelf on lines 15B, 15, and 15A. Evidence of channelling is lacking on the top of the Paleocene sequence beneath the present shelf on lines 13, 11, 9, 7, and 5C. However, the Paleocene unit shows a drop of approximately 75 to 100 m, indicating the position of the Paleocene shelf edge. Its distance from the present shelf edge increases to the north (Figure D-1).

Eocene

Figure C-3 represents the inferred distribution of Eocene sediments. Eocene sediments were recovered at drill sites J-1, J-2, J-5, J-6, and 6002, and CALDRILL C-5. The distribution of Eocene sediments is determined from the correlation of depth of the cored Eocene sequence with the depth of the unconformity observed on minisparker lines 5A, 25, 27, and 28 which pass through or close to the drill sites. In some instances Eocene sediments were inferred to be present because of the age of the overlying sequence.

Eocene sediments were observed in the southern region (lines 23-30) on all lines except 23 (Figures B-1 through B-3). In the southern region these sediments crop out on the southeastern end of lines 24 and

25, and on line 26 they appear as an outlier resting on the Paleocene.

Eocene sediments do not appear to have been deposited, or were possibly removed by subsequent erosion, in the middle region (lines 17-23) beneath the slope and Blake Plateau. This is confirmed by their absence in AMCOR hole 6004, by a thin section in J-4, and by their decrease in thickness on the acoustic records as the middle region is approached (Figure D-2). It is possible that subsequent drilling and dating of recovered sediments from beneath the shelf may prove that the greater thickness of sediment apparent on lines 17, 19, and 21 considered to be Miocene, may also contain Eocene and Oligocene materials. However, it is obvious that vigorous current activity impinged against the continental margin near the approximate position of the slope, curtailing the seaward deposition of these sediments. The eroded Paleocene sequence beneath the outer shelf and slope on lines 15-21 may have acted as a barrier restricting the seaward distribution of Eocene sediments.

The Eocene sequence in the northern region (lines 5A-15) overlies the Paleocene sequence on lines 13 through 5C. It is absent on 15 and was not identified on line 5A, although it was seen on tie line E, which crosses line 5. The Eocene sequence is seen beneath the shelf, slope, and Blake Plateau on lines 11, 9 and 5C, but is quite thin. It is restricted to the Blake Plateau on lines 13 and 7. Some evidence of erosion is seen on line 11. Eocene crops out on the southeastern end of lines 13 and 11 and on line 32. A large area of Eocene sediments beneath the Plateau has been removed by erosion on line 11.

Oligocene

The inferred Oligocene sediment distribution is presented in Figure C-4. Oligocene sediments were recovered at drill sites J-1, J-2, J-5, J-6, 6002, and CALDRILL C-5. The Oligocene sequence in the southern region overlies the Eocene sequence on lines 24-30 and the Paleocene sequence on line 23 (Figures B-1 through B-3). The Oligocene sequence reaches its maximum thickness beneath the Florida-Hatteras Slope (Figure D-3). A reversal in dip on line 29 is related to a fault beneath the slope. The Oligocene sequence crops out on lines 24-26 (Figures B-2 and B-3) and lines 28 and 29. Evidence of major post-Oligocene current erosion is visible on lines crossing areas where the Oligocene is exposed, but where the Oligocene is buried erosion is less extensive. The Oligocene sequence on line 23 pinches out towards the southeast beneath the plateau.

In the middle region (lines 17-22), Oligocene sediments may or may not be present beneath the shelf and slope as indicated above. Oligocene sediments apparently extend northward only as far as line 22, although small remnants are preserved as outliers on line 17. These outliers overlie a major unconformity, below which Paleocene sediments have been identified. It appears that Oligocene sediments were deposited on the plateau and have subsequently been removed by erosion with the exception of the few remnants on line 17. The Oligocene sequence in the northern region (lines 5A-15) has been highly eroded by bottom currents on lines 15, 13, 11, and 9. The channels produced have been filled by younger sediments (Figures B-5 through B-9).

Miocene

Figure C-5 shows the distribution of Miocene sediments. They were recovered at drill sites J-1, J-2, 6002, 6004, and CALDRILL C-5. The inferred distribution was determined in the same manner as previously mentioned. Several unconformities are observed within the Miocene, and the distribution of these sediments is the result of a continual balance between sedimentation and erosion (Figure D-4). In the seaward parts of lines 23-26 (Figures B-2 and B-3), the Miocene sediments either pinch out or have been totally removed by erosion, thus exposing older sequences. The pattern of Miocene sedimentation in the area of lines 29 and 30 indicates an episode of upbuilding and outbuilding on a previously existing southeast-ward dipping sequence of Oligocene sediments. Lines 23-28 (Figures B-1 through B-3) show extensive erosion of the Miocene sediments beneath the present slope and outer portion of the shelf, producing a rather abrupt notch beneath the present slope. Note the truncation of southeastward-dipping Miocene beds on lines 24-28. Erosion in Miocene time apparently concentrated in this area beneath the present-day shelf and slope.

In the middle region (lines 17-22) the Miocene is present beneath the shelf and slope and has filled eroded channels (see tie line ABCDE/FAY 025, Figures B-14 and B-15). Several unconformities are observed within the Miocene sequence. Miocene does not exist on the plateau except as an outlier on line 17. This indicates Miocene sediments were eroded or were not deposited due to vigorous current activity. On the plateau in the northern region (lines 5A-15) Miocene sediments have filled the channels cut into the Oligocene sequence (see lines 15, 13, 11 and 9). It exists below Pliocene sediments on line 5A, and is present as an erosional surface on the eastern portion of line 11. Some of the Miocene on the plateau has subsequently been removed by erosion shown on lines 9, 7 and 5C. Noticeable outbuilding and upbuilding of the continental shelf in Miocene time is demonstrated by lines 9 and 7, and is less noticeable on lines 5C and 5A. The Miocene on the plateau in the northern region, as seen on line 32 (Figures B-10 and B-11) appears to dip in a northeastward direction.

Pliocene

The distribution of Pliocene sediments is shown in Figure C-6. Pliocene sediments were recovered at drill sites J-1, J-2, J-5, 6004 and CALDRILL C-5 and their distribution was traced in the manner previously described. Pliocene sediments in the southern region (lines 23-30) are found beneath the present day shelf and slope on all lines (Figures B-1 through B-3), but they do not appear to extend onto the Plateau. The pattern of the Pliocene sediments (Figure D-5) shows increased thickness towards the northeast (lines 23-26), corresponding with the areas of greater erosion of the underlying Miocene sequence.

Pliocene sediments in the middle region appear as a thin sequence beneath the shelf and slope. The Pliocene sequence in the northern region (lines 5A-15) is present beneath the shelf and slope on lines 15 and 13 and beneath the shelf, slope, and Blake Plateau on lines 11, 9, 7, 5C and 5A. The Pliocene on the plateau has been subjected to varying degrees of erosion; small channels have been cut into the Pliocene on lines 11 and 9, and part of the Pliocene sequence have been totally removed by erosion on lines 5C and 5A. The Pliocene crops out on the surface of the slope and plateau on lines 11, 9, 7 and 5A (Figures 3 and C-6). Foreset bedding is obvious in the Pliocene sequence beneath the present shelf north of line 19. Changes in dip within the Pliocene sequence on alongshelf profiles (Figures B-16 through B-21) are observed, probably representing deposition from different source locations.

Pleistocene

The distribution of Pleistocene sediments is shown in Figure C-7. Pleistocene sediments were recovered at Sites 6004, 6005 and CALDRILL C-5 and traced to adjacent lines.

Pleistocene sediments also display foresets (Figure D-6) in the southern region (lines 23-30). They are present beneath the slope on line 30 and beneath the shelf and slope on all other lines. The Pleistocene sequence in the middle region (lines 17-22) is thinner than the underlying Pliocene sequence. Pleistocene strata underlie the outer shelf and slope and are especially evident on lines 19 and 17.

Pleistocene sediments are present in the northern region (lines 5A-15) on all lines, but occur on the plateau only in the area of lines 15, 7, 5C and 5A. Very little outbuilding of the shelf occurred during the Pleistocene except in the area of lines 5C and 5A (Figure D-6).

ENVIRONMENTAL HAZARDS

A number of potential environmental hazards can be identified for the Southeast Georgia Embayment. Many are similar to those discussed for the entire East Coast of the United States in that they might cause or aid in the distribution of oil spills. Damage to drilling rigs or similar structures might result from the following: (1) weather--generated waves, (2) high-velocity currents, (3) mass movements of bottom sediments, (4) collapse of solution cavities in calcareous materials at depth, (5) seismic hazards and faults, and (6) shallow gas pockets. Of particular interest in this region would be severe storms, the Gulf Stream currents, seismicity, and limestone solution cavities.

Potential Hazards Associated with Weather Conditions

Periods of severe weather with large waves and strong currents threaten the stability of rigs and platforms, and aid in the transport of oil spills. This weather may occur at any time of the year, and is generally related to the passage of intense frontal systems, local thunderstorms, and severe cyclonic storms (hurricanes). Large hurricane waves can act as shallow water waves anywhere on the continental shelf; their refraction by capes and underwater topographic features may result in the concentration of wave energy in localized areas, causing high energy breaking waves. This particular hazard cannot be assessed from the seismic reflection data.

High-Velocity Currents

The Gulf Stream skirts the edge of the continental shelf and has a maximum flow of about 180 cm/sec (3.5 knots). It flows north across the Southeast Georgia Embayment and meanders and gyres have been observed, particularly north of the bathymetric high on the northern Blake Plateau. Reverse flows of the Gulf Stream may occur near the surface (counter currents) and on the bottom (undercurrents). The Gulf Stream and associated currents are key factors in determining the outcome of drilling operations. This is exemplified by the drilling problems encountered by the JOIDES group in 1965 and by the U.S.G.S. aboard the GLOMAR CONCEPTION in 1976 (Site 6003, Hathaway and others 1976) while drilling in Gulf Stream currents. Large areas of scour on the Blake Plateau also attest to the strength of the Gulf Stream through a large span of geologic time.

Bottom Conditions

Bottom-supported structures on the outer continental shelf would be subject to damage by scour and mass movement of bottom sediments. Additional hazards could be posed by solution cavities or shallow, high pressure gas pockets which may be present in subbottom formations, by possible movement on subsurface faults, and seismicity. Variations in the physical properties of the bottom sediments are important in determining the stability of any bottom-supported structures.

Scour by Storm-Generated Waves and Currents

The mid- and outer shelf sediments are sands which appear to be in textural equilibrium on the shallow shelf. Active deposition or redeposition is indicated by the presence of such primary structures as cross bedding, ripple marks, and graded bedding. Near the high-energy zones of the capes, current and wave action transport the sediments across the shelf and deposit mud and sand on the slope. Between the various capes, the central and outer shelf sediments migrate shoreward. Thus, the movement of currents and sediments in varying directions across the shelf could result in scour around the support structures of platforms. Scour would also present a severe problem on the inner portion of the Blake Plateau where the Gulf Stream flows along the bottom with velocities on the order of 40 cm/sec (400 to 800 m depth). The only evidence of mobile sediments observed on the seismic records were sand waves present in the northern portion of the Southeast Georgia Embayment (Figure A-3), however sand waves are undoubtedly present on other areas of the shelf. The effects of strong current on the Florida-Hatteras Slope are especially obvious on lines 5A, 13 and 17. Scour and depositional features are also seen on the Blake Plateau and examples are presented in Figures A-6, A-9, A-12, and A-13.

Mass Movement of Sediments

The medium to coarse sand typical of the continental shelf is relatively dense due to reworking by oceanic currents and thus should provide good platform support, although it will also be resistive to pile penetration. Zones on the shelf characterized by differing sediments, such as lagoonal muds and peats and stream-channel fill, would possess lower supportive capabilities since static bearing capacity and stability against sliding can be drastically reduced by the presence of even thin layers of clay.

Slumping would be unlikely on the continental shelf as the average bottom slopes are only on the order of 1^{o}. Slumping on the Florida-Hatteras Slope would be likely to occur in areas where fine-grained sediments are accumulating, in areas of truncated foreset bedding near the shelf edge, and where erosion by the Gulf Stream has removed sediments farther down on the slope. The only slumping observed in the Southeast Georgia Embayment was on line 19 (Figure A-16).

Collapse Caused by Cavernous Limestones

Many of the limestone formations of the Florida Peninsula and Bahamian Banks area are known to contain extensive networks of caves which may present serious problems in drilling and completing wells. This seismic survey did not detect any cavernous limestones, but they may be present in the shallower Tertiary sections where subsurface erosion occurred during the Pleistocene when sea level was lower. Cavernous porosity was encountered during the drilling of the Bahamas Oil No. 1 Andros Island well and the Esso No. 1 Hatteras Light well. A serious threat to bottom-mounted platforms and structures will exist in the Southeast Georgia Embayment if cavernous limestones exist at depth.

Faulting

The only large fault detected by the seismic survey was observed on line 29 (Figure A-21) beneath the Florida-Hatteras Slope. It is a normal fault, with the downthrown side to the east. Miocene and lower Pliocene sediments are displaced, while the Pleistocene and Holocene sediments do not appear to have been affected. Other faults are apparent on lines 18A, 19 and 24.

Large faults beneath the continental shelf are unknown, although numerous minute faults with displacements of 1 m or less appear to be common in some areas (see Chapter 11 this volume).

On the minisparker line connecting lines 24 and 25 (Figures A-23 and A-24) and on lines A-16 and A-21, disrupted reflectors can be seen at depth. They may represent strata broken by faulting or the effects of differential compaction and draping on a buried unconformity within the Cretaceous (Paull and Dillon, Chapter 10 this volume). A more detailed look at this area is needed before a conclusion can be made.

Seismic Activity

Although the Eastern U.S. is an area of generally low earthquake activity, a narrow northwest trending zone of historical seismicity extends across the emerged Coastal Plain in the central part of the Southeast Georgia Embayment. The 1886 Charleston, S.C. earthquake, the largest historical earthquake in the eastern United States, occurred along this zone. Numerous investigators have proposed that the seismicity reflects a landward extension of the Blake Spur Oceanic Fracture Zone. The recurrence of weak seismicity in the Southeast Georgia Embayment indicates that stronger seismicity in the future must not be discounted although the reflection survey indicates that structural type faulting is rare to nonexistent on the shelf. The major danger to structures on the shelf from a large seismic event would probably be from liquifaction of sediments.

Drilling Hazards

Gas and oil leaks during petroleum exploration and development could occur as the result of accidents, severe weather, strong currents, seismic activity, or by the encountering of high pressure gas-charged reservoirs. Drilling areas located near faulting or channel fill would be more prone to these latter dangers. In deeper water clathrates (frozen gas-hydrates) could be present; however, clathrates are not known on the shelf or slope.

Hyperbolas of Reefal Origin

Hyperbolas are observed on several lines across the Blake Plateau within the Southeast Georgia Embayment (Figure 4). The single consistent characteristic of these features on lines 8, 9, 11-13, 15-17, 14-21, 24-29, 31, and 32 is that they are always observed in water depths in excess of 420 m. They occur on portions of the Plateau where the surficial sediment ranges in age from Miocene to Upper Cretaceous. The anomalies vary in size (5-25 m high, 500-1,000 feet wide), shape and concentration. Very few of these anomalies are associated with obvious bottom structures or impede the acoustic penetration beneath them. In certain areas the hyperbolas appear to be beneath the surface of the Blake Plateau on the minisparker records, which suggests that their source is within the cone of sound, but off to the side of the survey line. Possible origins to be considered are: (1) gas seeps, (2) fresh water seeps, (3) concentrations of fish, and (4) deep-water coral mounds.

The possibility of gas seeps as the cause seems unlikely since these hyperbolas are observed above bottoms characterized by sediments ranging in age from Miocene to Upper Cretaceous age, sediments not known to contain gas at present. Furthermore, no obvious outcropping of beds or faults are observed in these regions, thus eliminating the pathways by which gas can reach the surface.

Fresh-water seeps are known beneath the shelf. Their occurrence at these depths is a matter of conjecture at this point.

The variations in size and distribution of hyperbolas, their depth, and apparent attachment to the bottom does not support that they

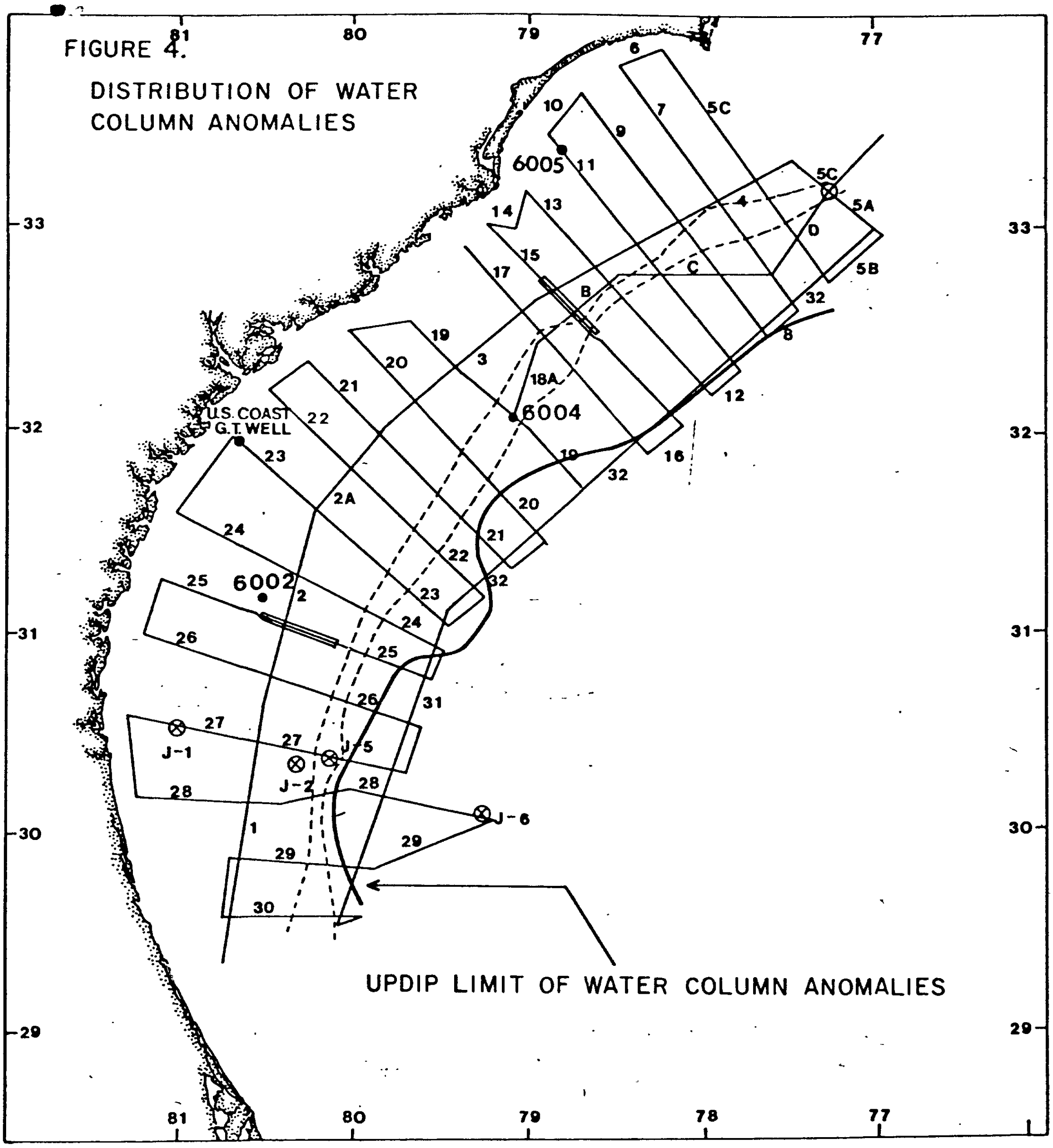
FIGURE 4.
DISTRIBUTION OF WATER
COLUMN ANOMALIES
UPDIP LIMIT OF WATER COLUMN ANOMALIES
U.S. COAST G.T. WELL
6005
6004
6002
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29

originate from large schools of fish. Therefore, the most logical cause appears to be deep-water coral banks. John Milliman (personal communication, 1978) suggests that these are deep-water coral banks similar to ones he has seen in this area from the ALVIN and which are discussed by Stetson and others (1962). The linear pattern of several sequences of hyperbolas (Figure E-1) suggests that their source is nearly linear, like many of the coral banks Milliman observed. The reefal features in the other Figures (Figures E-2 through E-5) appear to be individual or patch-type. The lack of reef-type reflectors beneath the surface reefs suggests that they have grown above the floor of the plateau in recent times and do not have a substantial base of older reefal materials.

CONCLUSIONS

Acousto-stratigraphic units, ranging in age from Upper Cretaceous to Holocene have been identified and dated by extrapolation of paleontologic ages assigned to samples recovered from four JOIDES, three U.S.G.S. drill sites, CALDRILL C-5, and from vibracore, piston core, and dredge samples. The post-Upper Cretaceous sequence is thin and exhibits a complex history of erosion and deposition with numerous unconformities. The Southeast Georgia Embayment has been subjected to erosion by north to northeast flowing currents since at least Paleocene time. These currents have shifted back and forth across the continental margin and have effectively blocked the seaward accumulation of the various Cenozoic sequences. In addition, currents have incised into Cenozoic sequences, producing numerous channels. The Southeast Georgia Embayment can be divided into three distinct regions. The southern region (lines 23-30) has had the Gulf Stream and its predecessors flowing northward along the margin near the base of the present Florida-Hatteras Slope since Miocene time. Pliocene and younger sequences have been unable to bypass the currents and reach the Plateau. In the middle region (lines 17-22), these currents have turned slightly to the northeast. The lack of sediments younger than Paleocene on the Plateau in the middle region attests to the strenuous activity of currents since that time. The northern region (lines 5A-15) demonstrates that these currents have turned in a more easterly direction, thus allowing Eocene and younger sediments to reach the Blake Plateau. Minor channels are locally present in the younger sequences which suggests that major current activity in the northern region (lines 5A-15) has not occurred since post-Oligocene time.

The distribution of the Cenozoic sequence suggests that the Continental Shelf, Slope, and Blake Plateau have formed in an area where dynamic equilibrium has been established between sediment supply and the erosional activities of the Gulf Stream and its predecessors.

A number of potential environmental hazards have been identified in the previous section. It is reasonable to expect that problems associated with severe weather conditions and the Gulf Stream and its associated flows would be the most consistent problems to be encountered. Problems related to bottom conditions, other than scour of bottom sediments, can probably be avoided by detailed site surveys before drilling. The collapse of material above solution cavities or the presence of shallow gas pockets may be more difficult to predict. The only unpredictable event, other than weather-generated phenomena, which could create major difficulties, would be seismic activity in the embayment. There is no way at present of predicting these events, except for the historical record, which does not indicate seismicity on the shelf.

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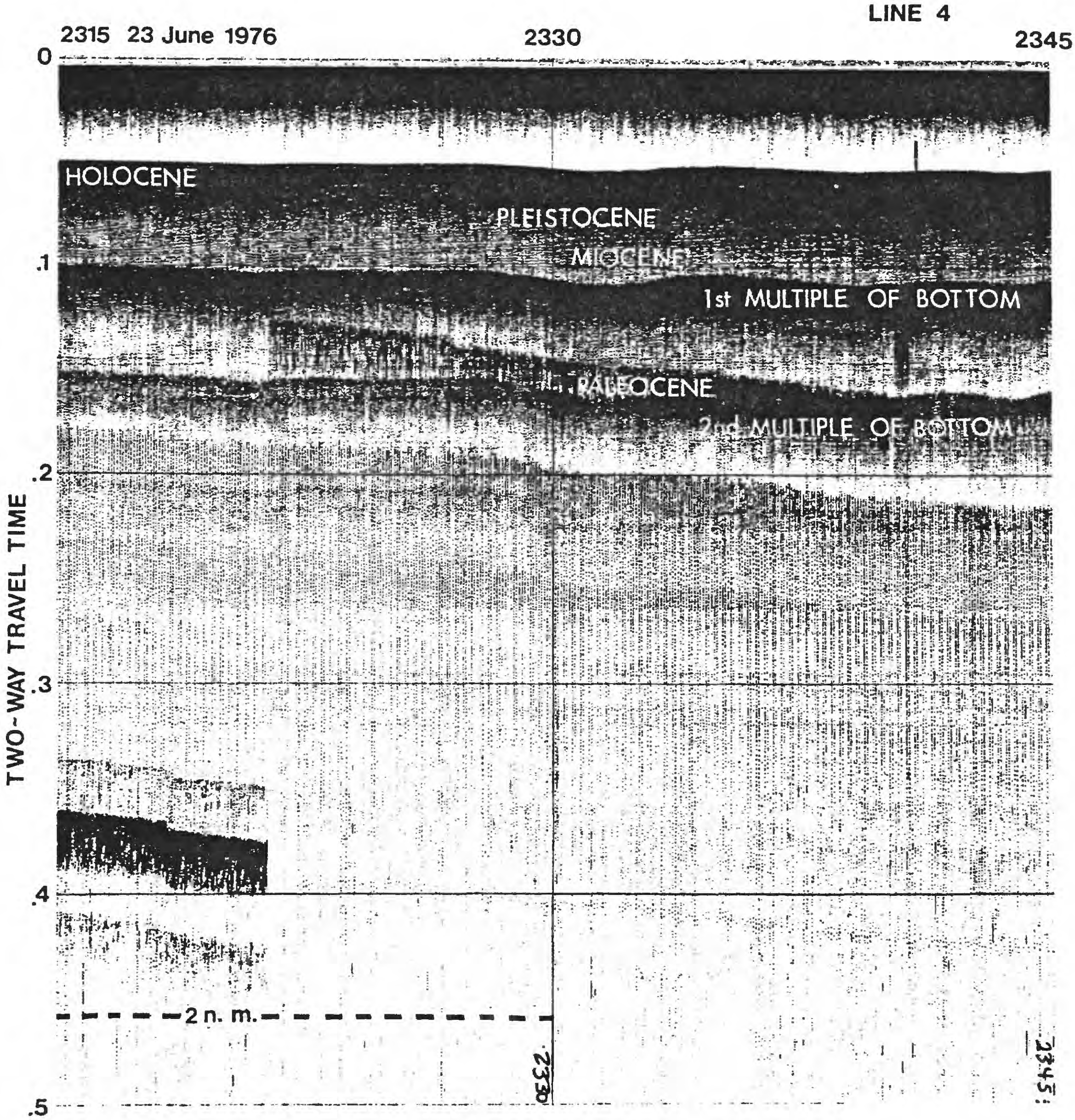
APPENDIX A

