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Shallow Sedimentary Framework of Georges Bank

by

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Abstract

Two thousand nine hundred kilometers of minisparker data were collected on Georges Bank by the United States Geological Survey during October of 1975. Several sedimentary features have been observed in the data. The bank is recognized as a compound feature resulting from erosion of Tertiary coastal-plain strata followed by deposition of an extensive sediment wedge on the western flank of the cuesta. Marine planation (probably Late Pleistocene) truncated this bank morphology producing an erosion surface roughly paralleling the present sea floor. The truncated bank surface is blanketed by a veneer of complex Late Pleistocene drift which masks underlying features, and is being reworked by modern processes. Present bank morphology is inferred to be a rather recent development.

A proper understanding of the significance of complex bank sediments with respect to the potential geologic hazards of drilling or placement of bottom supported structures necessitates a more detailed seismic reflection program in conjunction with geotechnical analysis of core samples.

Introduction:

During the fall of 1975 the U.S. Geological Survey conducted a detailed geophysical survey of Georges Bank. The work included high-resolution (mini-sparker) coverage carried out in conjunction with seismic and magnetic studies of deeper structure. This is a report of the analysis of minisparker data collected during the study. The data represent the most complete seismic coverage of Georges Bank undertaken to date, and the analysis has led to a broadening of our understanding of the stratigraphy and structure of the upper 350 m of the bank. Minisparker data have also been instrumental in the search for possible geologic hazards, which must concern those who wish to initiate drilling programs or consider placement of bottom supported structures on Georges Bank. It is our purpose to discuss several features recognizable in the data, provide a plausible explanation for the relationships observed, and briefly discuss their environmental significance.

Methods:

Our findings are based on 22 high-resolution seismic lines obtained during the third U.S. Geological Survey cruise aboard the R.V. FAY, between October 2 and 17, 1975. Approximately 2,900 km of the bank were surveyed using a Del Norte 800 joule sparker and a 200 element hydrophone (Fig. 1). Northwest-southeast trending tracklines were spaced about 25 km apart, and east-west lines about 50 km apart. Navigation was based on 15 minute Loran C fixes supplemented by Loran A. Reflected seismic signals were filtered between 200 and 1000 H_z and displayed on a dry paper graphic recorder. Ship speed averaged 5 knots during the cruise.

Interpretation of Records:

Tracings of reflectors observed on the seismic records were reduced to interpretive line drawings (distance vs depth), assuming sound velocities of 1.5 km/sec in water and 1.7 km/sec in bank sediment (L. McGinnis, oral communication, 1976).