Features Demonstrated on Minisparker Records

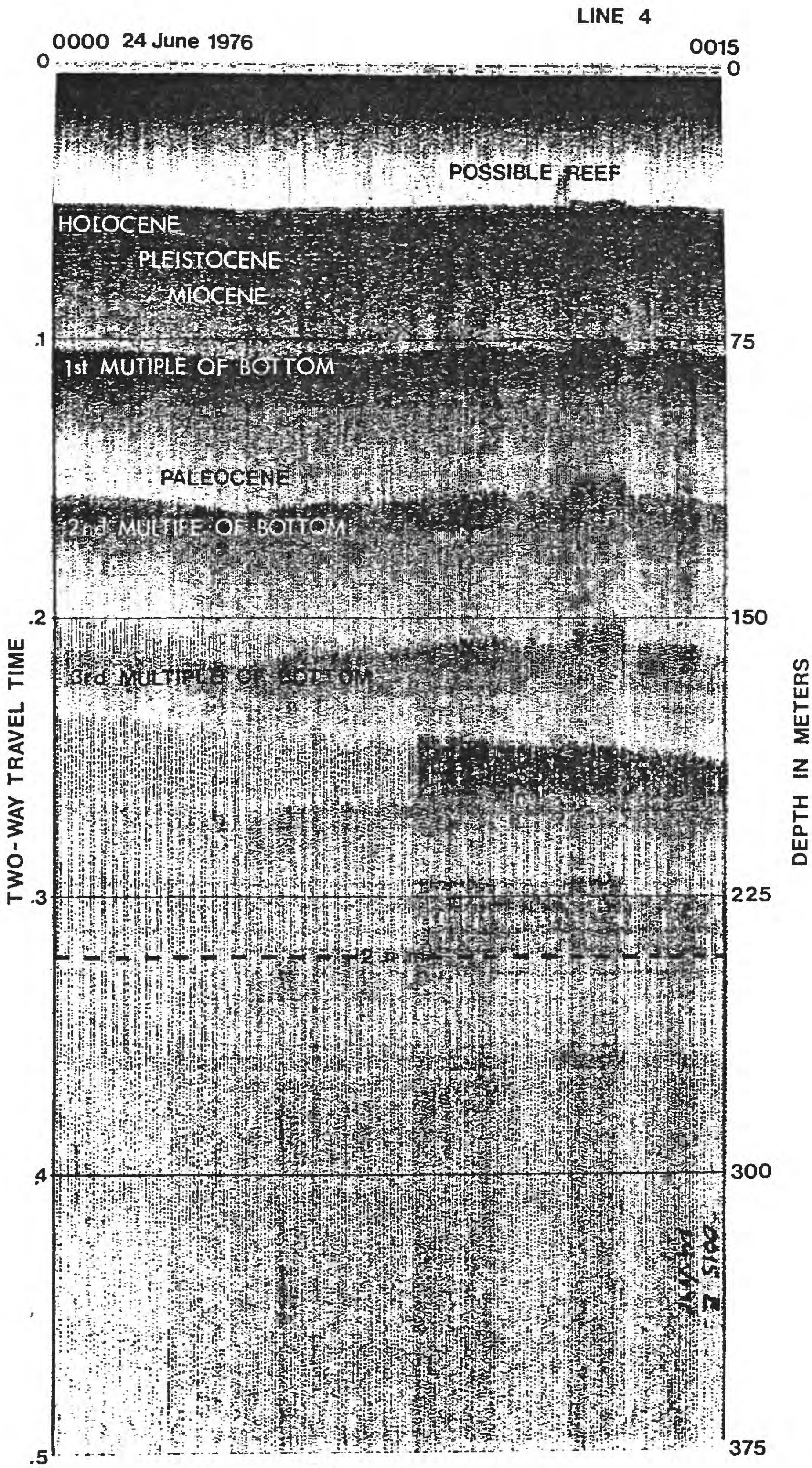
Photograph No.	Line No.	Time	Date	Feature
A- 1	4	2315-2345	23 June	Continental Shelf, minimum penetration
A- 2	4	0000-0015	24 June	Continental Shelf, possible reef
A- 3	5A	0115-0145	24 June	Continental Shelf, sand waves
A- 4	5A	0230-0245	24 June	Shelf Break, reef
A- 5	5A	0300-0330	24 June	Florida-Hatteras Slope, CALDRILL C-5 location and dating control
A- 6	5A	0400-0430	24 June	Blake Plateau, erosional channel
A- 7	5C	1445-1515	24 June	Florida-Hatteras Slope, pinchout of sedimentary sequences at base
A- 8	11	1530-1545		Line 11 crossing drill site 6005
A- 9	7	1430-1500	25 June	Blake Plateau, channel fill
A-10	9	2230-2300	25 June	Blake Plateau, erosional appearance of Oligocene sediments
A-11	11	2115-2145	26 June	Continental Shelf-Florida-Hatteras Slope transition
A-12	11	0030-0100	27 June	Blake Plateau, erosional detail on Miocene sequence
A-13	13	0930-1000	27 June	Blake Plateau, Oligocene outliers
A-14	15	0630-0700	28 June	Continental Shelf-Florida-Hatteras Slope transition
A-15	17	0400-0430	29 June	Florida-Hatteras Slope, subbottom struc tures
A-16	19	0400-0430	15 July	Florida-Hatteras Slope, slump
A-17	22	0015-0045	6 July	Florida-Hatteras Slope, recent reefs
A-18	27	1515-1530	10 July	Florida-Hatteras Slope, vicinity of drill site J-5

Appendix A - Features Demonstrated on Minisparker Records (continued)

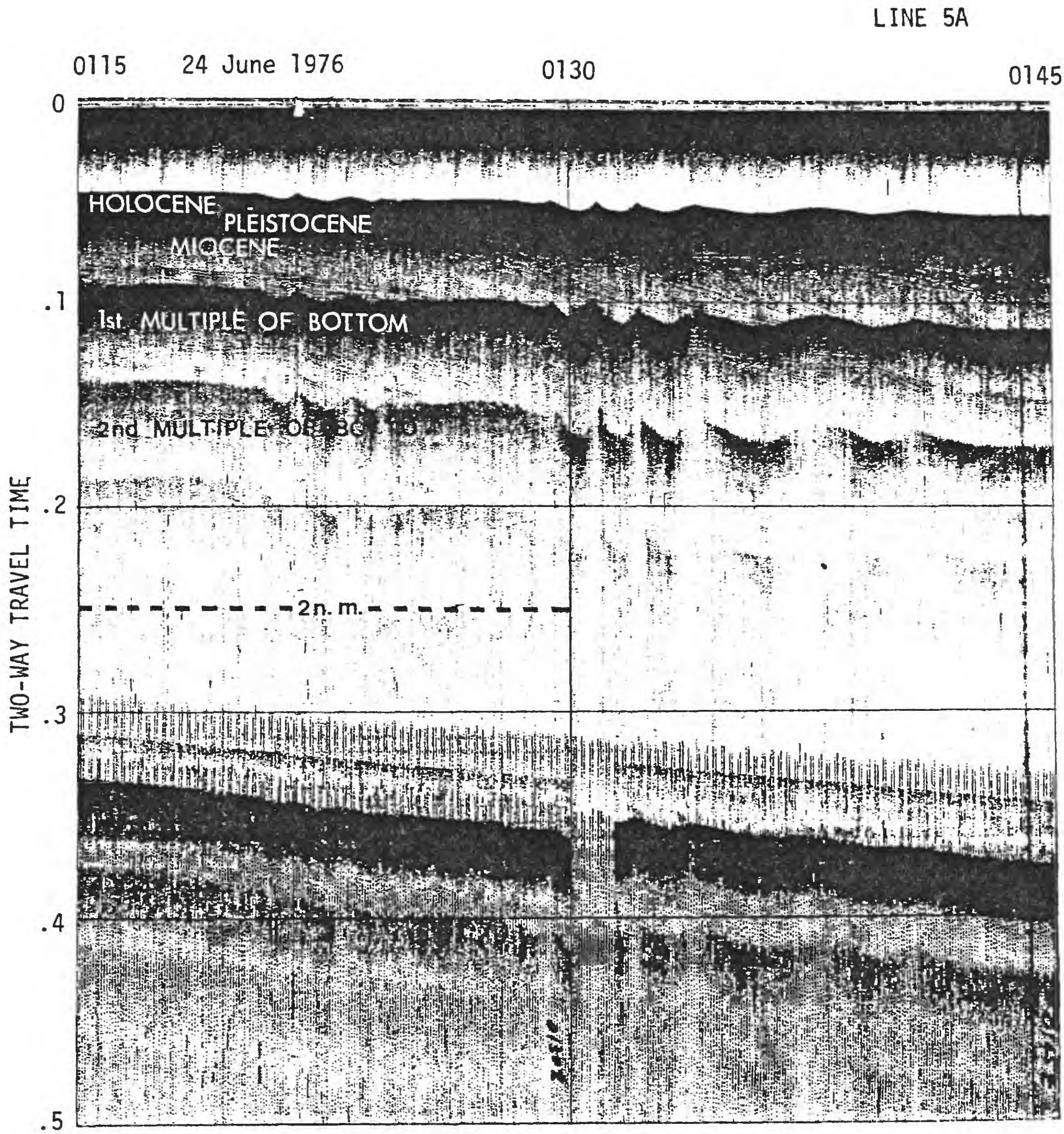
Photograph No.	Line No.	Time	Date	Features
A-19	27	1415-1450	10 July	Florida-Hatteras Slope, erosion
A-20	29	1100-1130	12 July	Continental Shelf-Florida-Hatteras Shelf transition, reefal feature
A-21	29	1030-1100	12 July	Florida-Hatteras Slope, shallow fault
A-22	32	0815-0900	14 July	Blake Plateau, pinchout of Pleistocene, Pliocene, and Miocene
A-23	24-25	2030-2115	7 July	Blake Plateau, subsurface faulting
A-24	24-25	2230-2300	7 July	Blake Plateau, subsurface faulting



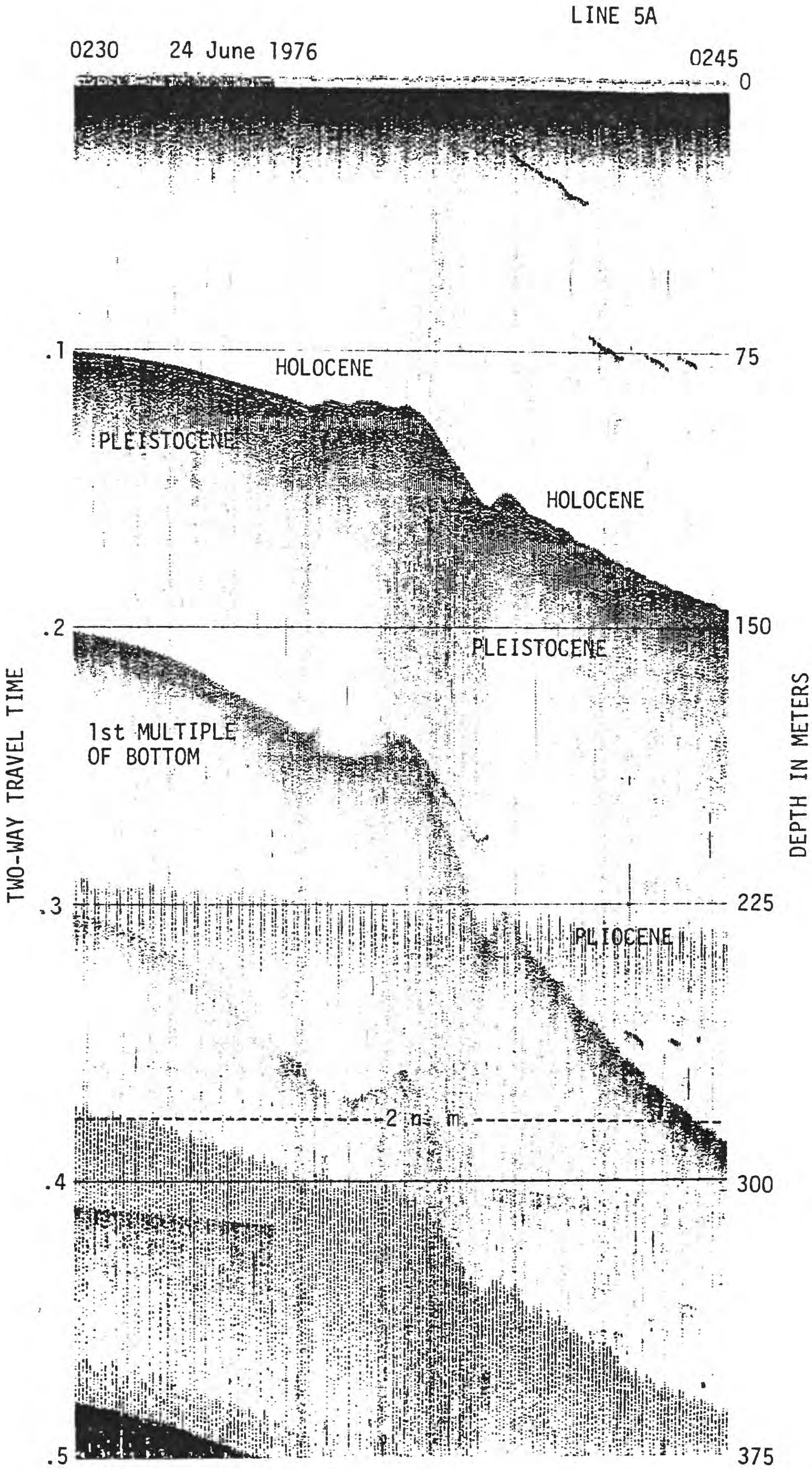
A 1 Crossing of Line 4 and Line 5C
Note minimum amount of penetration and interference of bottom multiples.



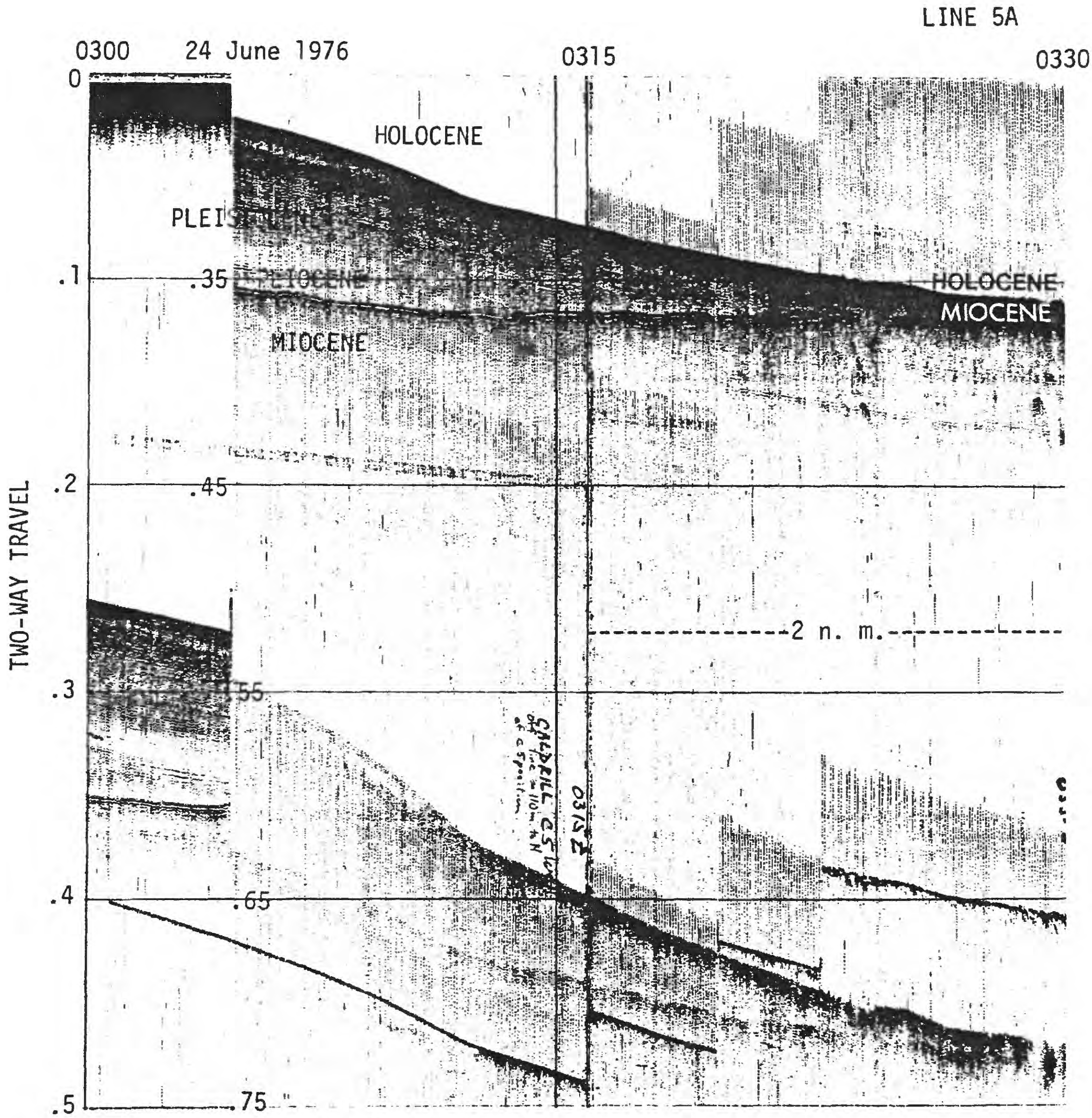
A 2 Possible reef or gas seep



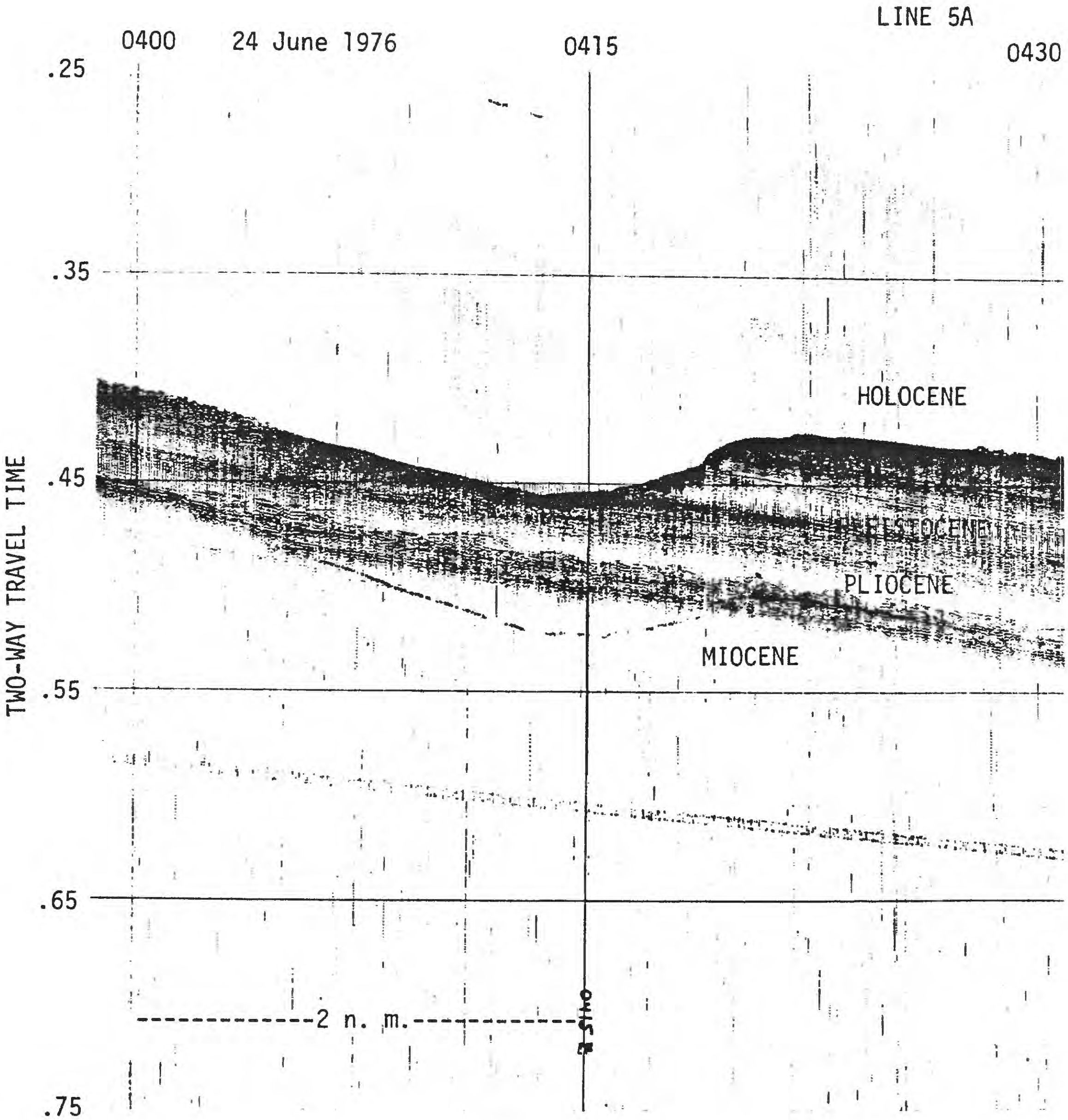
A 3 Sand waves near shelf break



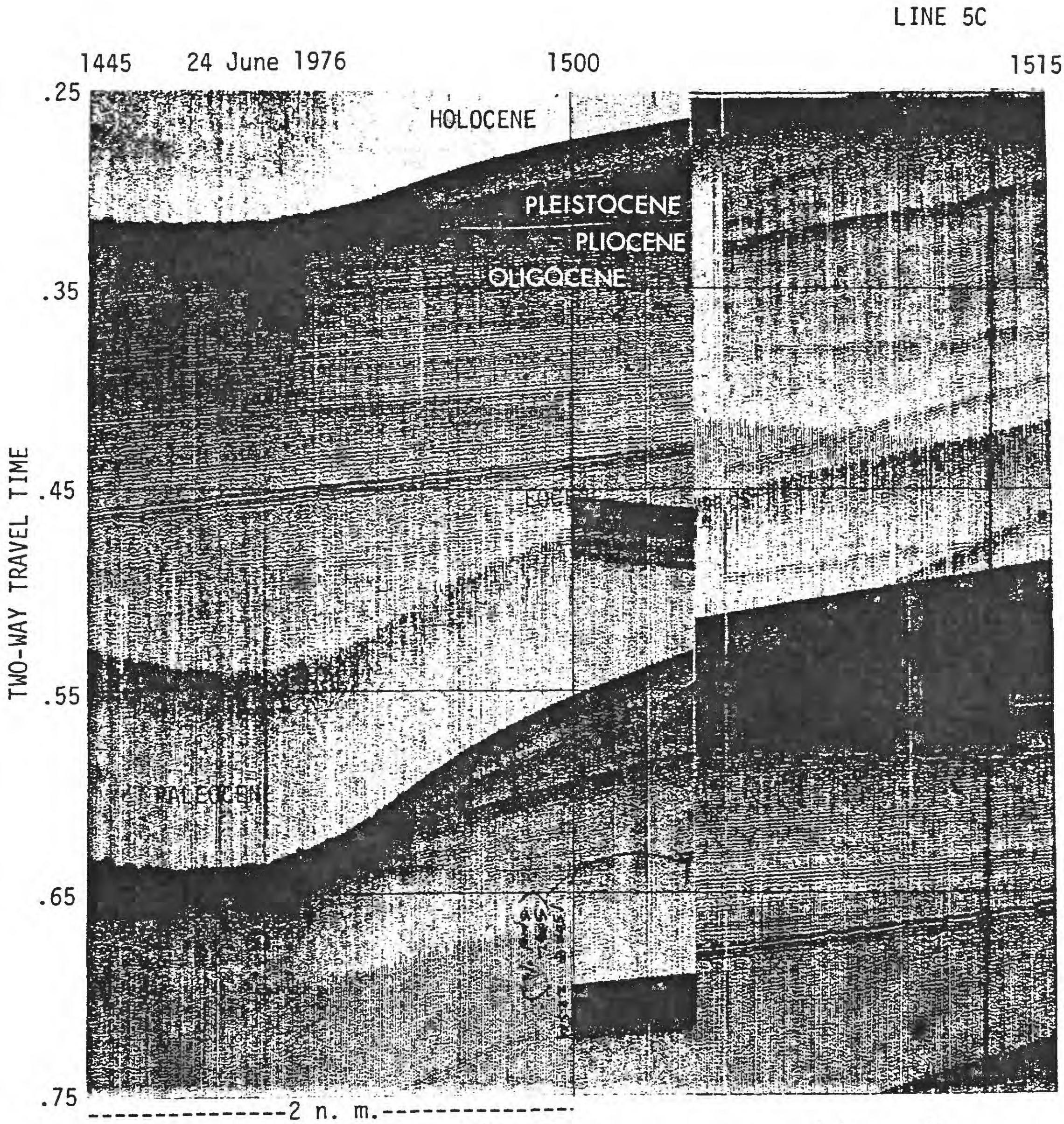
A 4 Shelf edge reef



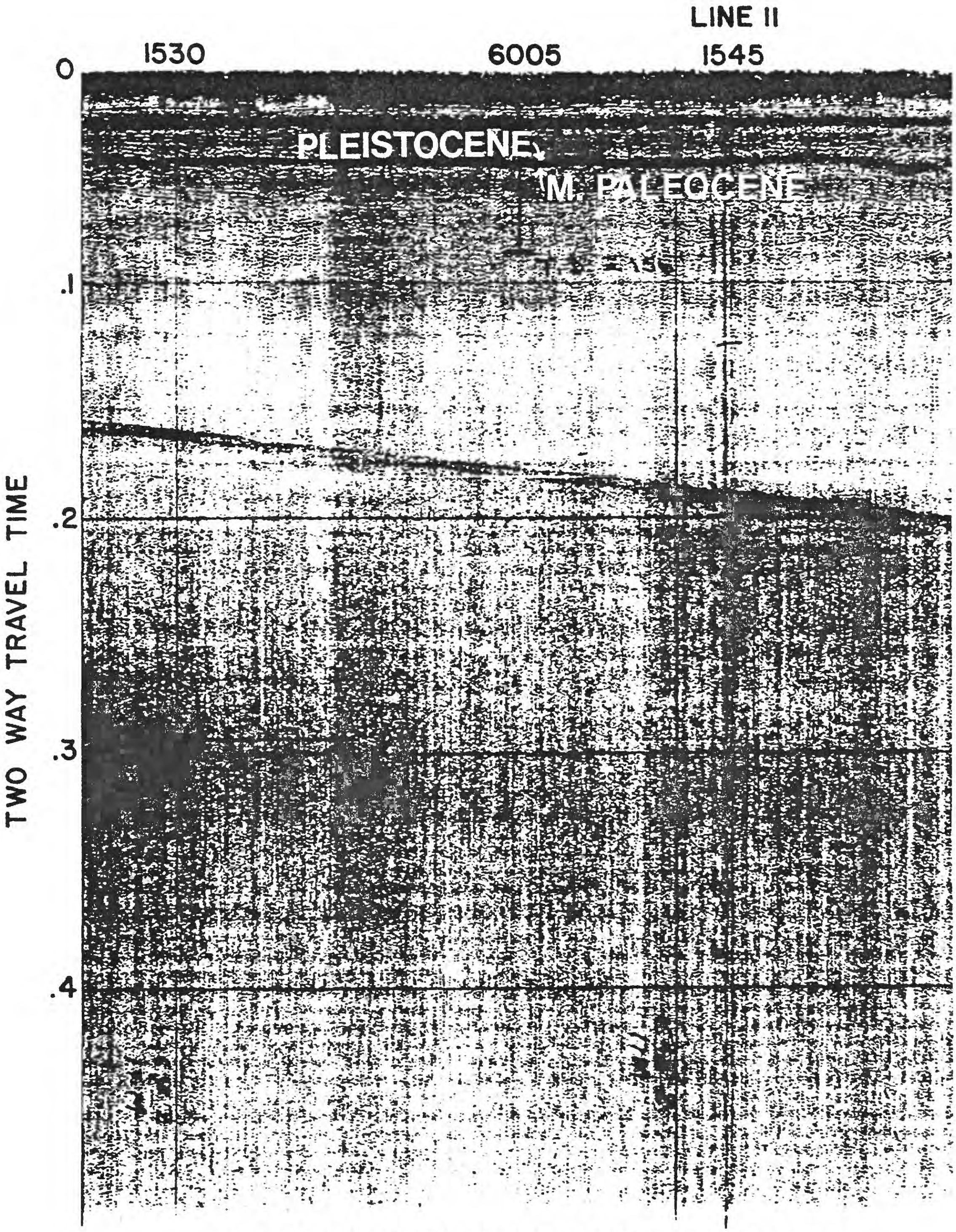
A 5 Florida Hatteras Slope-Blake Plateau transition
Dating control provided by Caldrill C-5 well



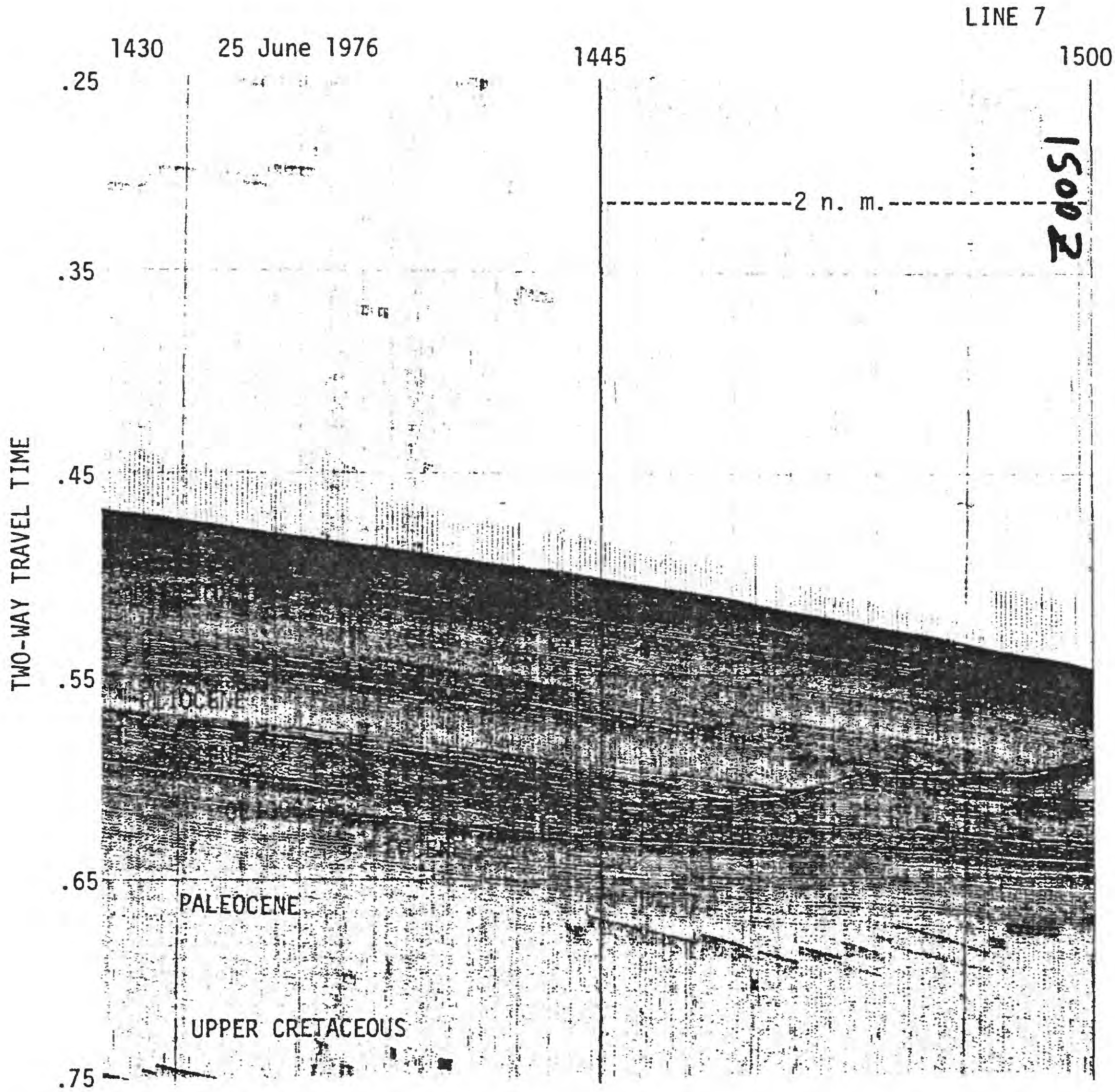
A 6 Erosional channel on Blake Plateau



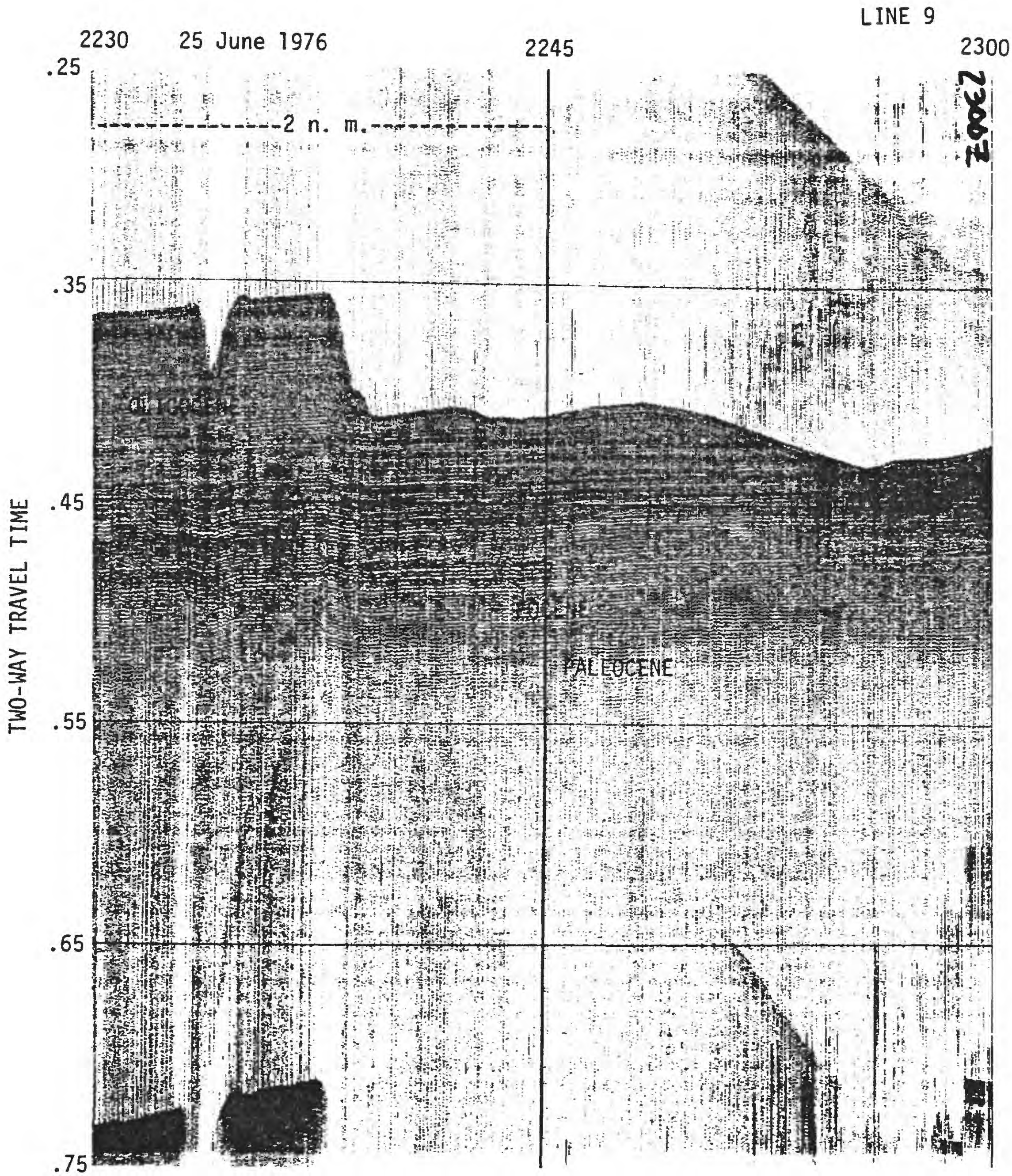
A 7 Pinchout of sedimentary sequences at base of Florida-Hatteras Slope



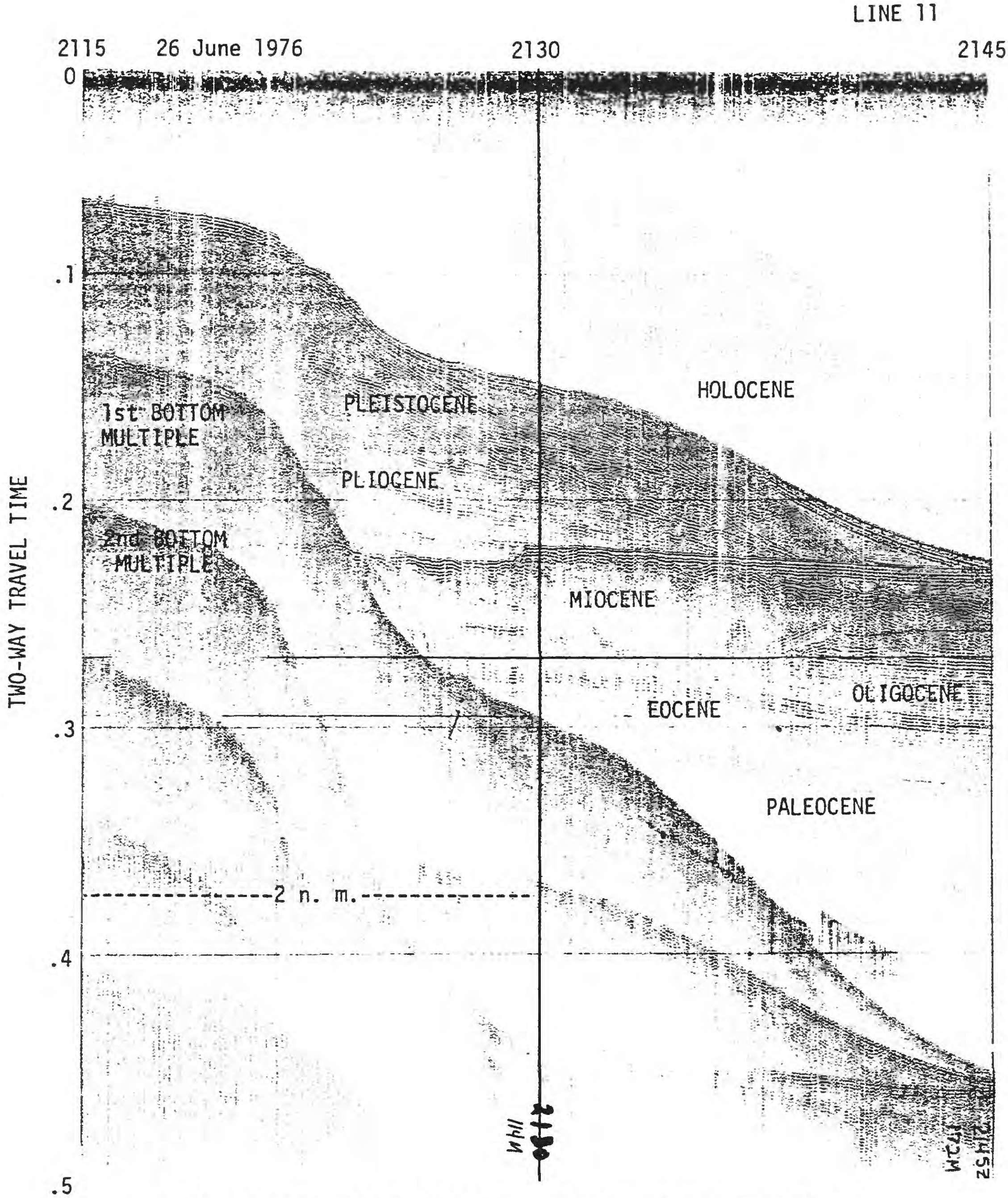
A-8 LINE II CROSSING DRILL SITE 6005



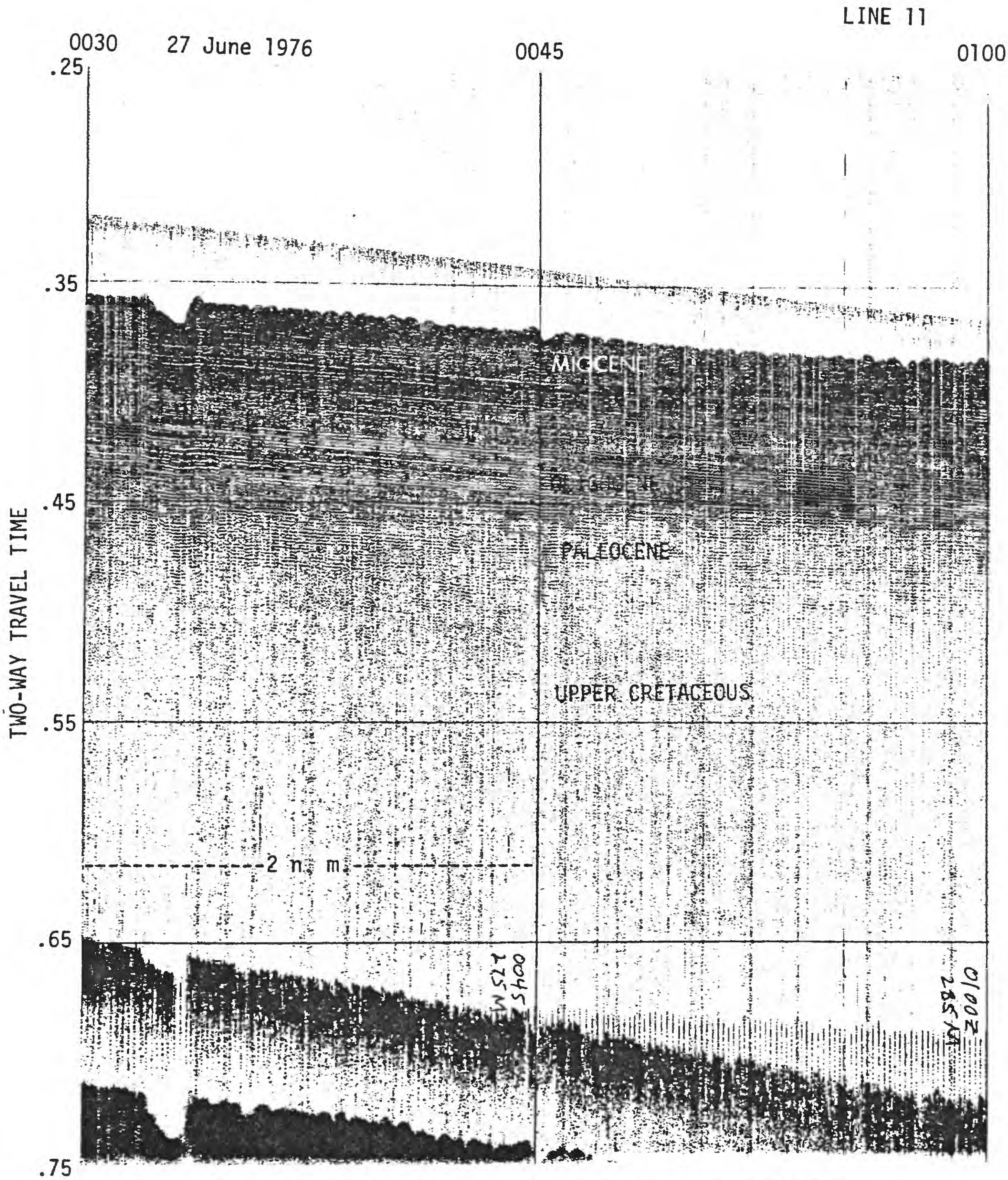
A 9 Fill of channel cut into Oligocene sediments on Blake Plateau



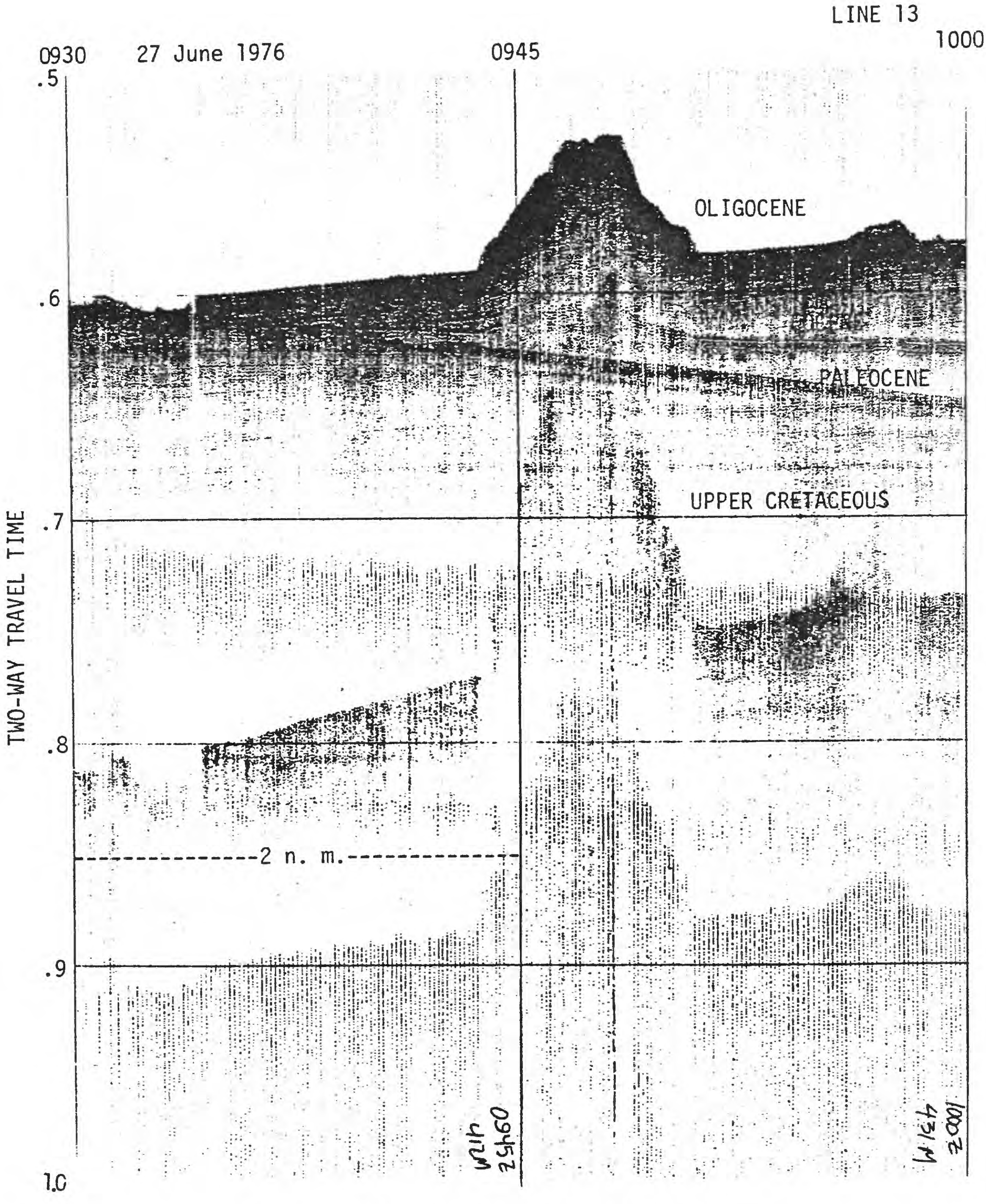
A 10 Typical erosional appearance of Oligocene sequence on Blake Plateau in northern region



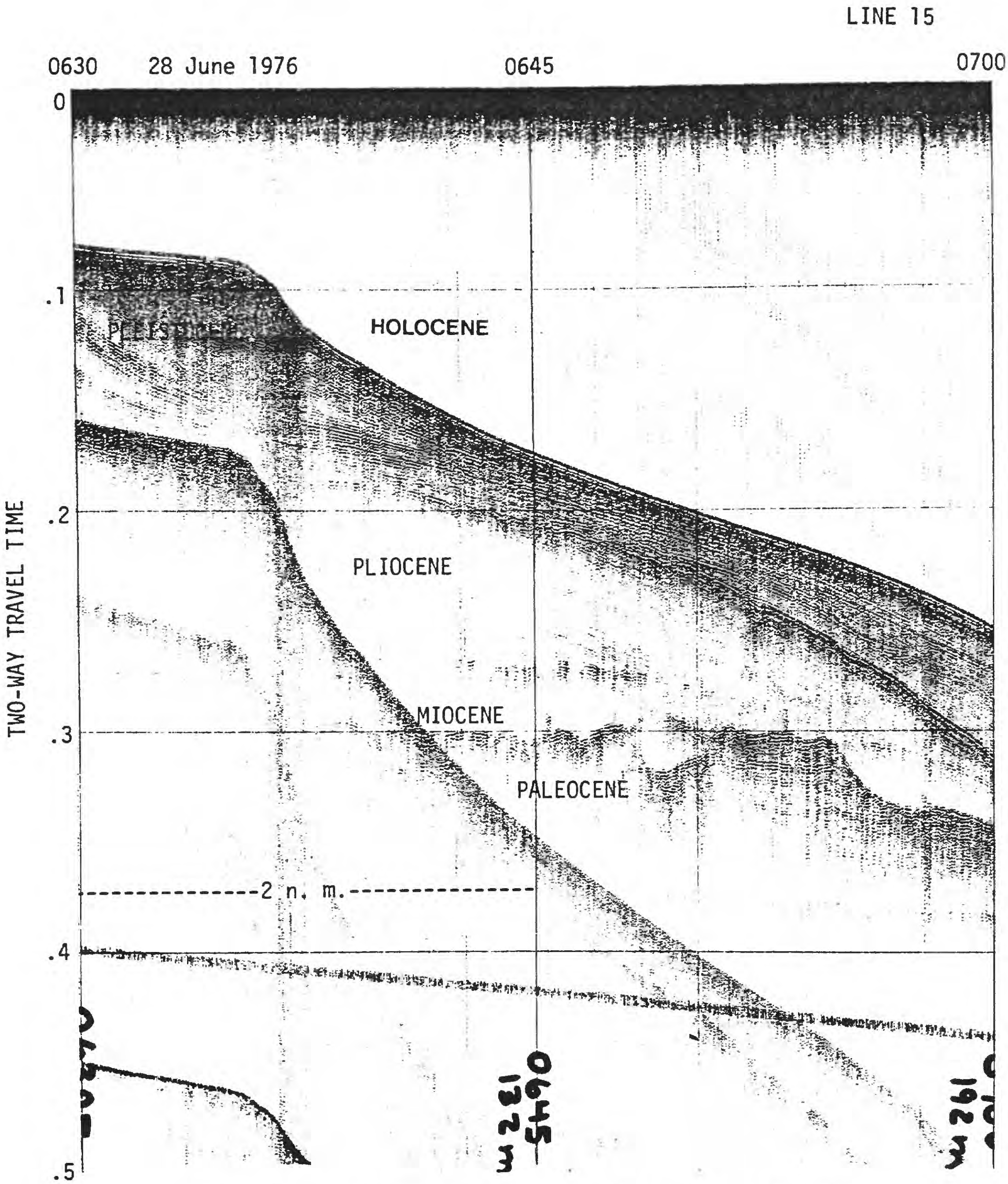
A 11 Continental Shelf-Florida-Hatteras Slope transition



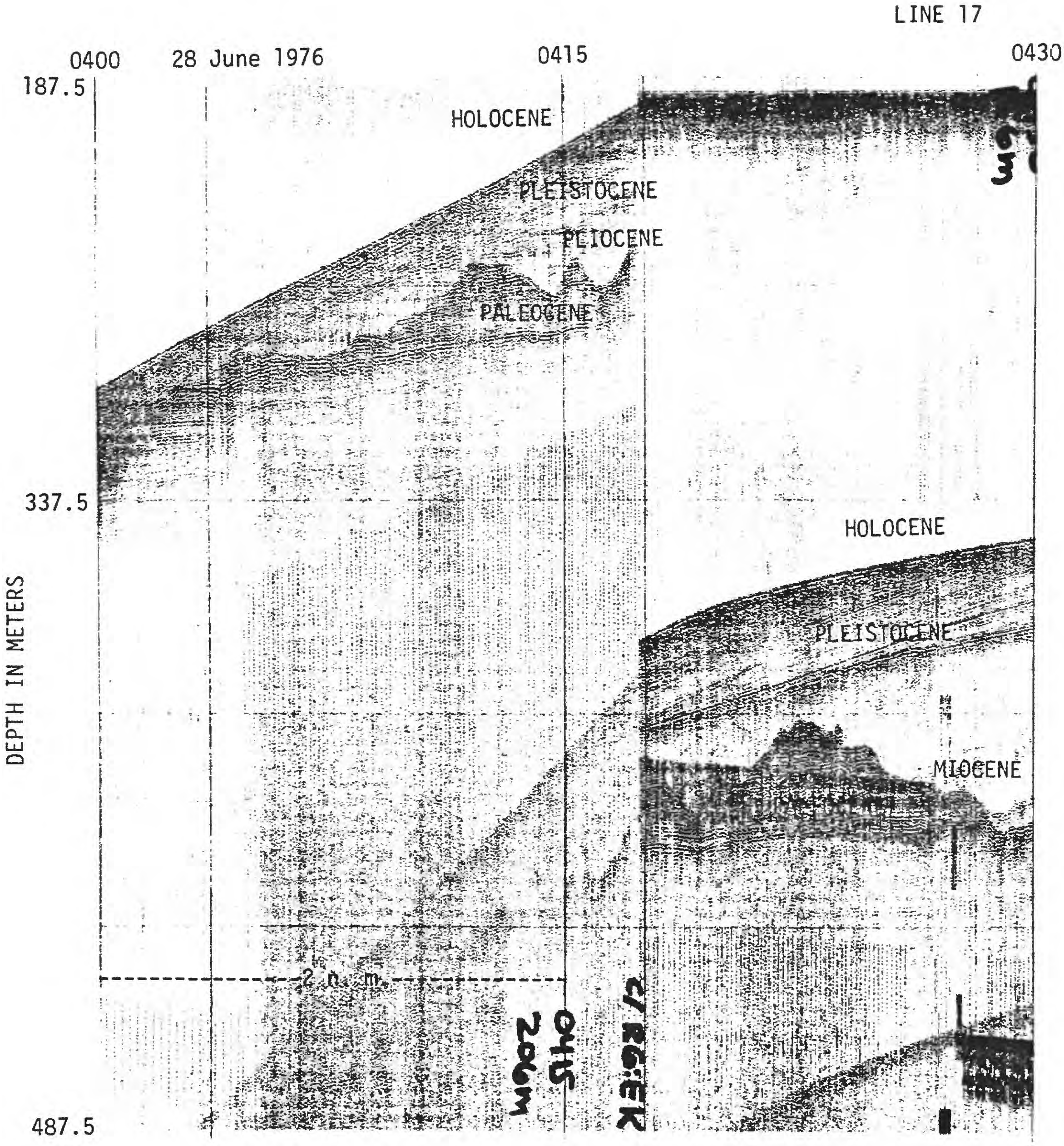
A 12 Erosional detail on Miocene sequence exposed on Blake Plateau



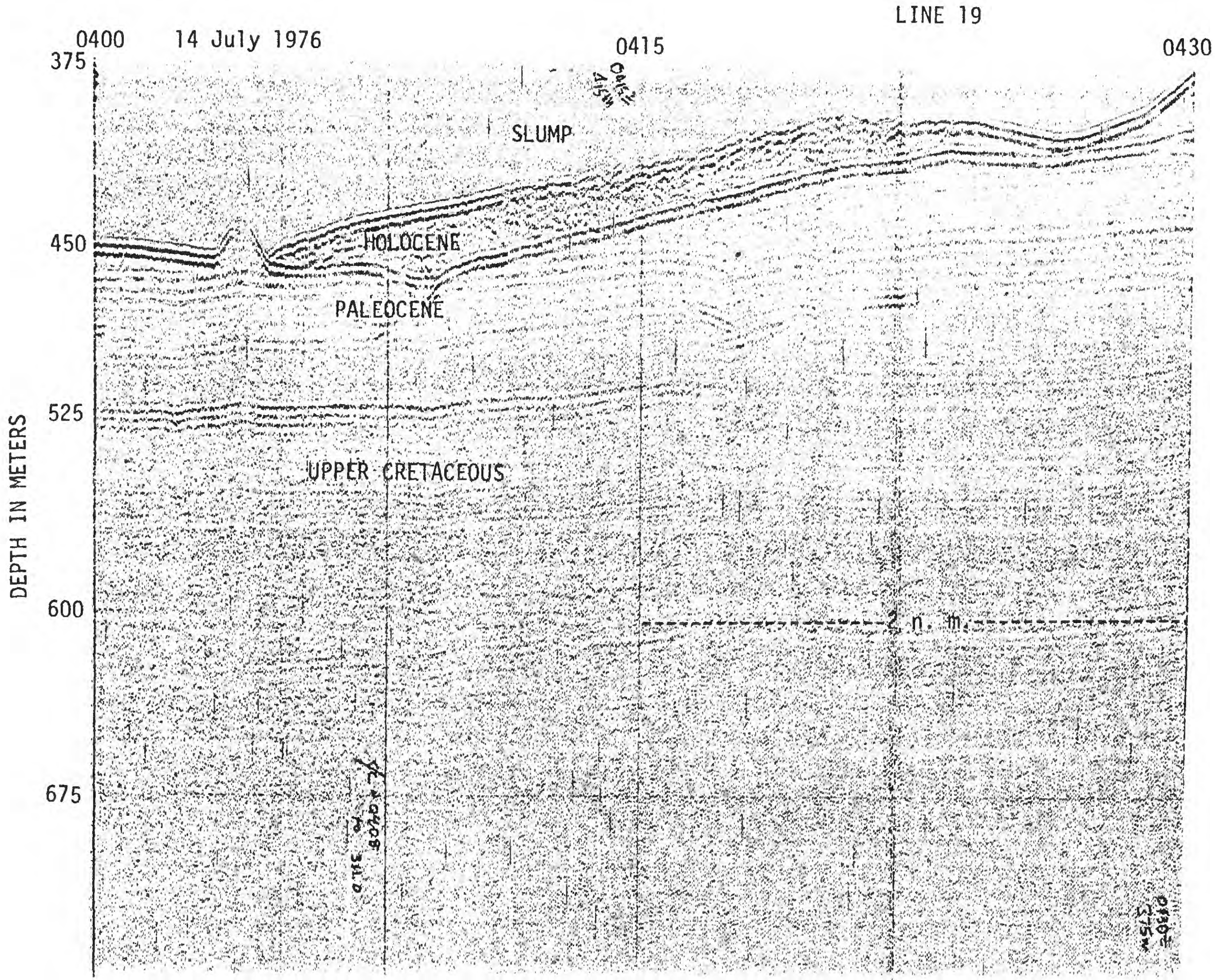
A 13 Oligocene outliers on Blake Plateau