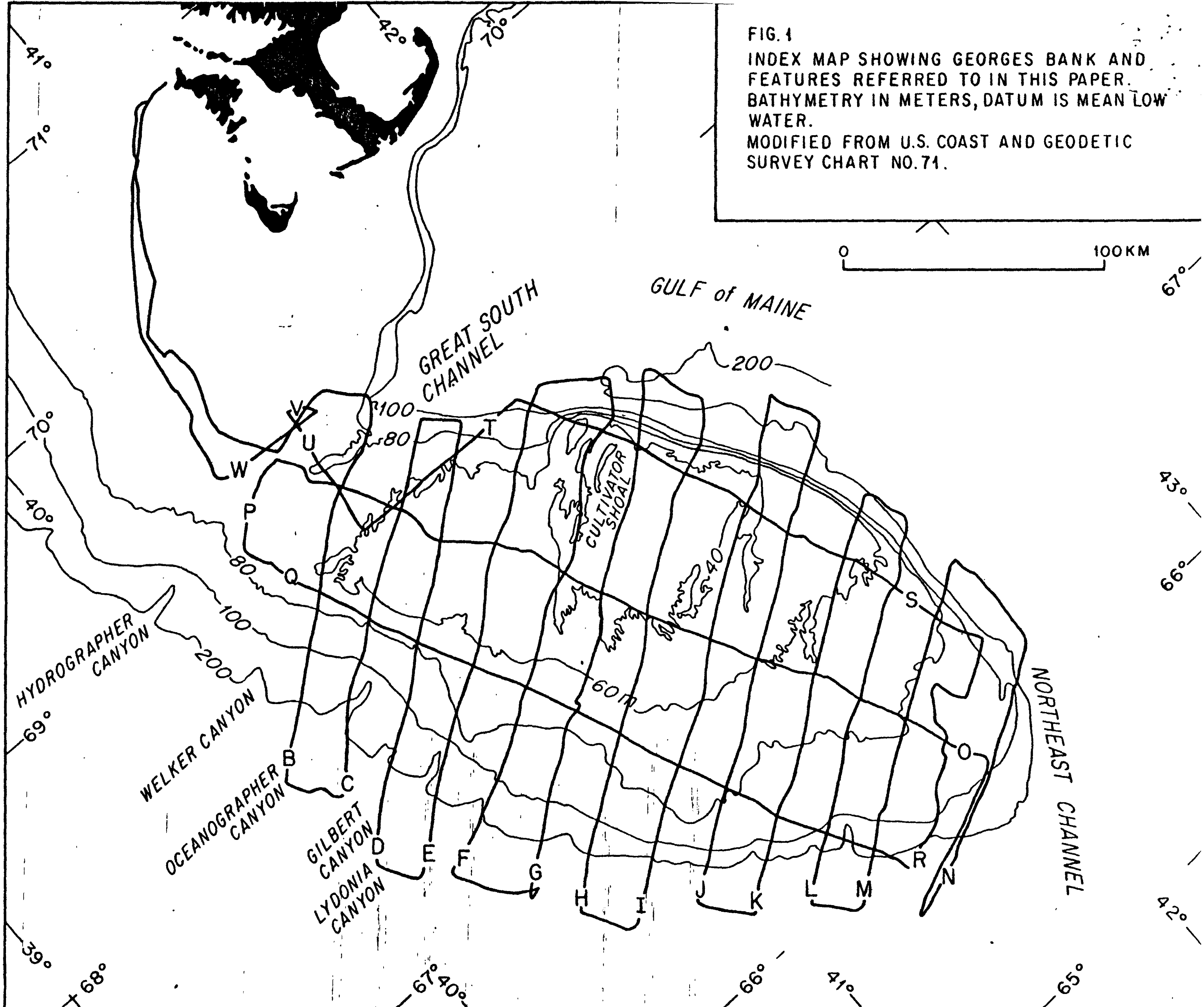


FIG. 1
INDEX MAP SHOWING GEORGES BANK AND FEATURES REFERRED TO IN THIS PAPER. BATHYMETRY IN METERS, DATUM IS MEAN LOW WATER.
MODIFIED FROM U.S. COAST AND GEODETIC SURVEY CHART NO. 71.

Interpretive sections were also corrected for variations in ship speed. Vertical exaggeration is approximately X40 on line drawings.

Discussion of Data:

The deepest acoustical reflector visible on the records, reflector C, lies at or near the limit of minisparker penetration and is observed on a limited number of track lines (Plate 2, line J). Where reflector C is visible it appears to dip slightly to the south, deepening from about 275 meters to about 325 meters below sea level, southward across the bank.

Horizon C is unconformably overlain by a series of sub-parallel southeast dipping reflectors herein termed the "T" sequence. Track-line J (Plate 2) illustrates this angular relationship and reveals a southeastward thickening of the sequence, as evidenced by the southeastward divergence of several major internal reflectors (identified by a T on the record). Analysis of the northern 10-20 kilometers of lines J,K and L indicates the sequence is terminated at an erosional scarp along the northern edge of Georges Bank.

West of trackline I and east of trackline J the "T" reflectors are unconformably overlain by sediment wedges which thicken southeastward and southwestward from the Mid-Bank region. Figure 2 presents an idealized E-W section illustrating this relationship and Figure 3 shows the inferred areal extent of these "Eastern" and "Western" wedges.