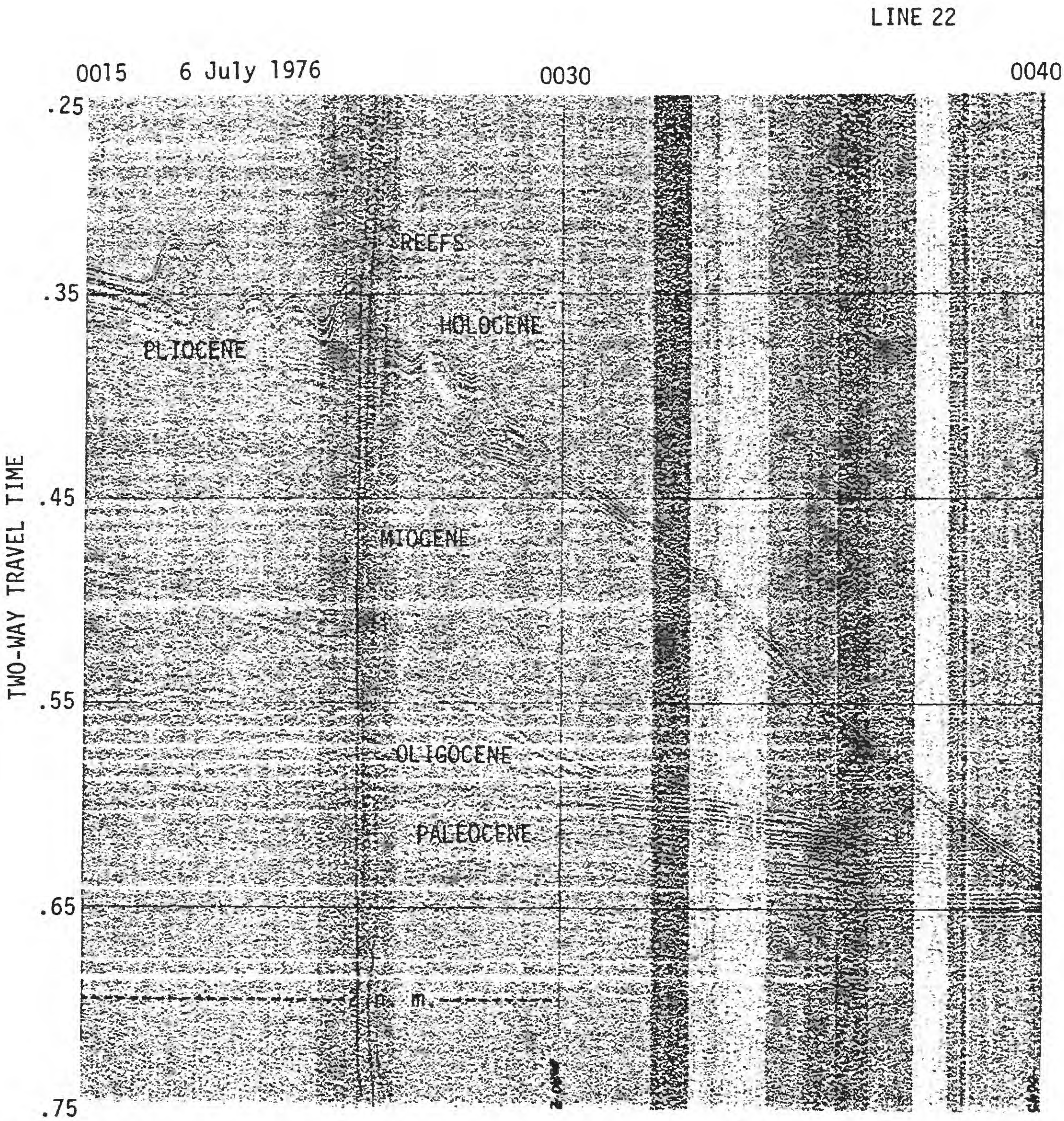
A 14 Sedimentary sequences beneath Continental Shelf Edge and Florida-Hatteras Slope



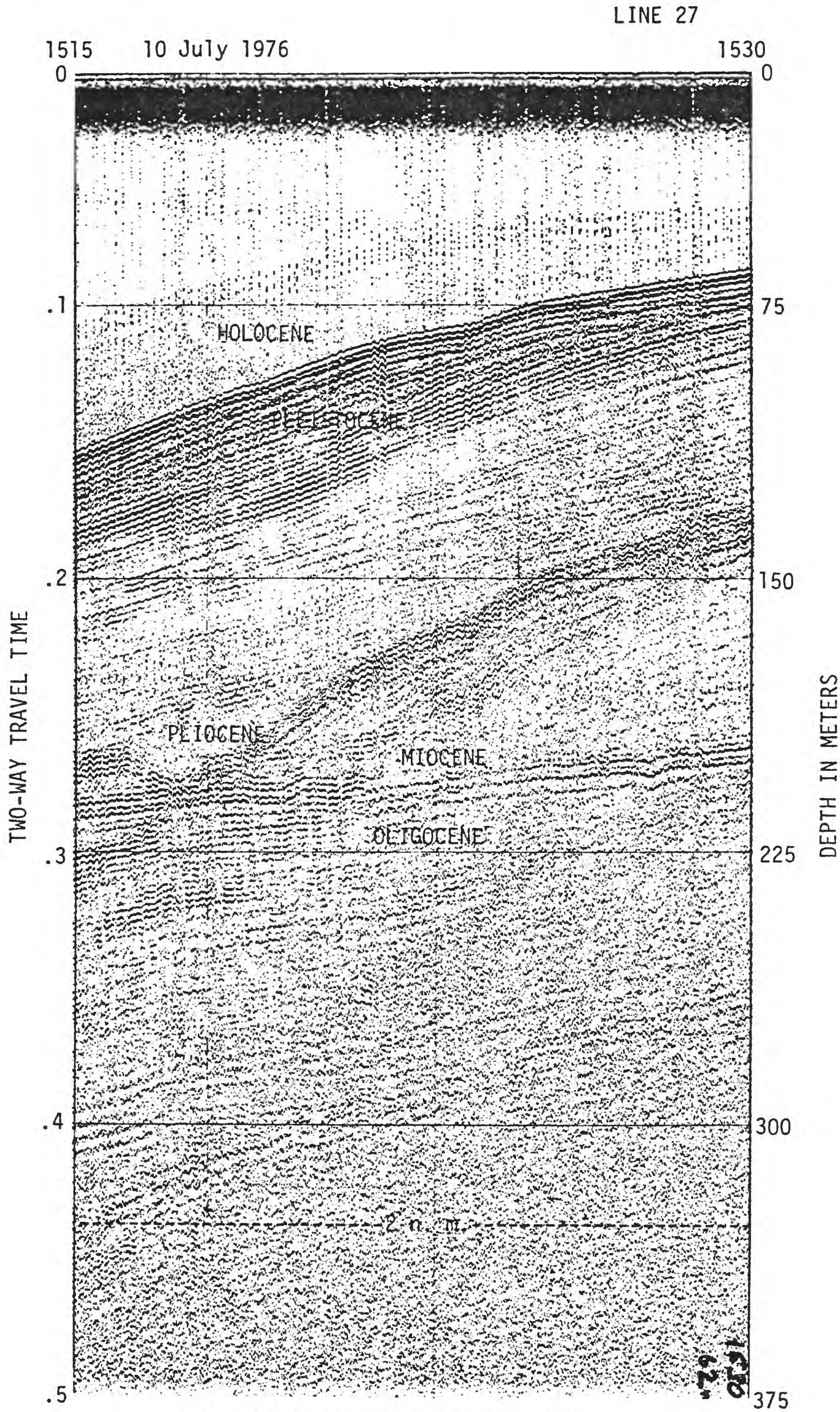
A 15 Sedimentary sequences beneath Florida-Hatteras Slope. Note prominent Paleocene shelf-edge which has effectively blocked Pliocene and older sediments from reaching Blake Plateau



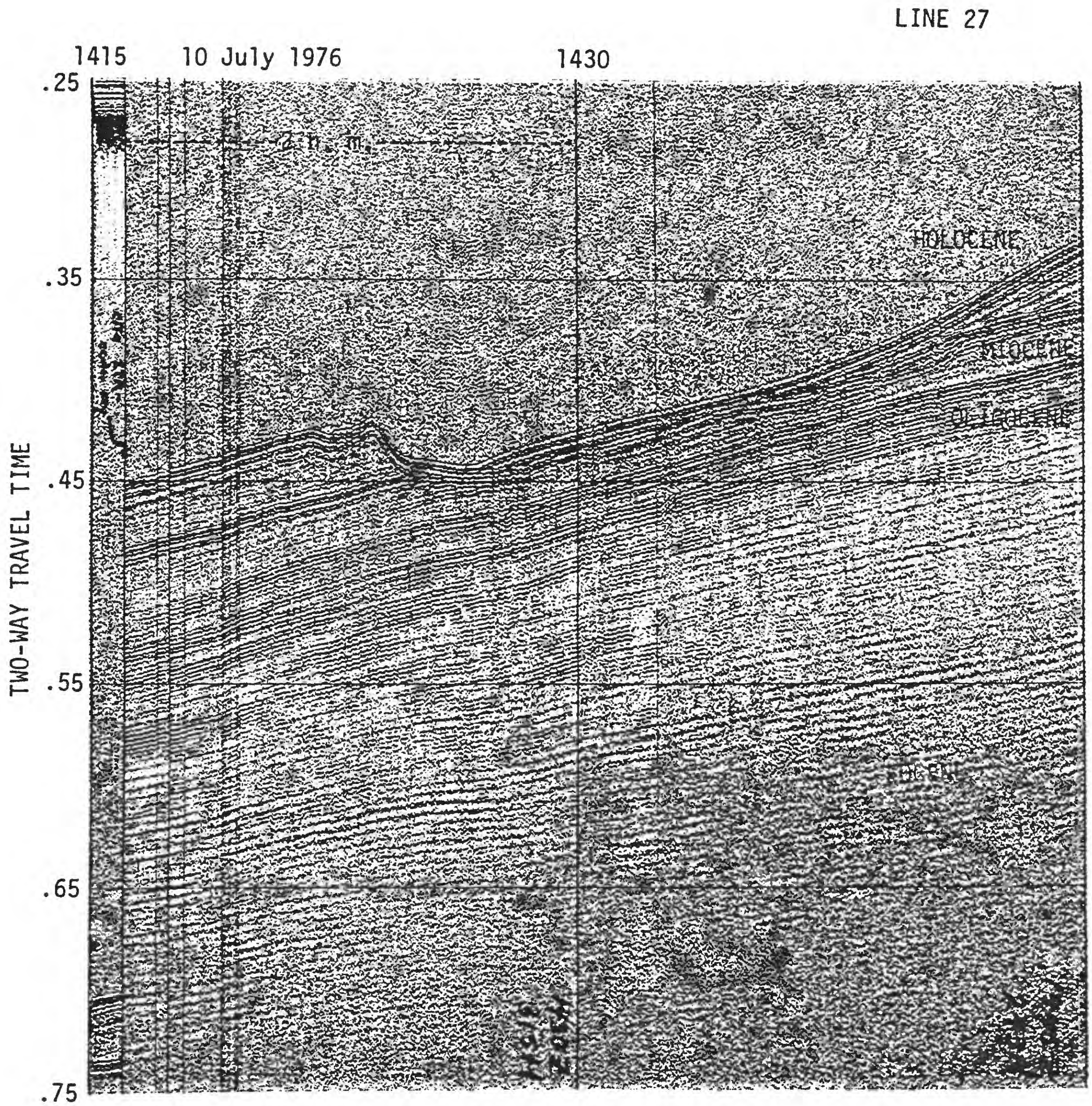
A 16 Slump sheet at base of slope



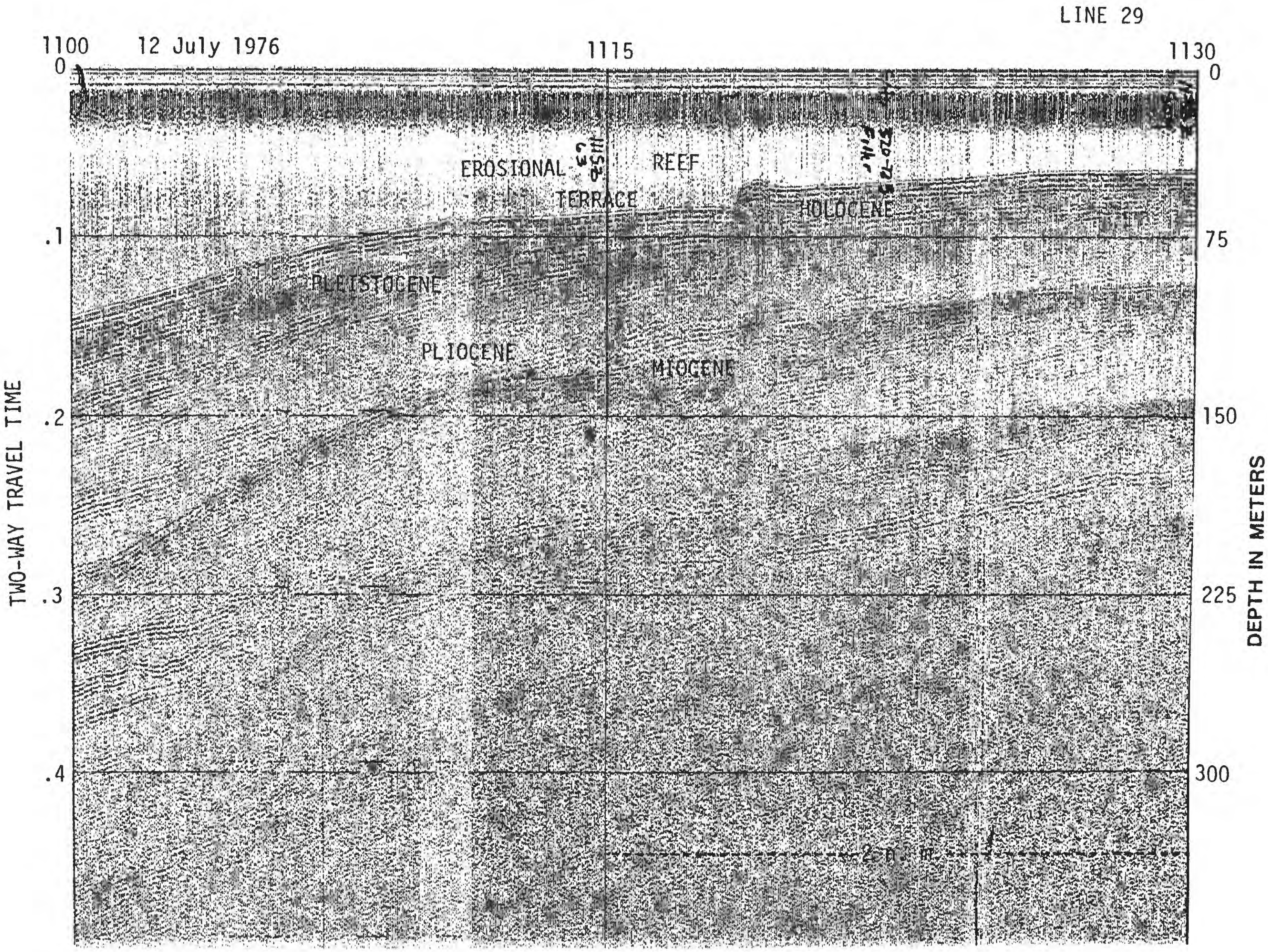
A 17 Recent reefs on Florida-Hatteras Slope



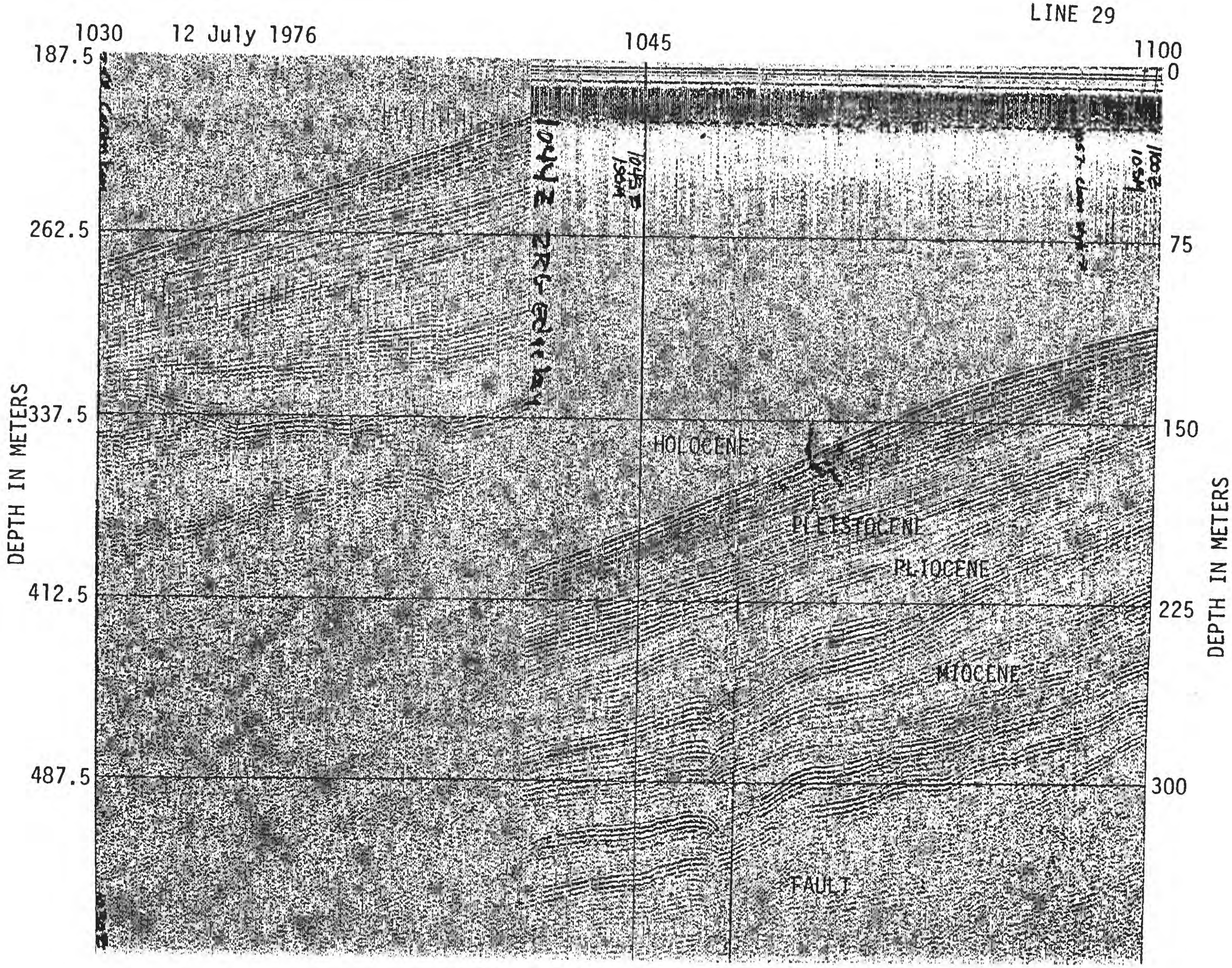
A 18 Northwest of drill hole J-5



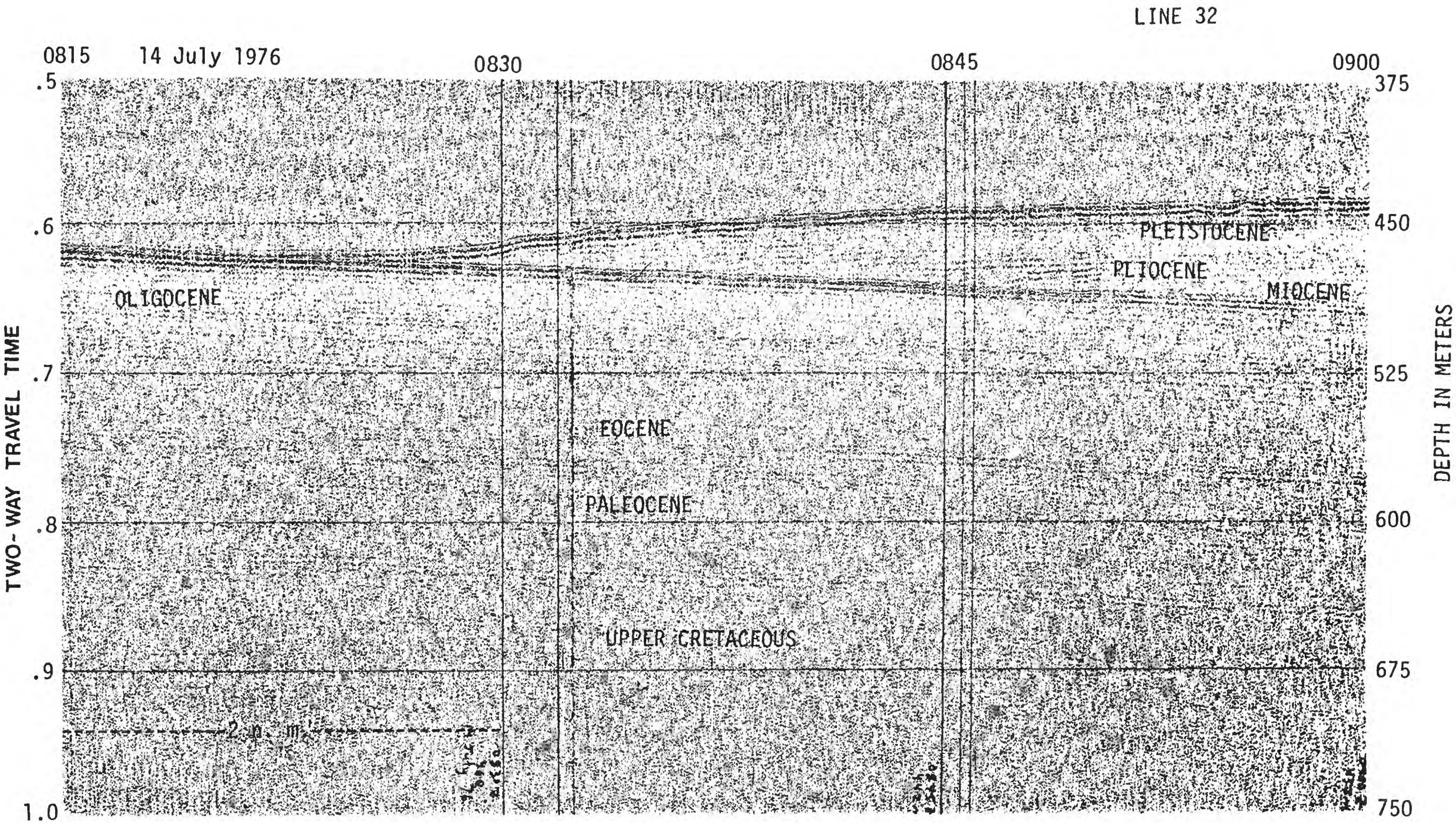
A 19 Erosion at base of Florida-Hatteras Slope



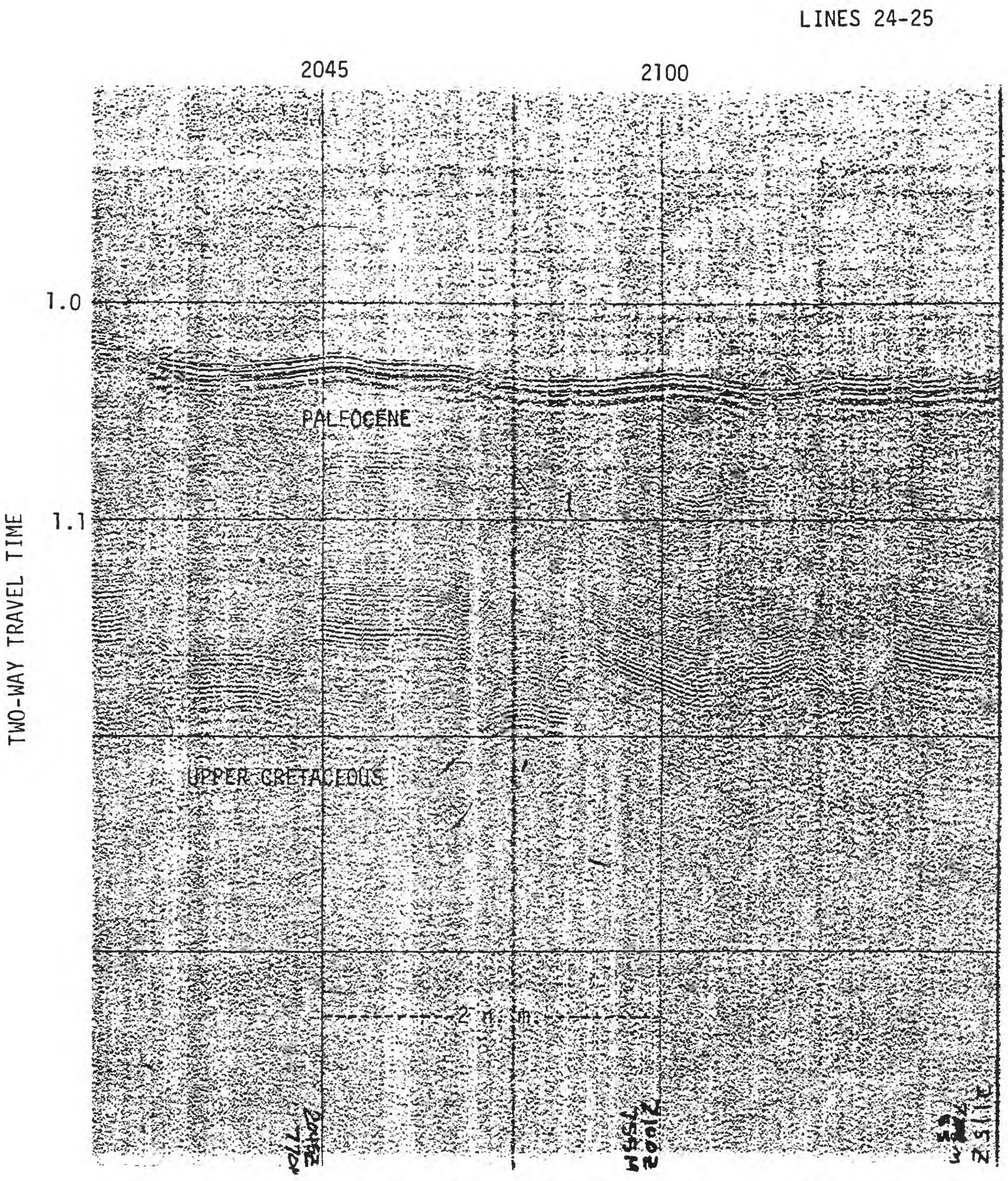
A 20 Shelf edge reef



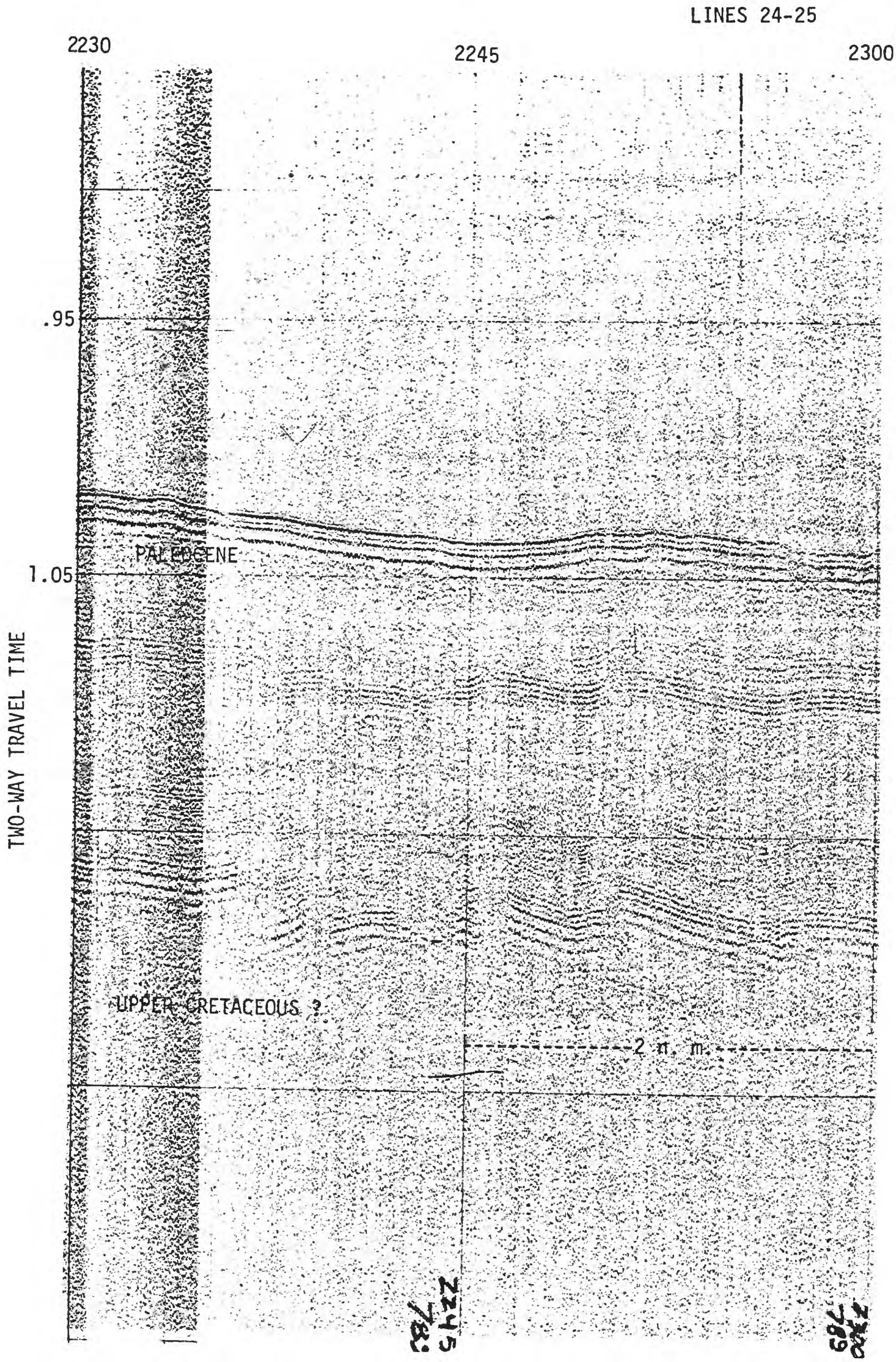
A 21 Shallow fault on slope



A 22 Pinchout of Pleistocene, Pliocene, and Miocene sequences between lines 5C and 5



A 23 Possible subsurface faulting or draping of sediments across buried unconformity



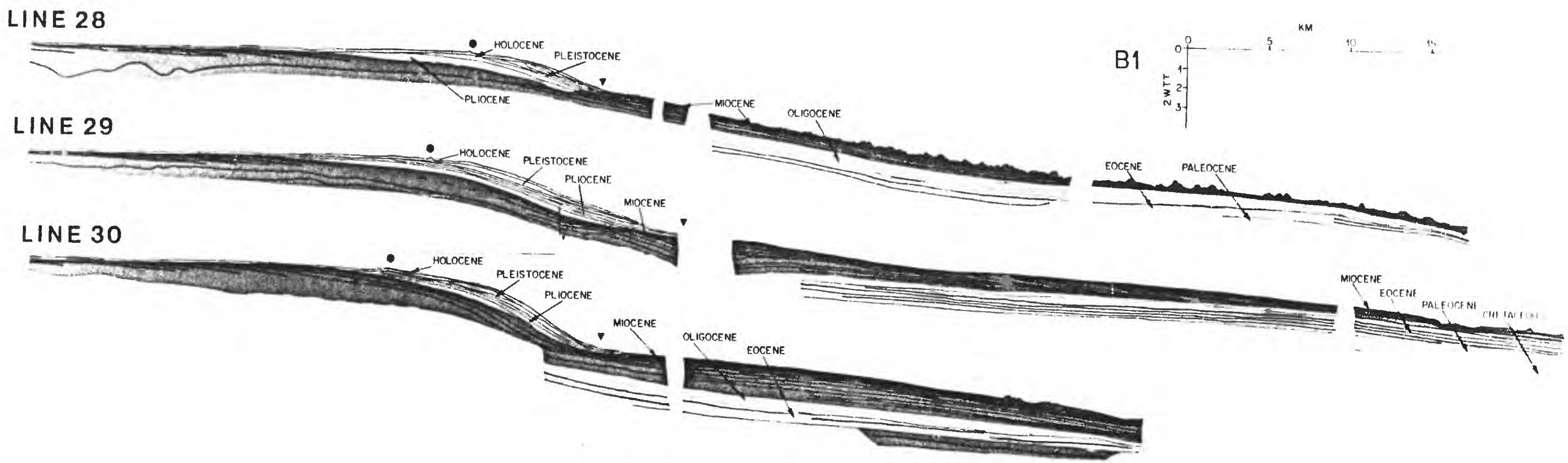
A 24 Possible subsurface faulting or draping of sediments over buried topography

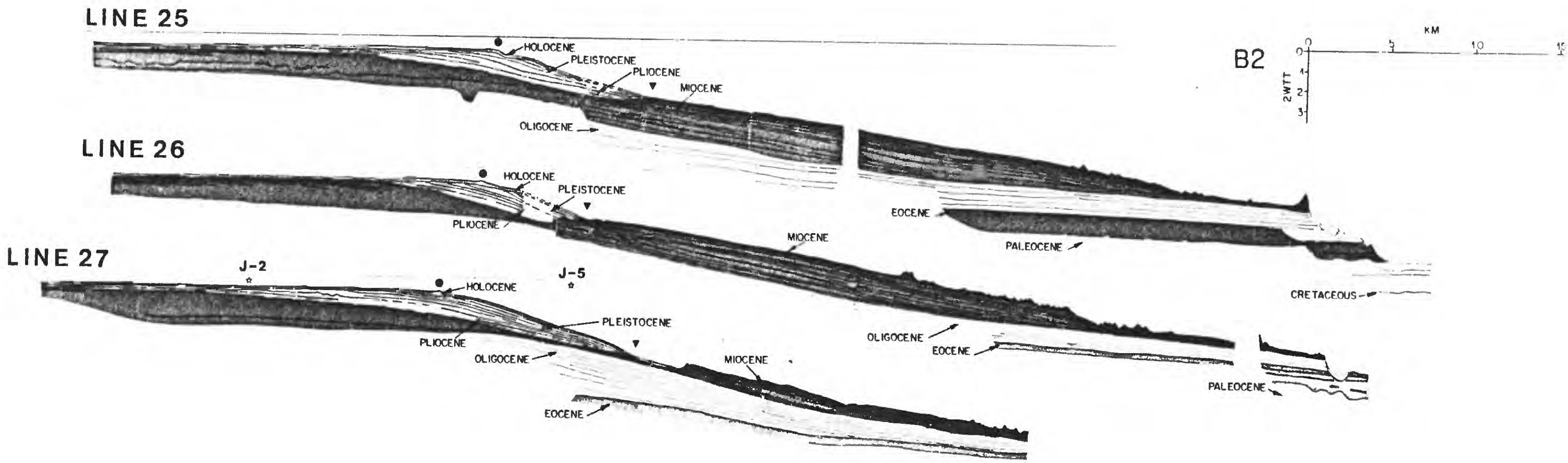
APPENDIX B

Line Drawings of Minisparker Record Interpretations

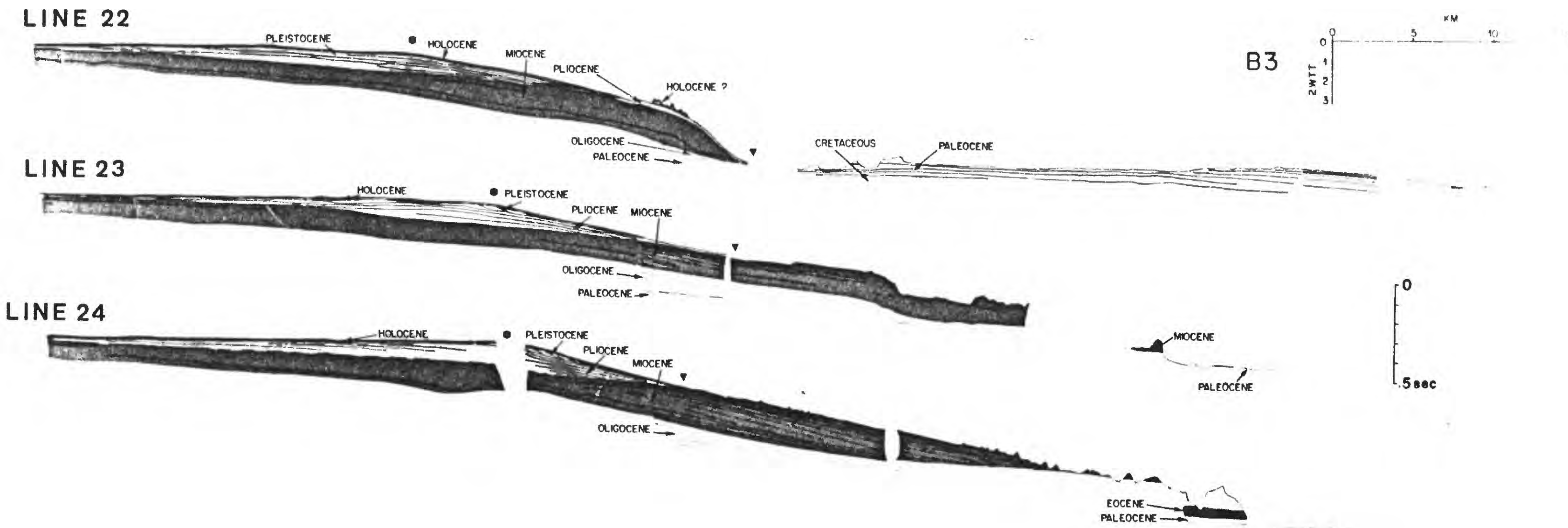
B- 1	lines 30, 29 and 28
B- 2	" 27, 26 and 25
B- 3	" 24, 23 and 22
B- 4	" 21, 20 and 19
B- 5	" 17, 15B, 15 and 15A
B- 6	" 13, 11 and 9 - part 1
B- 7	" 13, 11 and 9 - part 2
B- 8	" 7, 5C and 5 - part 1
B- 9	" 7, 5C and 5 - part 2
B-10	tie lines 32 and 31
B-11	tie line 18
B-12	tie lines 1, 2, 2A, 3 and 4

△	location of cross or tie line
○	shelf edge reef

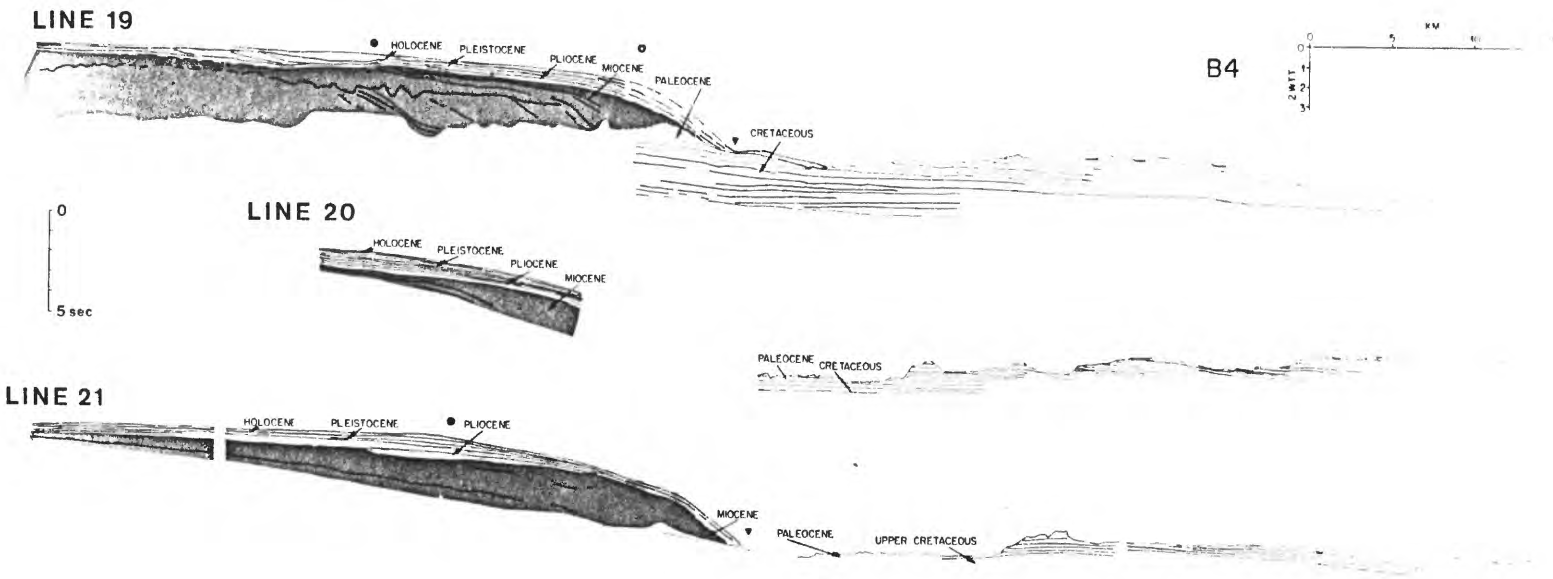

LINE 28
LINE 29
LINE 30
B1
KM
0
5
10
0
1
2
3
2WTT
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE



B2
KM
0
5
10
15
2WTT
0
1
2
3
LINE 25
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
LINE 26
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
LINE 27
J-2
J-5
HOLOCENE
PLEISTOCENE
PLIOCENE
OLIGOCENE
MIOCENE
EOCENE

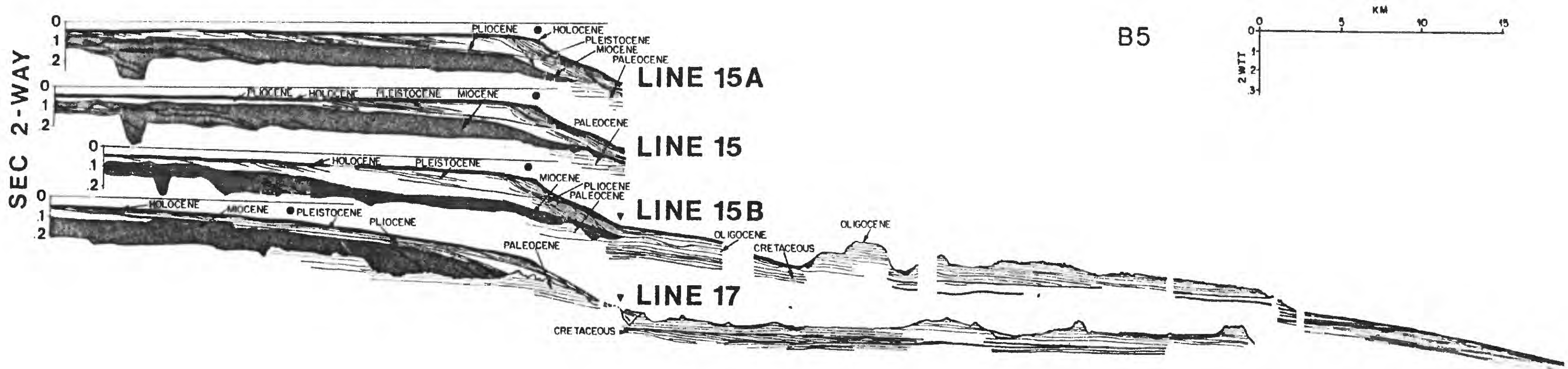

LINE 22
PLEISTOCENE
HOLOCENE
MIOCENE
PLIOCENE
HOLOCENE ?
OLIGOCENE
PALEOCENE
CRETACEOUS
PALEOCENE
B3
KM
0
5
10
2WTT
0
1
2
3
LINE 23
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
PALEOCENE
LINE 24
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
MIOCENE
PALEOCENE
EOCENE
PALEOCENE
0
.5 sec

8_5

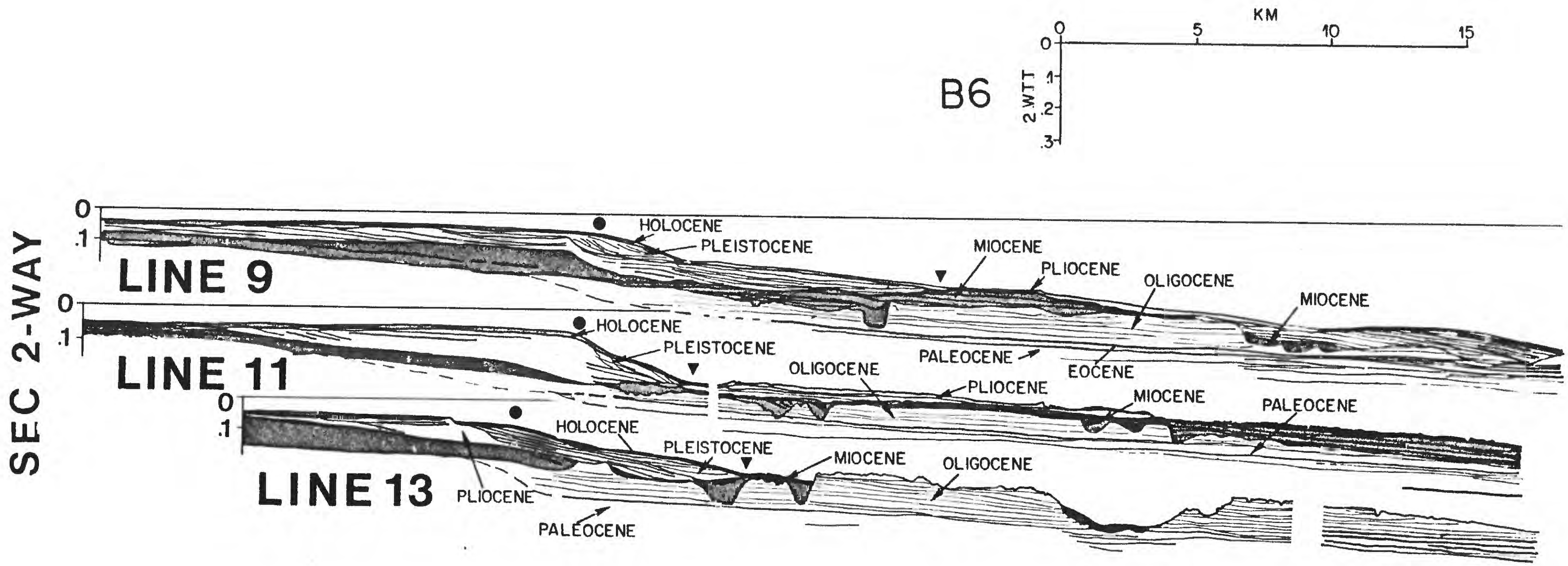

LINE 19
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
PALEOCENE
CRETACEOUS
B4
0
5
KM
10
15
2WTT
1
2
3
0
5 sec
LINE 20
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
PALEOCENE
CRETACEOUS
LINE 21
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
PALEOCENE
UPPER CRETACEOUS

59

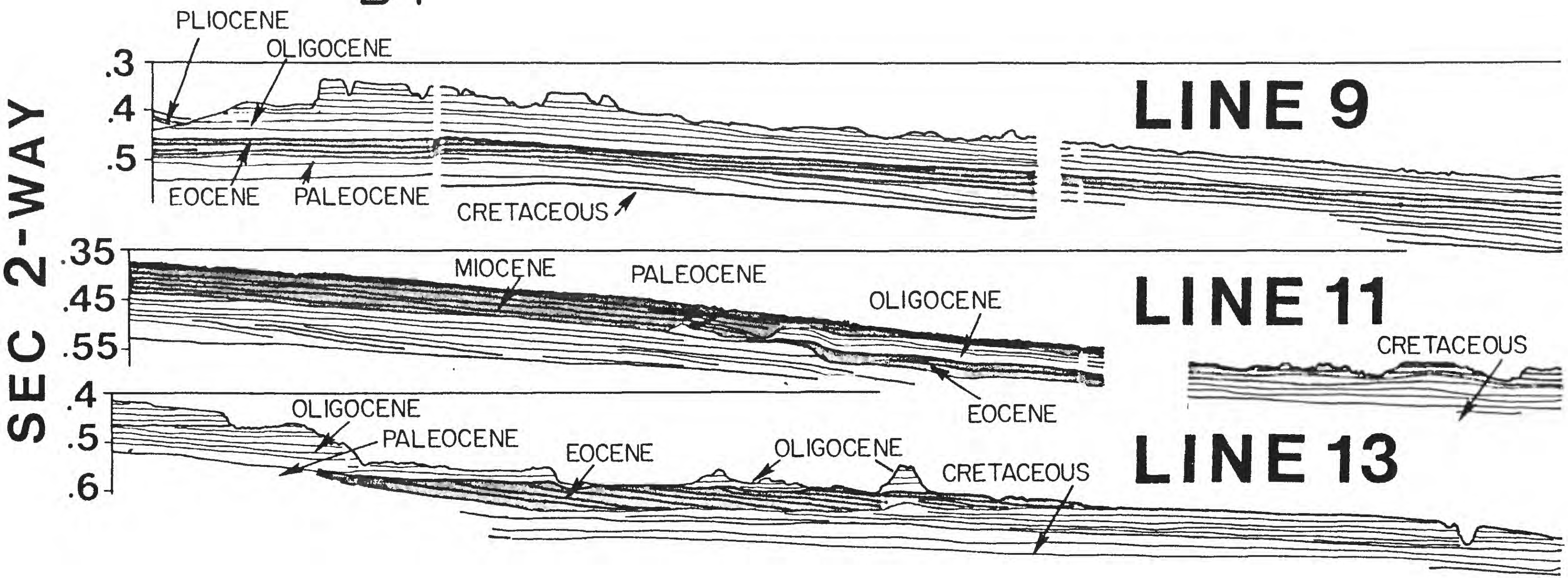
B5

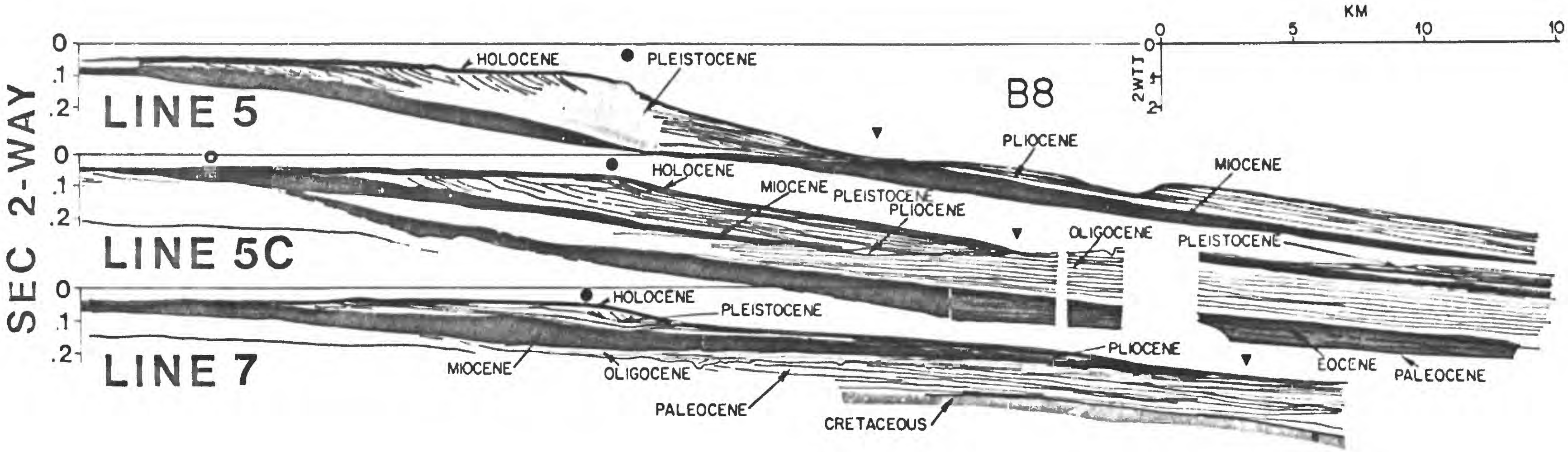


SEC 2-WAY
0
1
2
LINE 15A
PLIOCENE
HOLOCENE
PLEISTOCENE
MIOCENE
PALEOCENE
LINE 15
PLIOCENE
HOLOCENE
PLEISTOCENE
MIOCENE
PALEOCENE
LINE 15B
HOLOCENE
PLEISTOCENE
MIOCENE
PLIOCENE
PALEOCENE
OLIGOCENE
CRETACEOUS
OLIGOCENE
LINE 17
HOLOCENE
MIOCENE
PLEISTOCENE
PLIOCENE
PALEOCENE
CRETACEOUS
KM
0
5
10
15
2 WTT

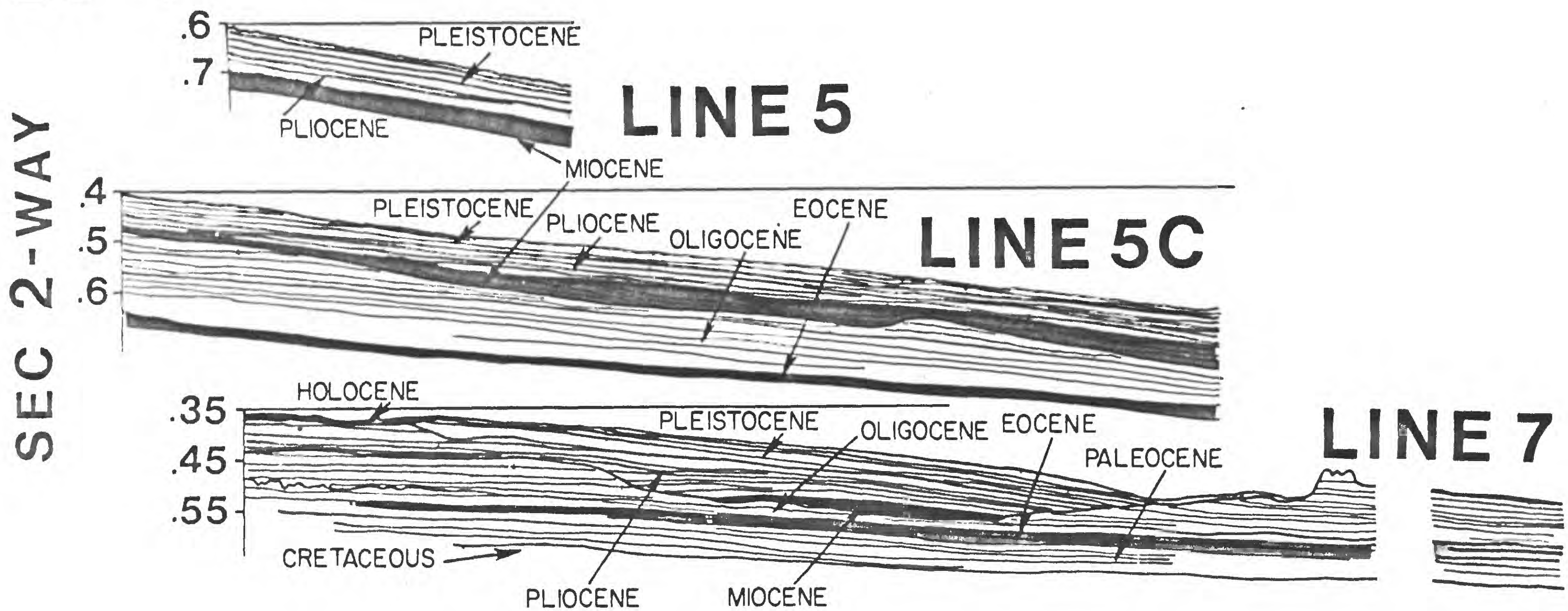

B6
KM
0
5
10
15
2 WTT
0
.1
.2
.3
SEC 2-WAY
LINE 9
0
.1
HOLOCENE
PLEISTOCENE
MIOCENE
PLIOCENE
OLIGOCENE
MIOCENE
PALEOCENE
EOCENE
LINE 11
0
.1
HOLOCENE
PLEISTOCENE
OLIGOCENE
PLIOCENE
MIOCENE
PALEOCENE
LINE 13
0
.1
HOLOCENE
PLEISTOCENE
MIOCENE
OLIGOCENE
PLIOCENE
PALEOCENE

B7

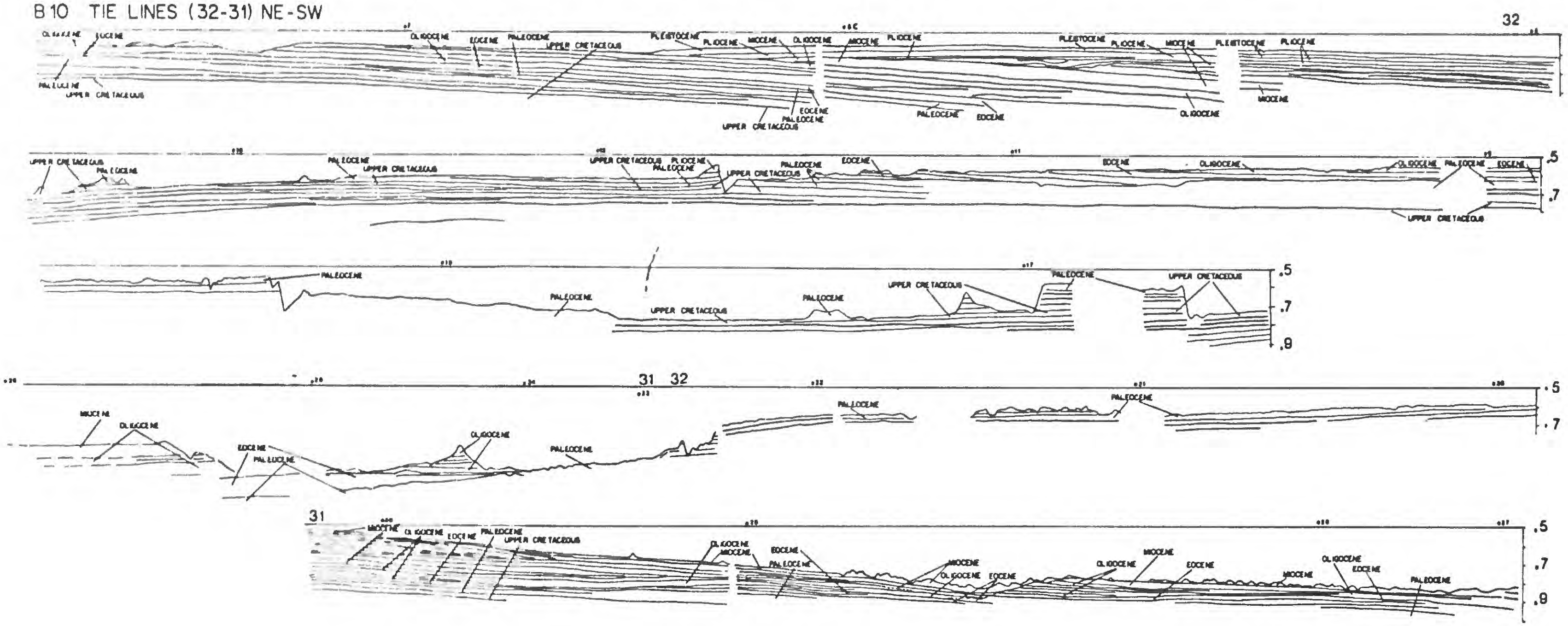

SEC 2-WAY
.3
.4
.5
PLIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
LINE 9
.35
.45
.55
MIOCENE
PALEOCENE
OLIGOCENE
EOCENE
LINE 11
CRETACEOUS
.4
.5
.6
OLIGOCENE
PALEOCENE
EOCENE
OLIGOCENE
CRETACEOUS
LINE 13


SEC 2-WAY
LINE 5
LINE 5C
LINE 7
B8
KM
2WTT
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS

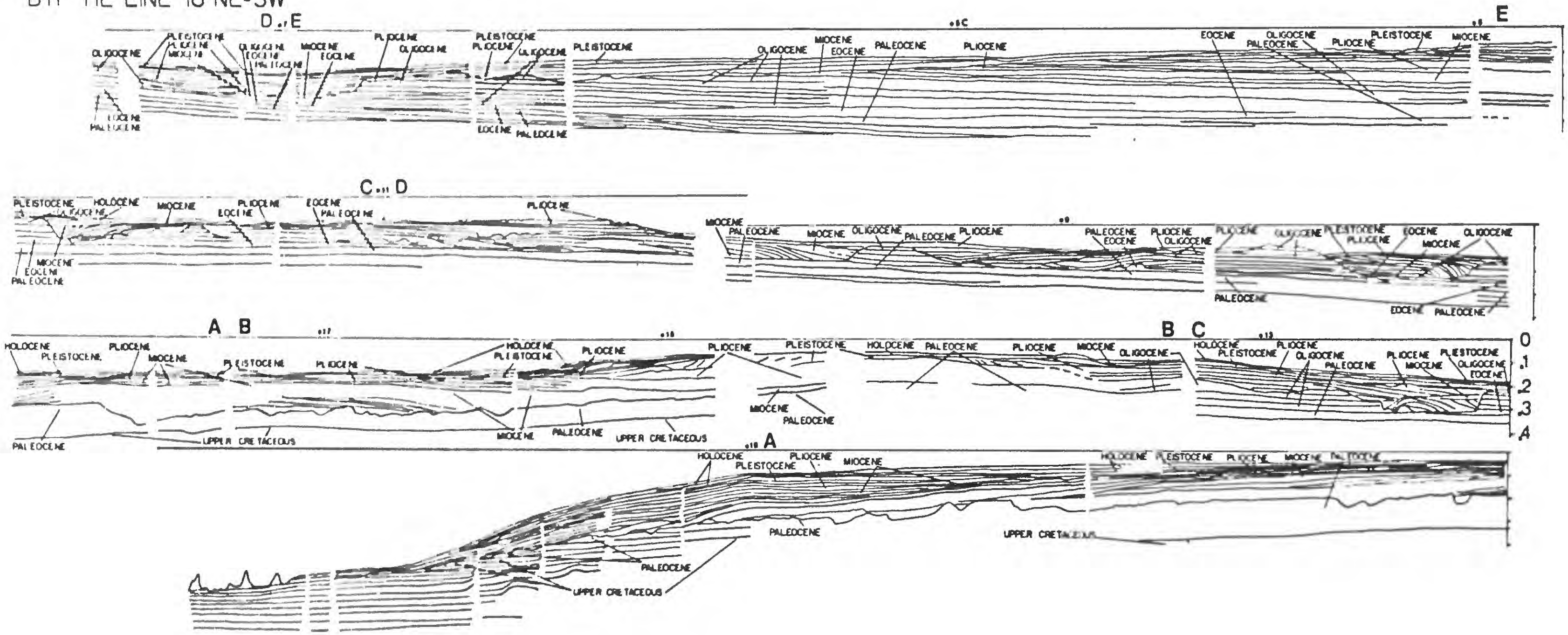
B9


SEC 2-WAY
.6
.7
PLEISTOCENE
PLIOCENE
MIOCENE
LINE 5
.4
.5
.6
PLEISTOCENE
PLIOCENE
OLIGOCENE
EOCENE
LINE 5C
.35
.45
.55
HOLOCENE
PLEISTOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
PLIOCENE
MIOCENE
LINE 7

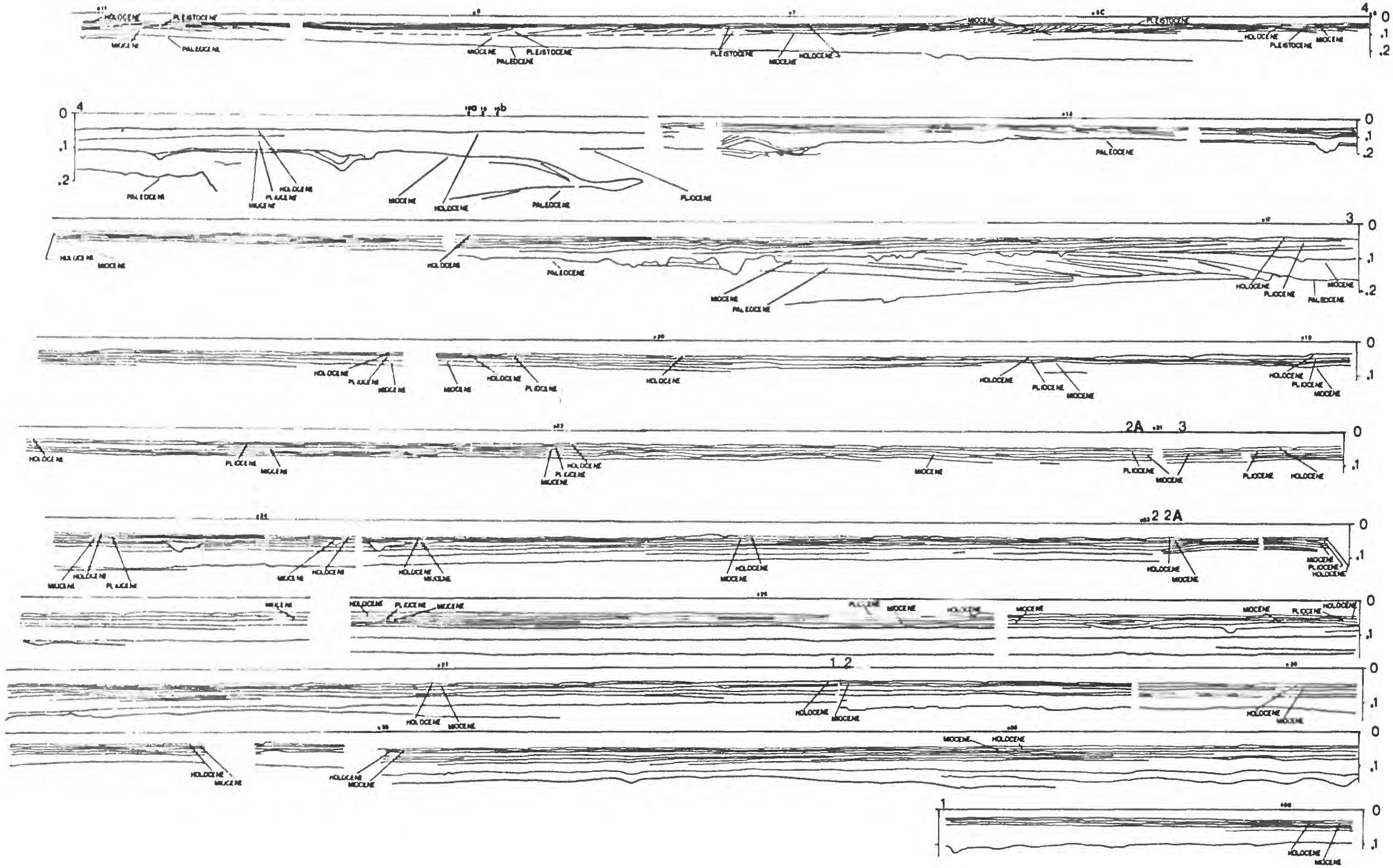
B10 TIE LINES (32-31) NE-SW



B11 TIE LINE 18 NE-SW

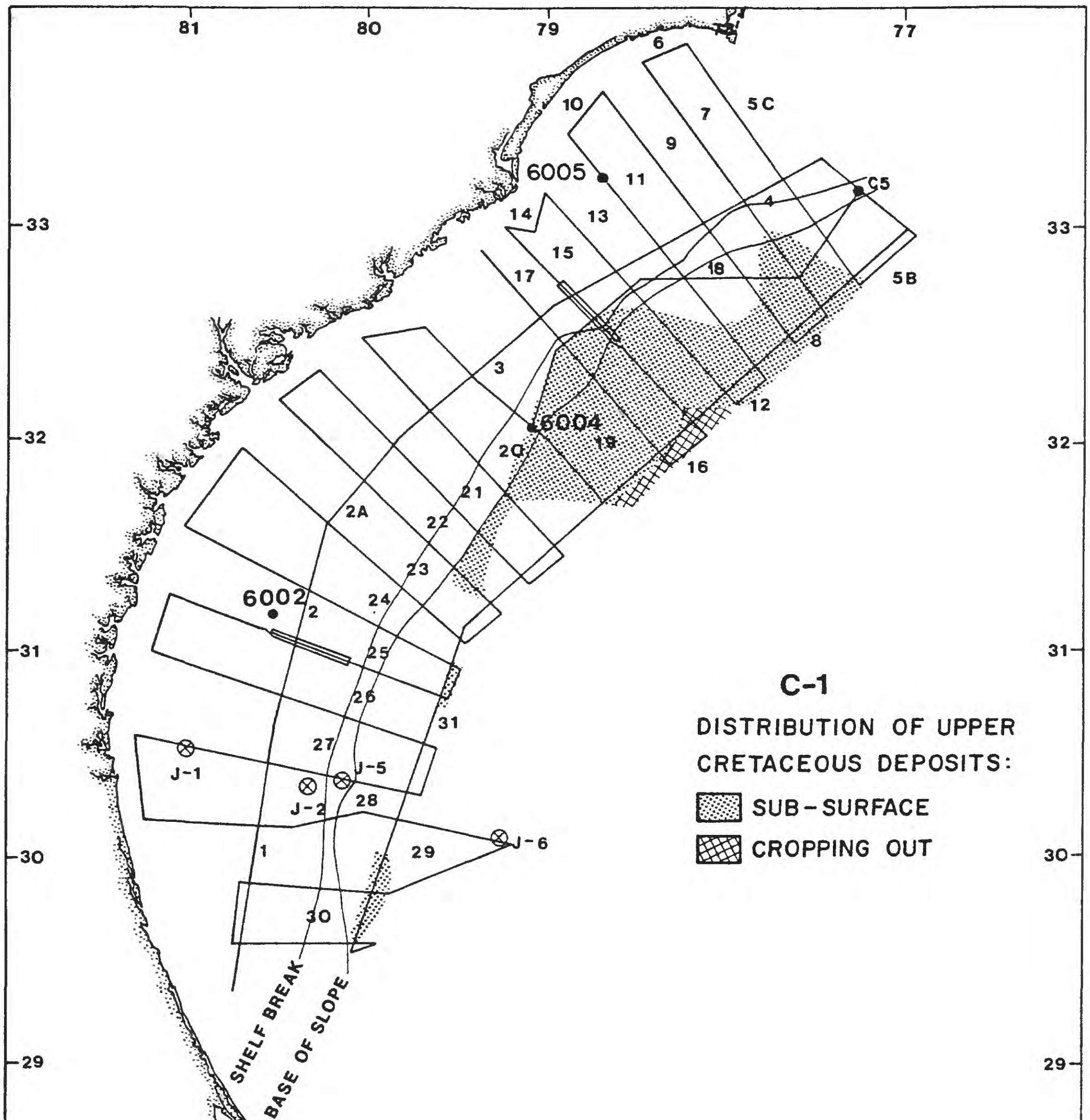


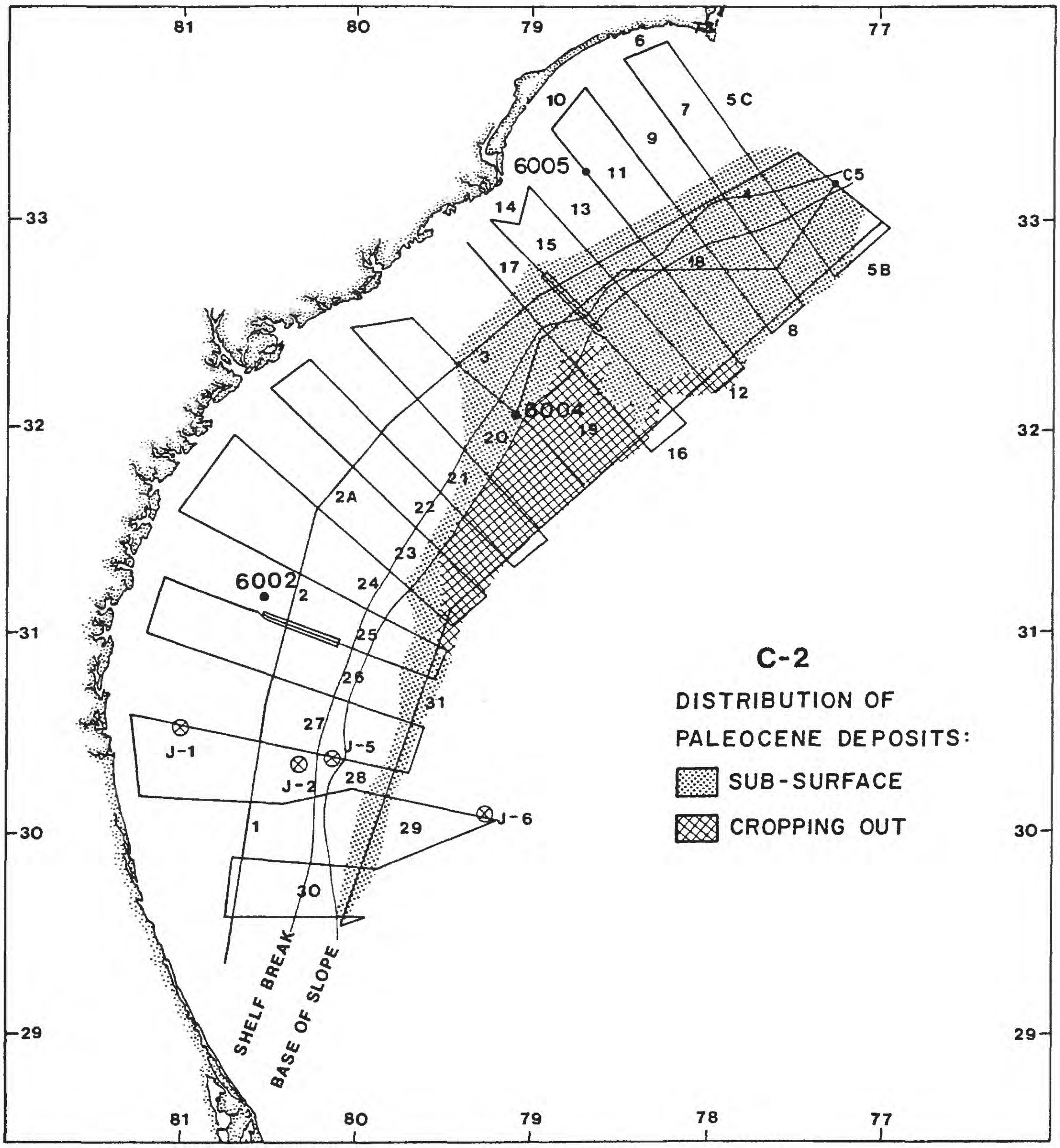
B 12 TIE LINES (4-1) NE-SW

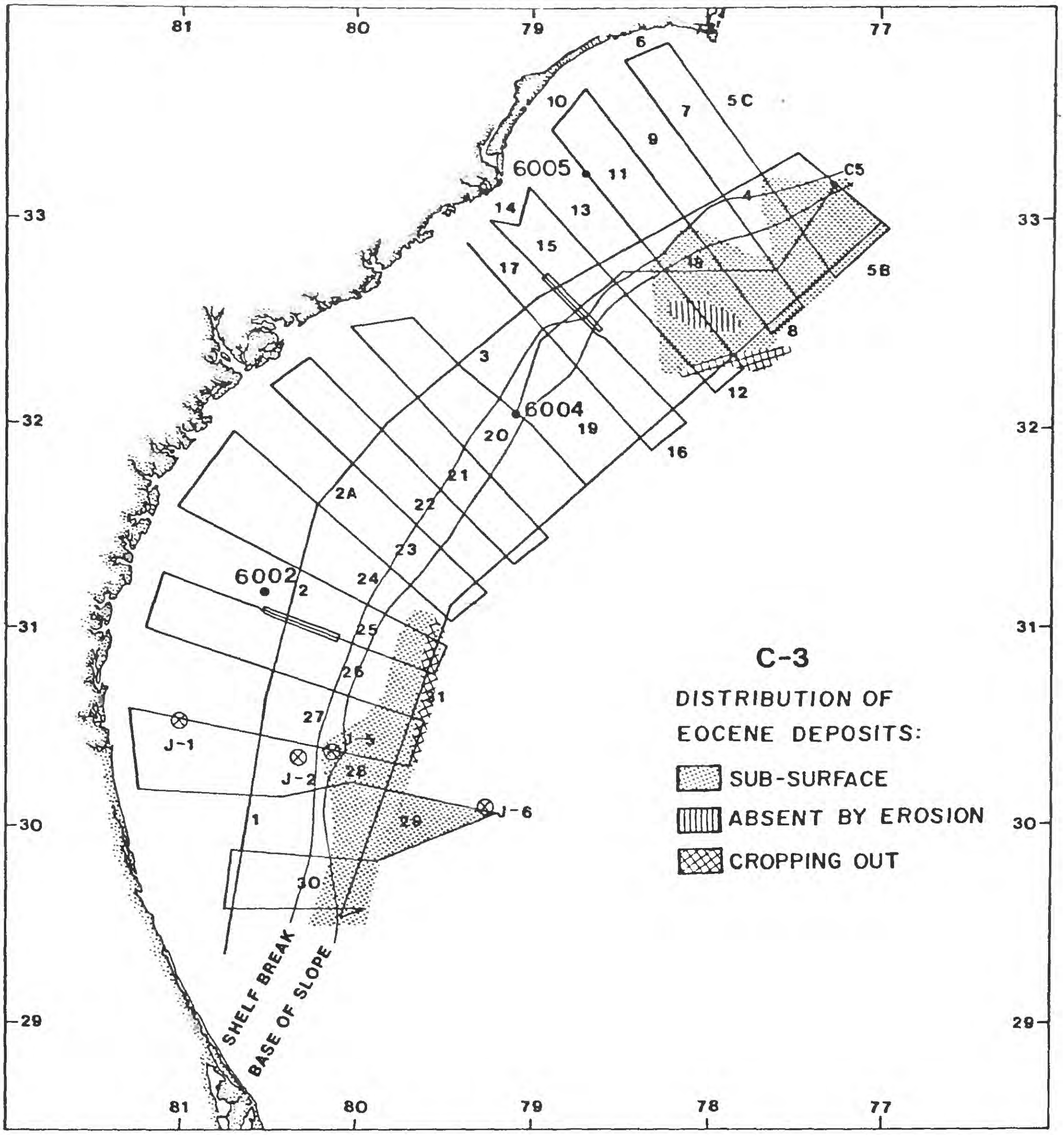


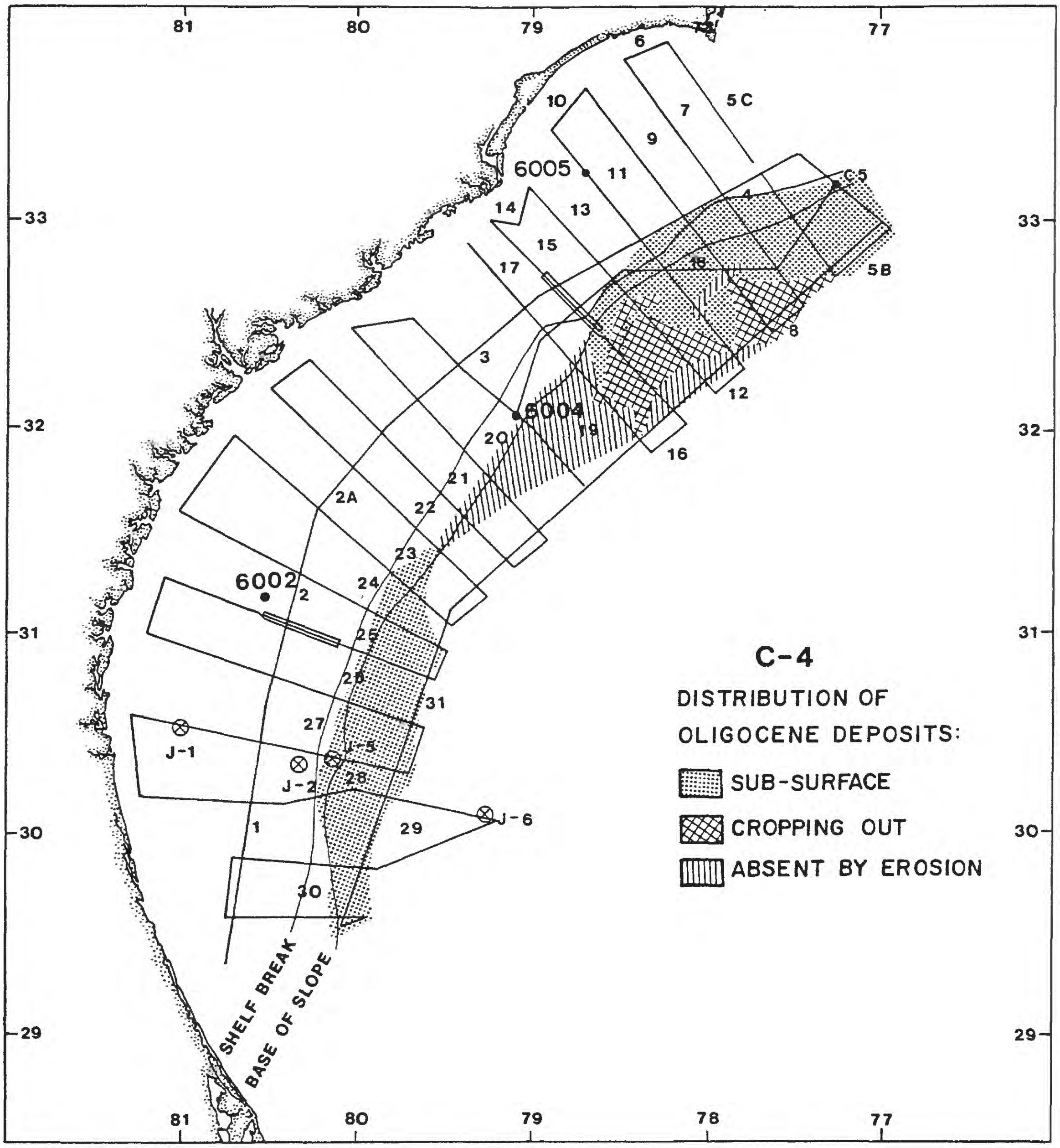
APPENDIX C

Maps Showing Sediment Distribution by Epoch

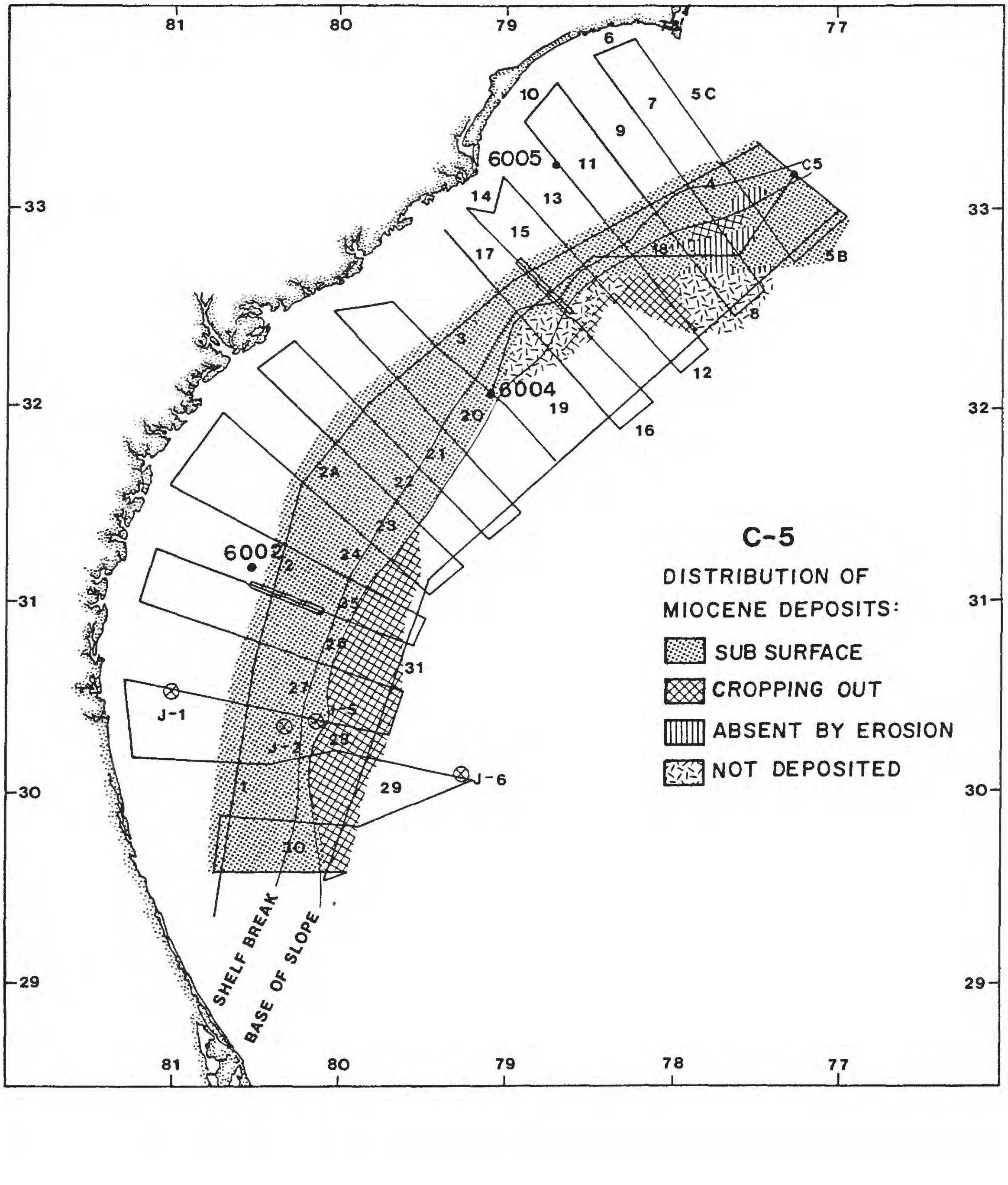

C-1
DISTRIBUTION OF UPPER CRETACEOUS DEPOSITS:
SUB-SURFACE
CROPPING OUT
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
C5
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29
1
2
2A
3
4
5B
5C
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

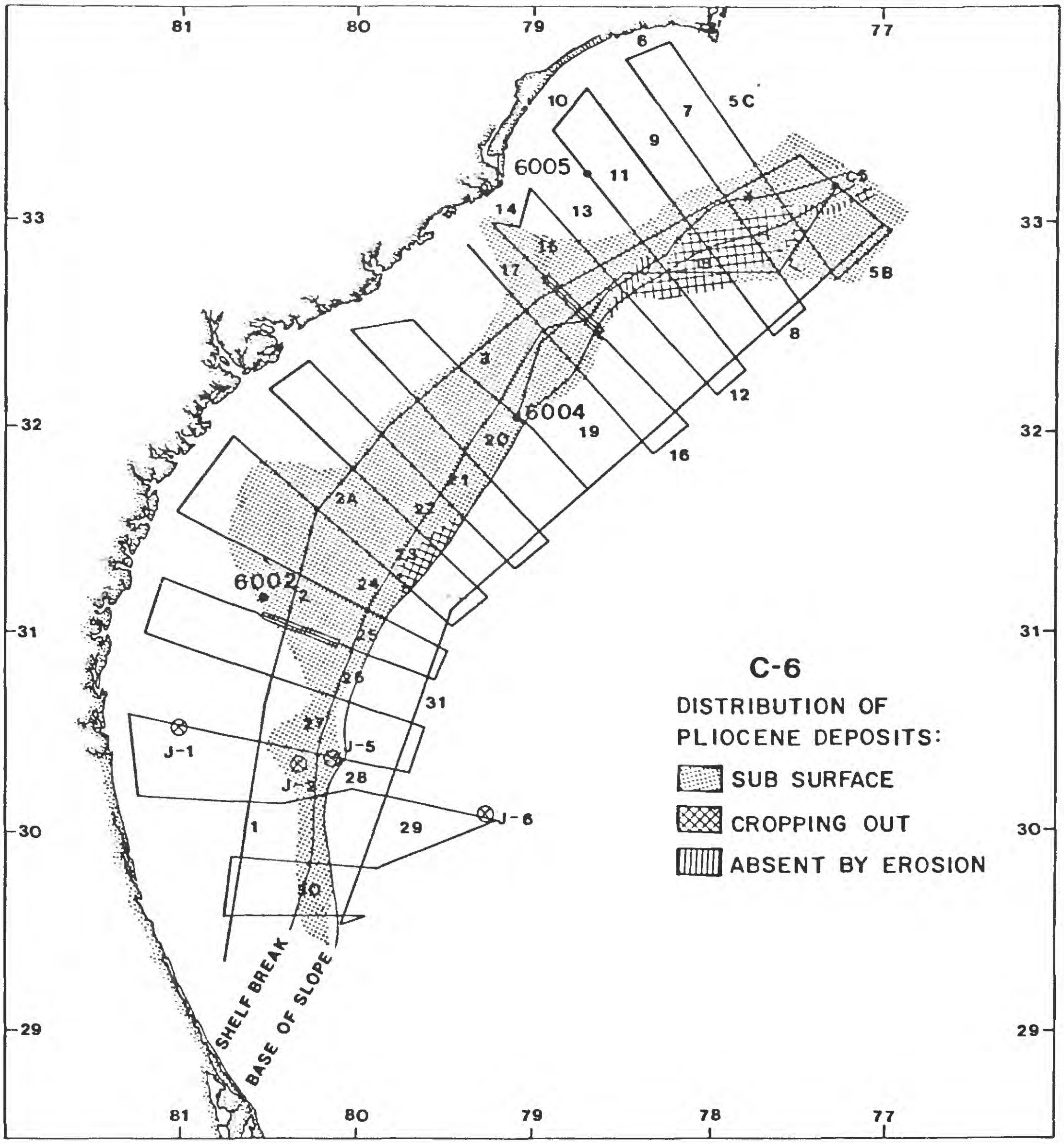

C-2
DISTRIBUTION OF
PALEOCENE DEPOSITS:
SUB-SURFACE
CROPPING OUT
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
C5
5B
5C
2A

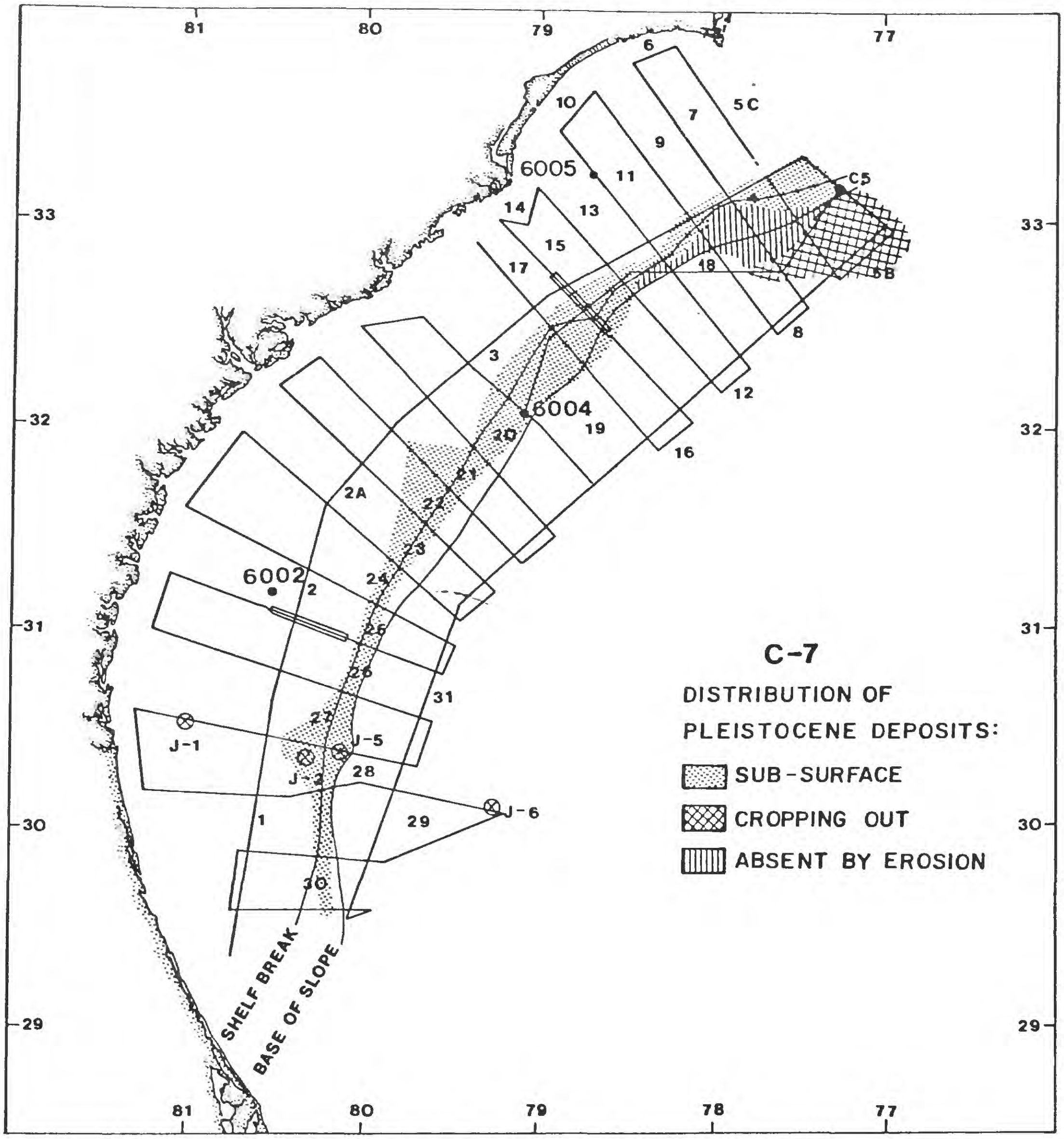

C-3
DISTRIBUTION OF EOCENE DEPOSITS:
SUB-SURFACE
ABSENT BY EROSION
CROPPING OUT
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
C5
5C
5B

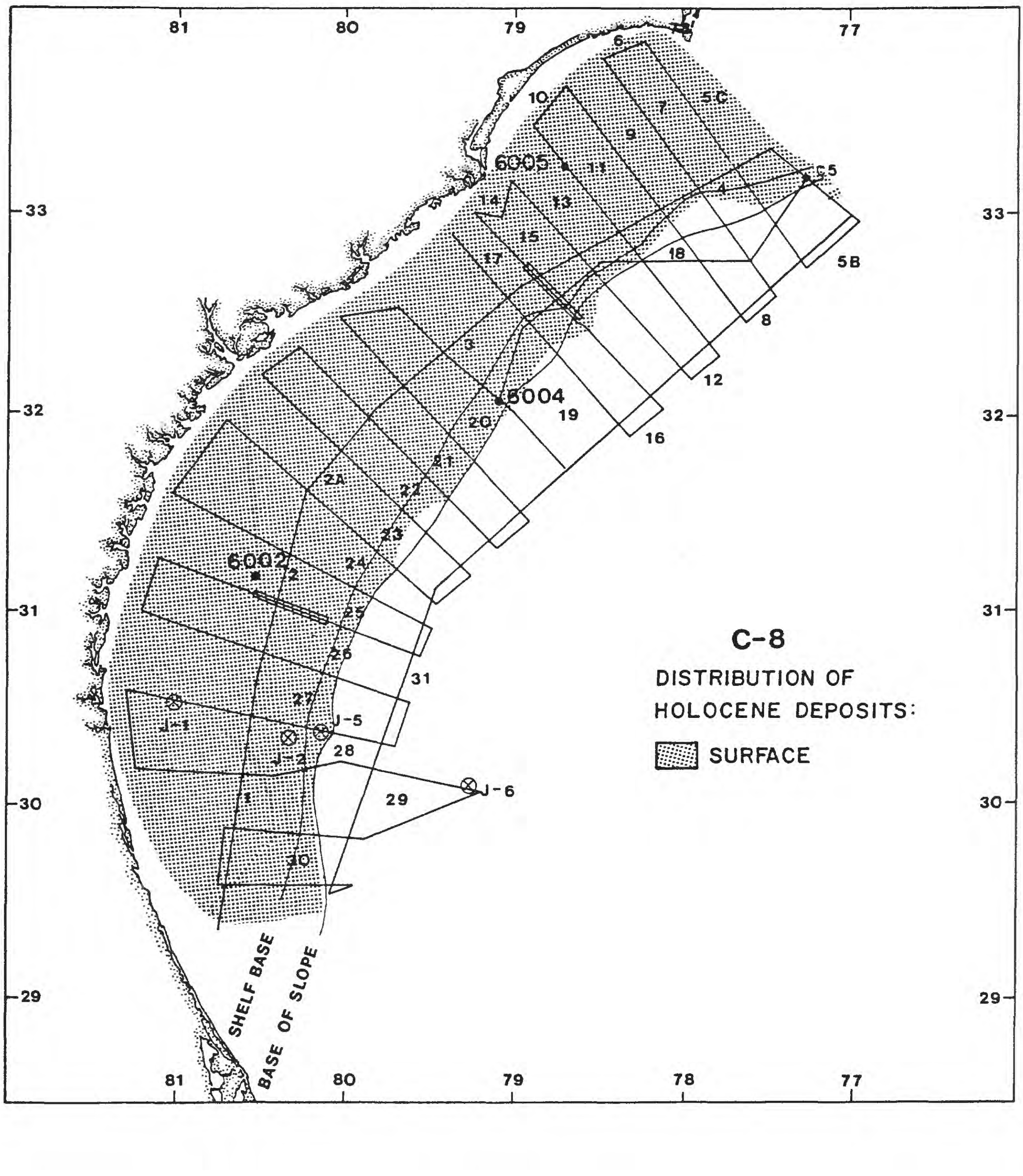


C-4
DISTRIBUTION OF
OLIGOCENE DEPOSITS:
SUB-SURFACE
CROPPING OUT
ABSENT BY EROSION
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-6


C-5
DISTRIBUTION OF MIOCENE DEPOSITS:
SUB SURFACE
CROPPING OUT
ABSENT BY EROSION
NOT DEPOSITED
6005
6004
6002
C5
J-1
J-2
J-6
SHELF BREAK
BASE OF SLOPE
81
80
79
78
77
33
32
31
30
29

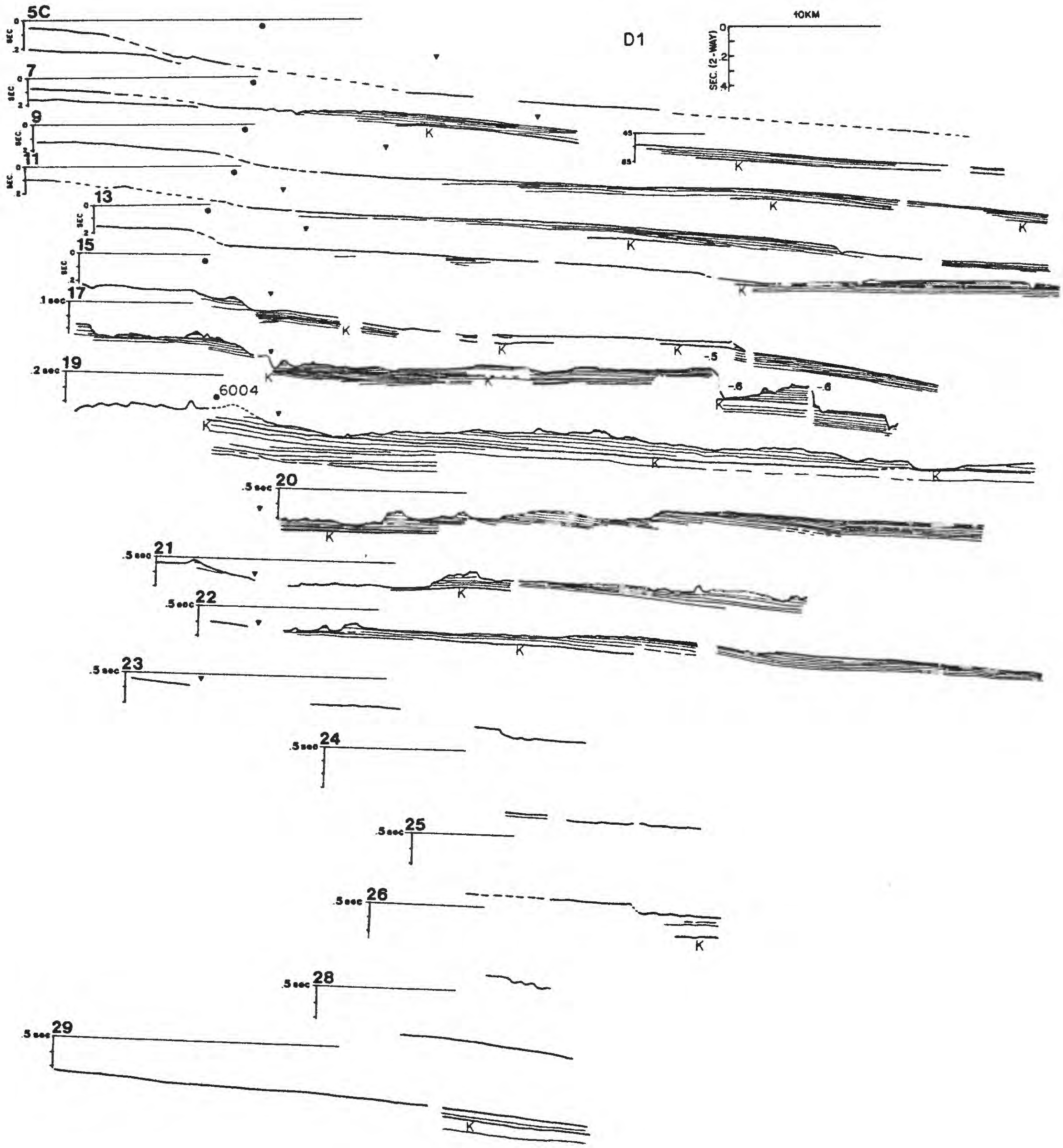

C-6
DISTRIBUTION OF
PLIOCENE DEPOSITS:
SUB SURFACE
CROPPING OUT
ABSENT BY EROSION
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6

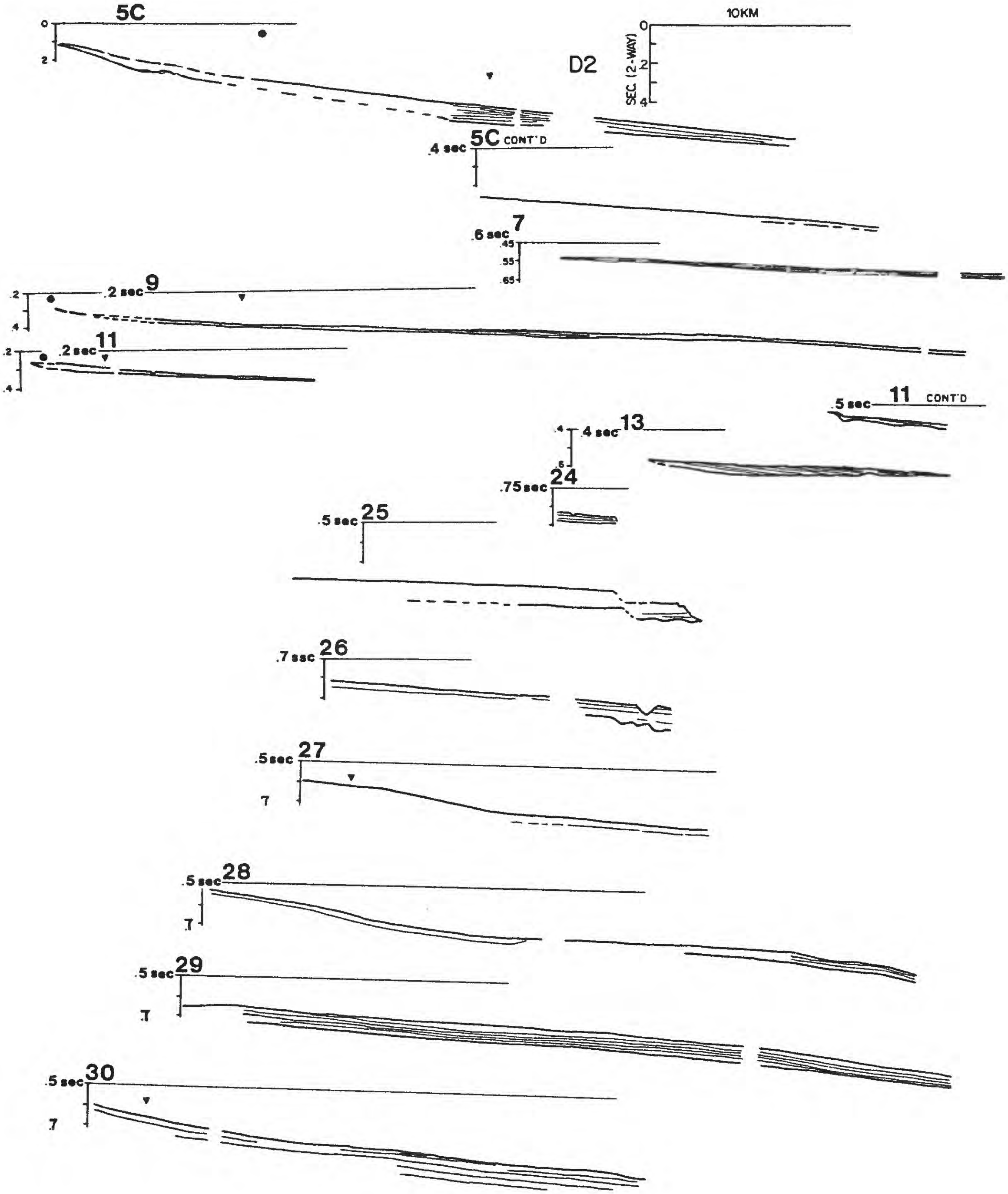

C-7
DISTRIBUTION OF
PLEISTOCENE DEPOSITS:
SUB-SURFACE
CROPPING OUT
ABSENT BY EROSION
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-5
J-6
C5
81
80
79
78
77
33
32
31
30
29

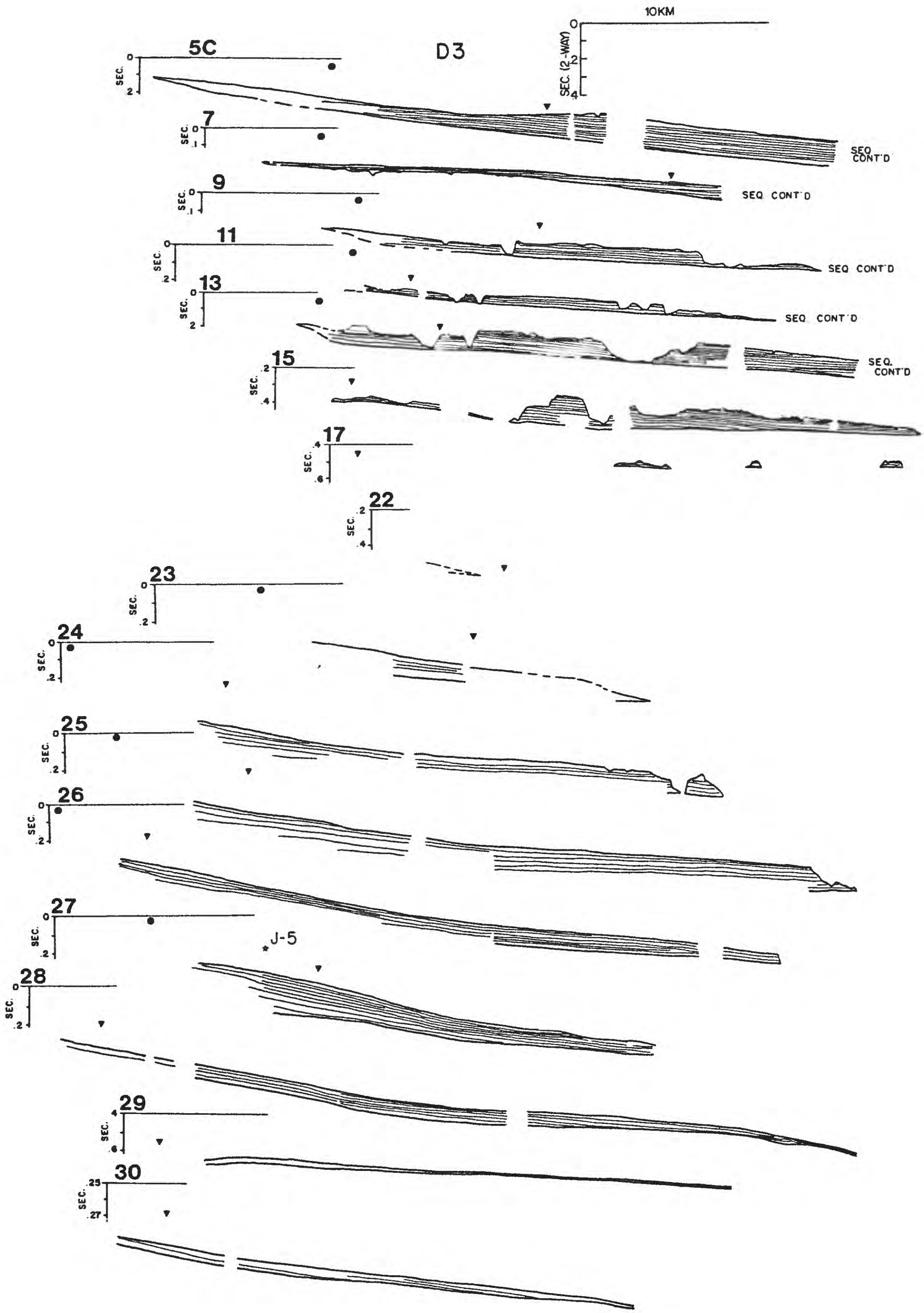

C-8
DISTRIBUTION OF
HOLOCENE DEPOSITS:
SURFACE
SHELF BASE
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29

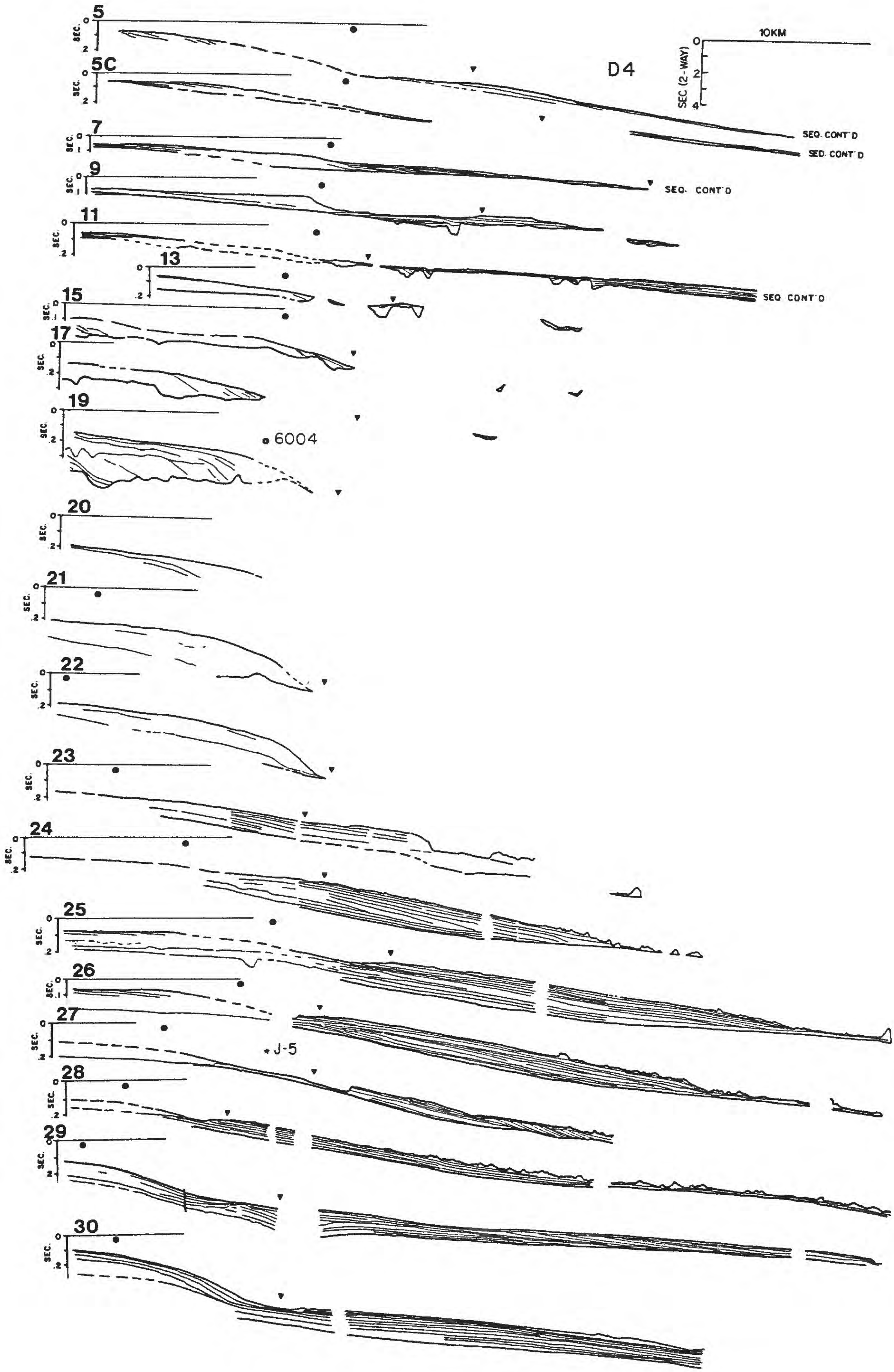
APPENDIX D

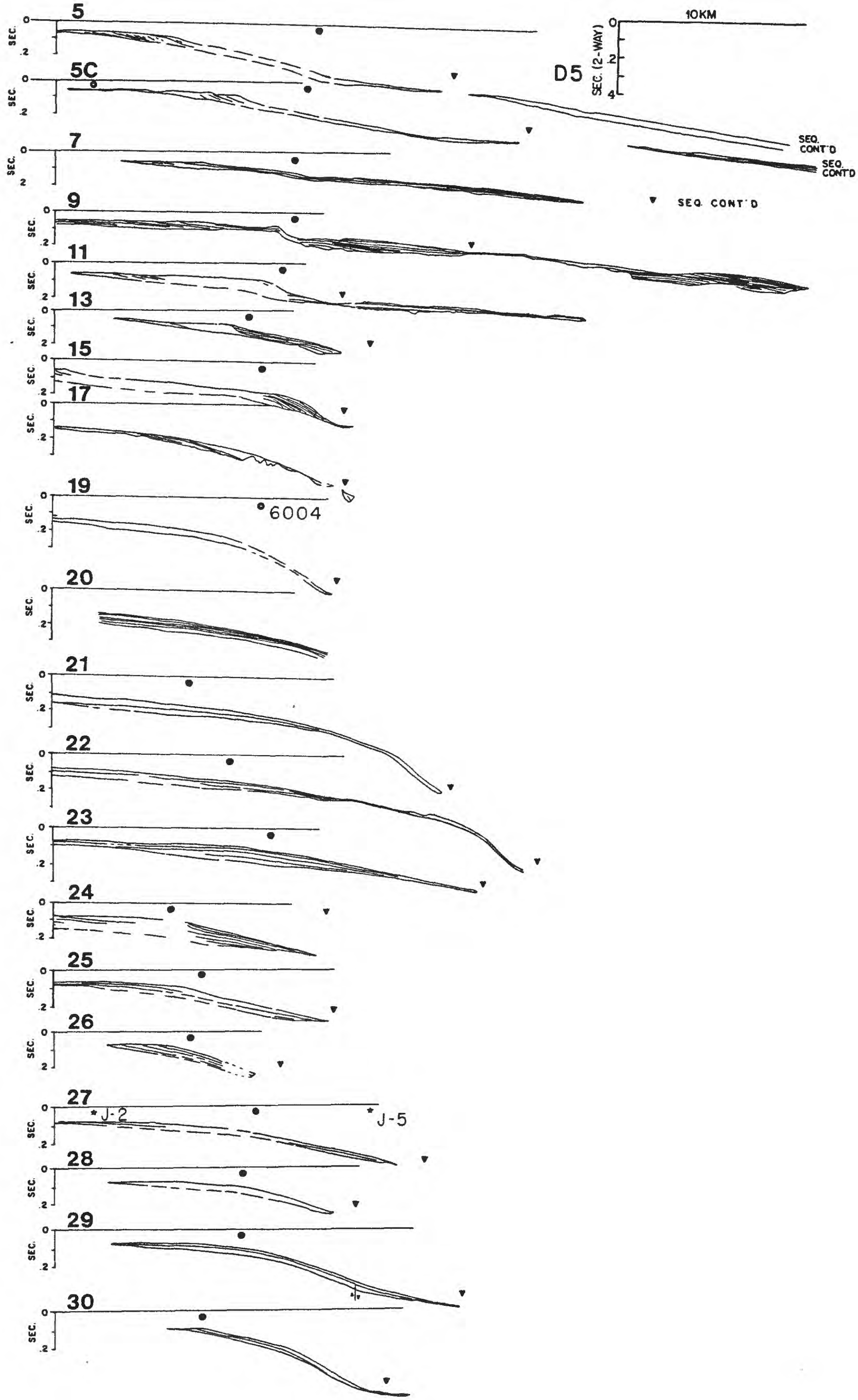
Line Drawings of Minisparker Records Showing Distribution of Sediments of Each Geologic Epoch within the Cenozoic and Upper Cretaceous

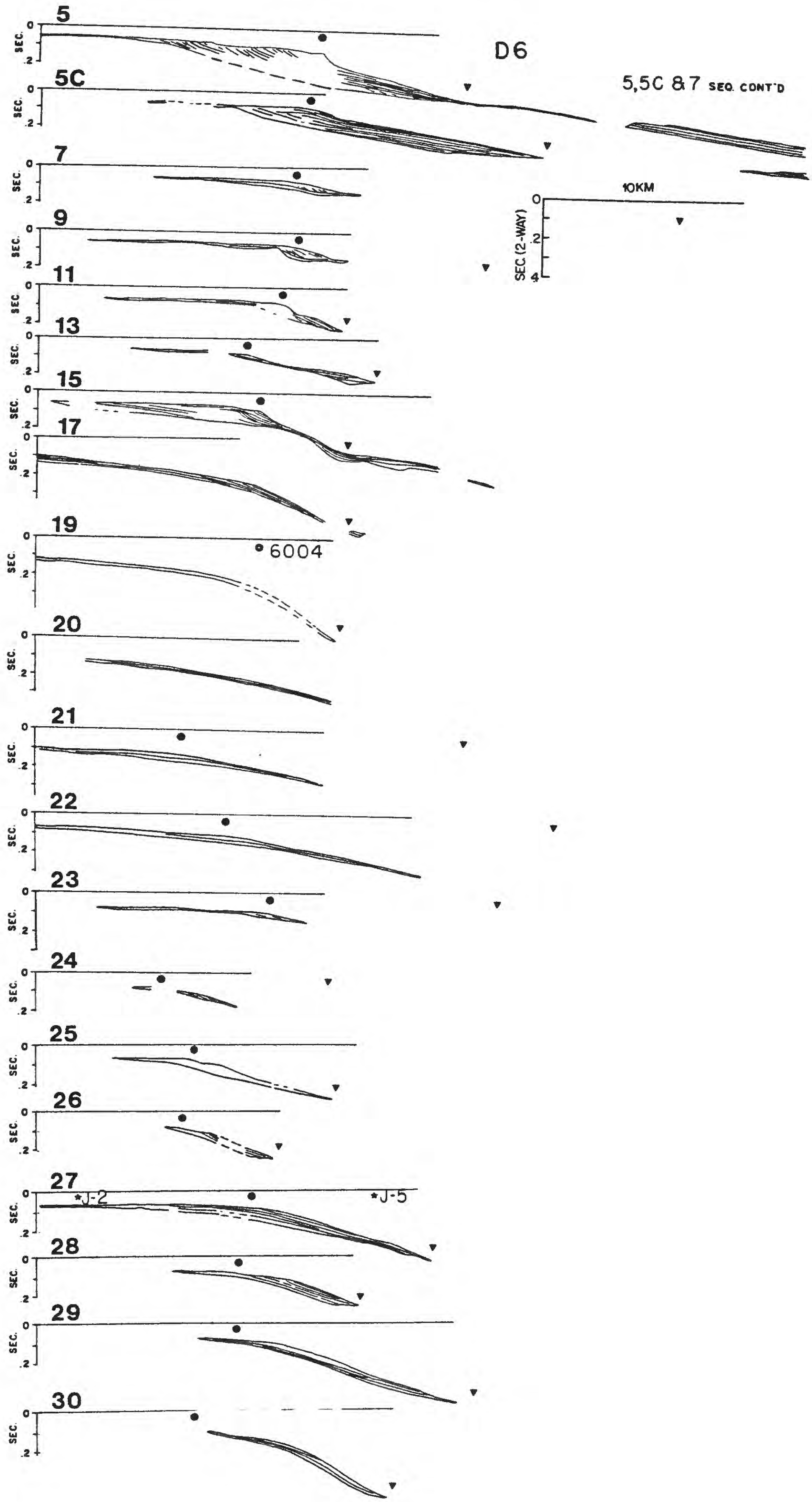

D1
10KM
SEC. (2-WAY)
5C
7
9
11
13
15
17
19
6004
20
21
22
23
24
25
26
28
29
K


5C
D2
10KM
SEC (2-WAY)
.4 sec 5C CONT'D
.6 sec 7
.2 sec 9
.2 sec 11
.5 sec 11 CONT'D
.4 sec 13
.75 sec 24
.5 sec 25
.7 sec 26
.5 sec 27
.5 sec 28
.5 sec 29
.5 sec 30


D3
10KM
SEC. (2-WAY)
5C
7
9
11
13
15
17
22
23
24
25
26
27
28
29
30
SEQ CONT'D
J-5


D4
10KM
SEC (2-WAY)
SEQ. CONT'D
6004
J-5

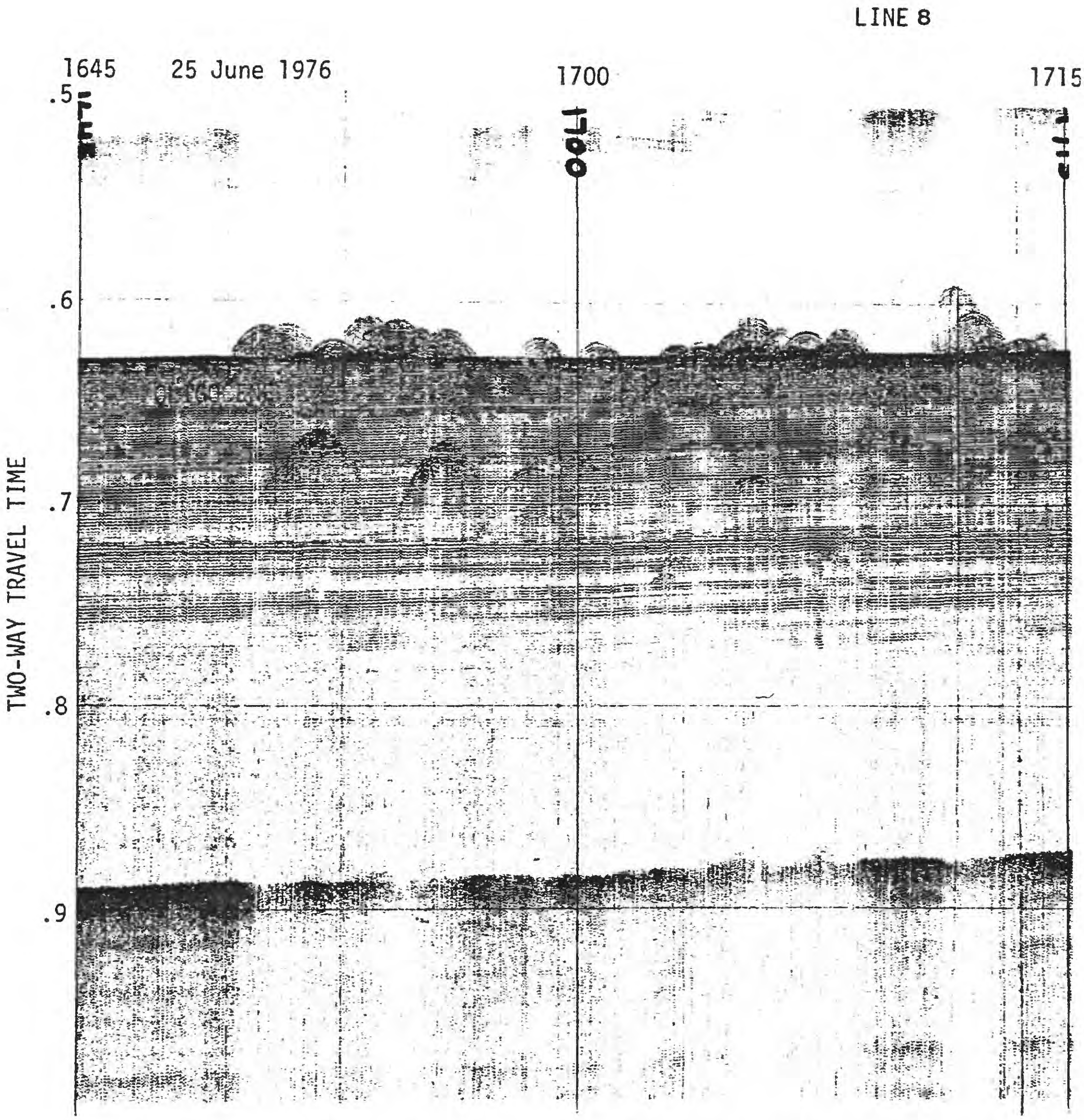

D5
10KM
SEC. (2-WAY)
SEQ. CONT'D
5
5C
7
9
11
13
15
17
19
6004
20
21
22
23
24
25
26
27
J-2
J-5
28
29
30
SEC.


D6
5,5C & 7 SEQ. CONT'D
10KM
SEC (2-WAY)
5
5C
7
9
11
13
15
17
19
6004
20
21
22
23
24
25
26
27
J-2
J-5
28
29
30

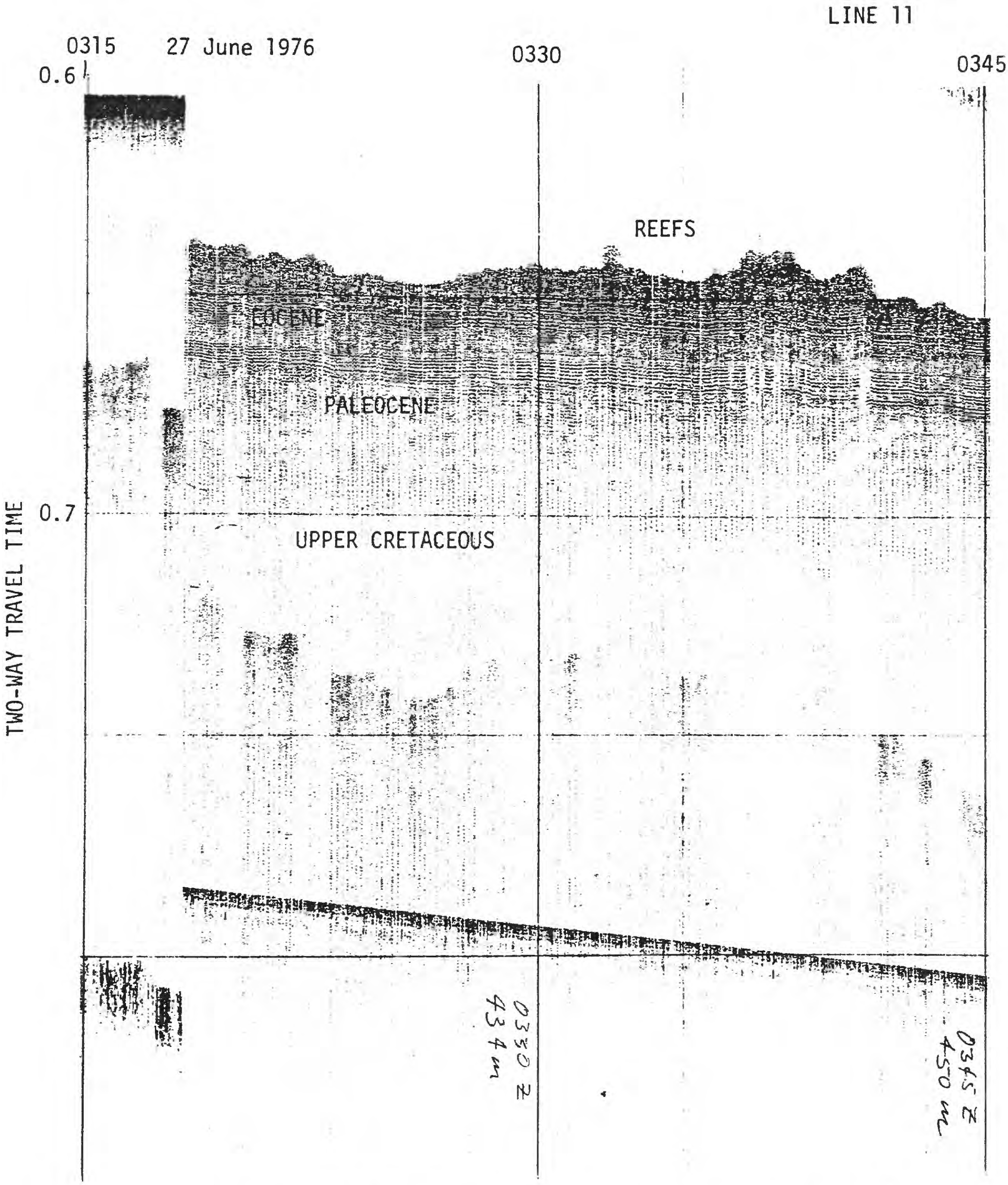
APPENDIX E

Water Column Anomalies on the Blake Plateau

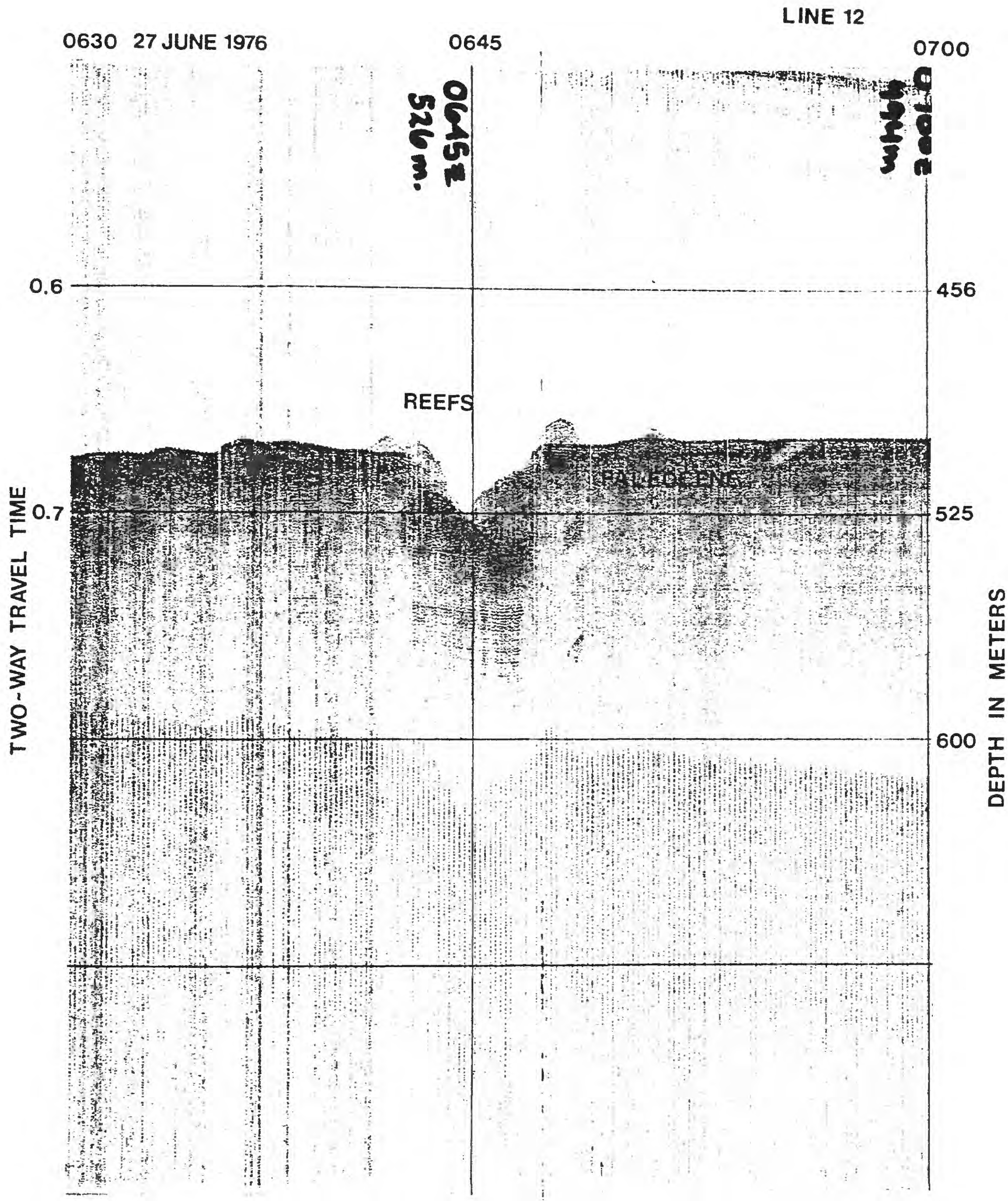
Photograph	Line No.	Time	Date
E-1	8	1645-1715	25 June
E-2	11	0315-0345	27 June
E-3	12	0630-0700	27 June
E-4	15	1915-1945	28 June
E-5	17	2230-2315	28 June
E-6	24	1830-1900	7 July



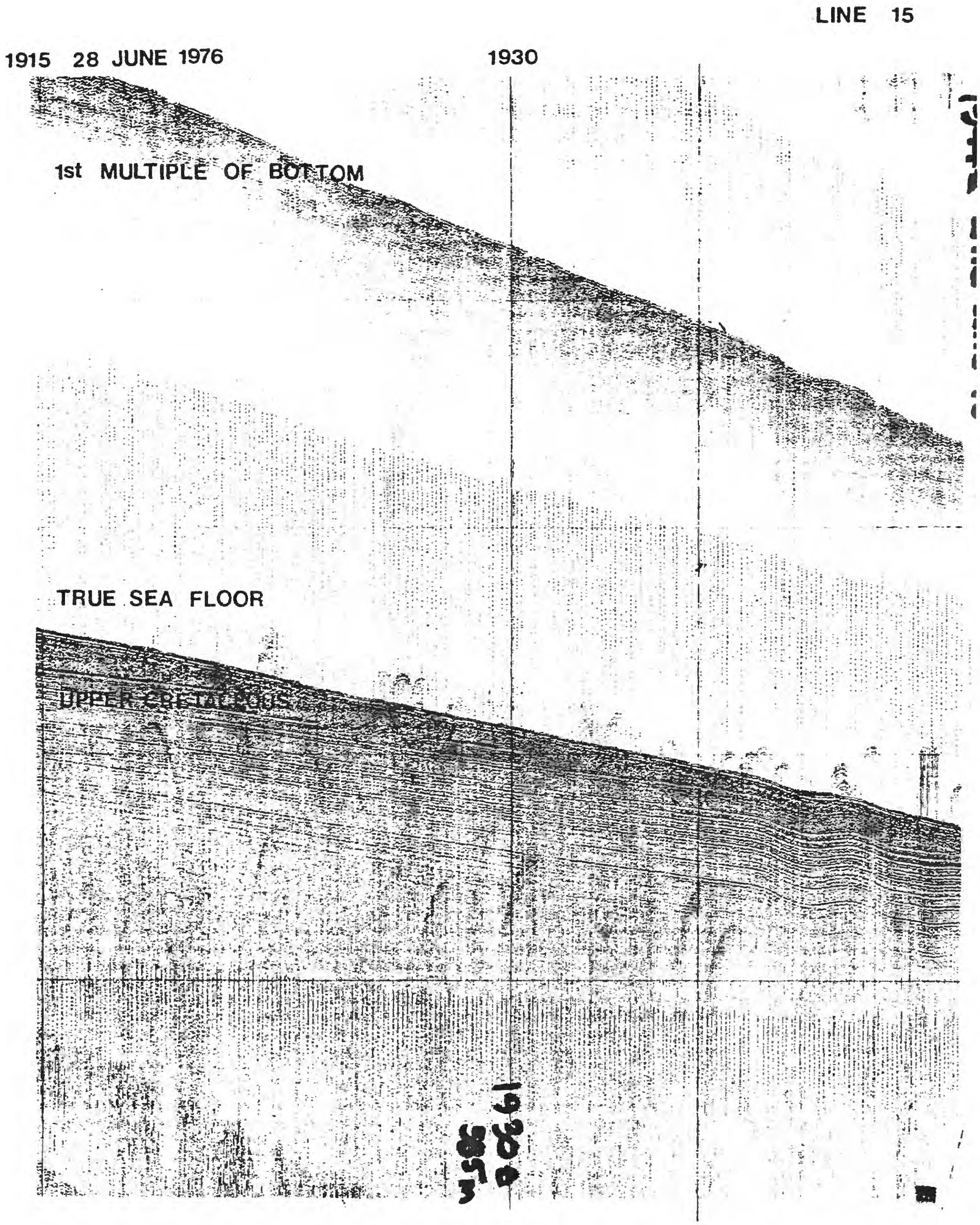
E 1 Hyperbolas from Blake Plateau in northern region
Note hyperbolas beneath present sea floor, their source is within cone of sound but off to side



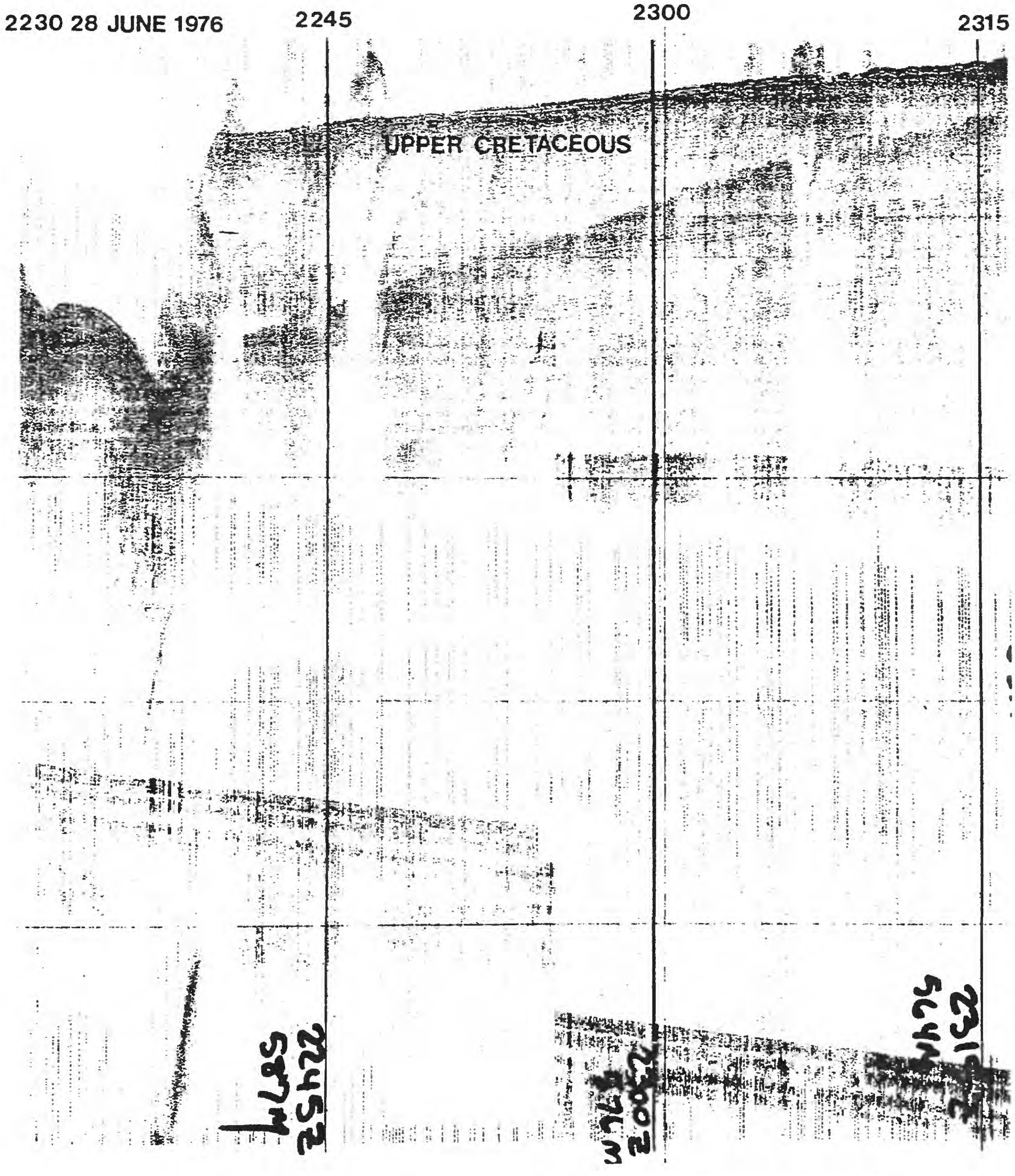
E 2 Hyperbolas on Blake Plateau, probably due to reefs



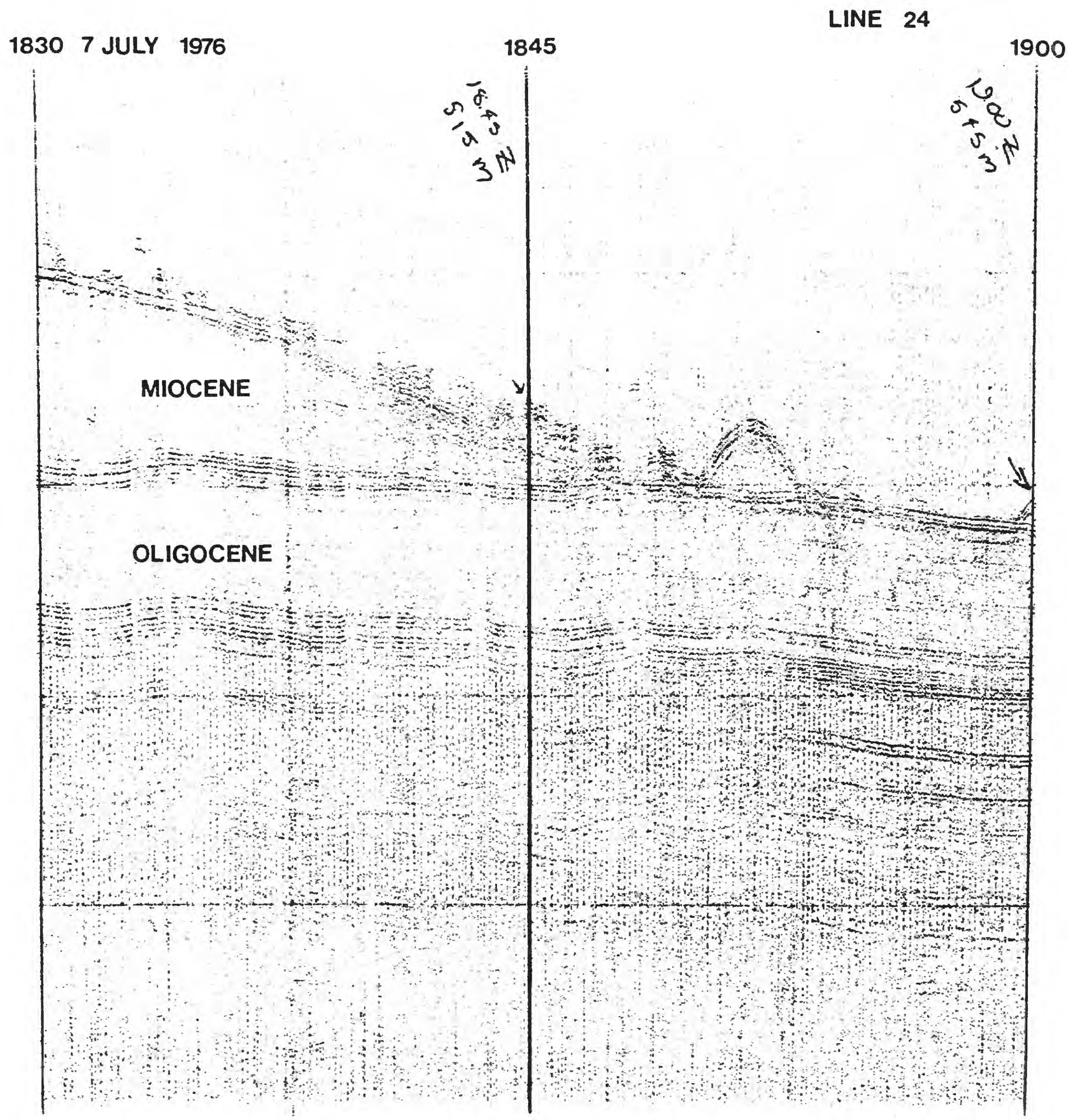
E 3 Hyperbolas on Blake Plateau, generated by reefs



E 4 Hyperbolas on Blake Plateau, some above the bottom, others below, suggestions of linearity



E 5 Hyperbolas on Blake Plateau, probable reef origin



E 6 Hyperbolas on Blake Plateau, probably of reef origin