Sediments composing the western wedge thicken southward along lines C,D and E (Plate 1) and westward along lines O,Q and S (Plate 4). As previously mentioned the underlying "T" sequence dips southeastward, along line S, deepening from about 150 m below sea level in the west to about 350 m below sea level in the east. Wedge sediments can be differentiated from this underlying material because they exhibit a reversal of dip relative to the "T" sequence. A three dimensional view of the wedge can be constructed by viewing the intersection of tracklines C,D,E and

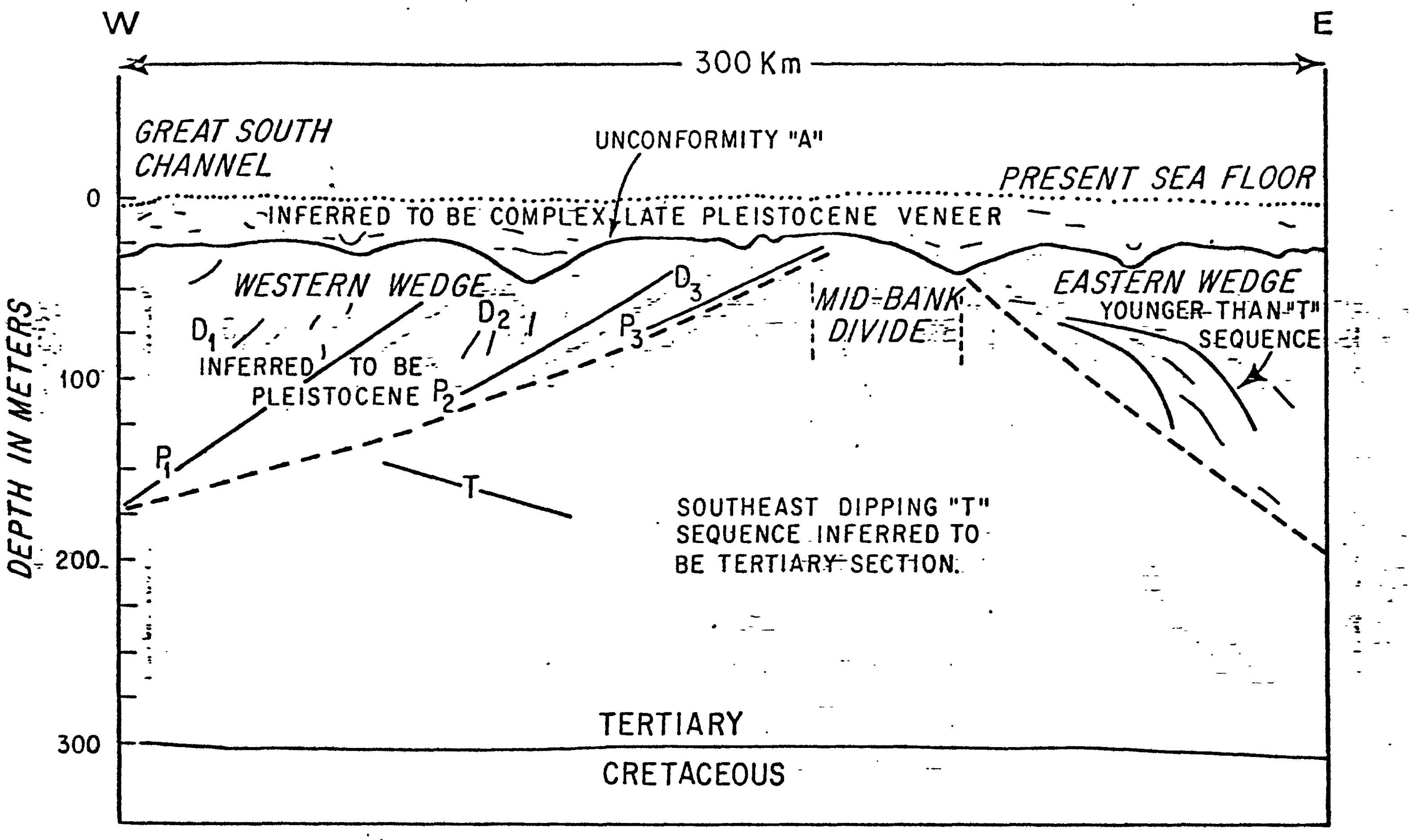


FIG.2 IDEALIZED E-W SECTION VIEW OF GEORGES BANK, SHOWING STRATIGRAPHIC FEATURES AND THEIR INFERRED RELATIONSHIP (NOT TO SCALE).

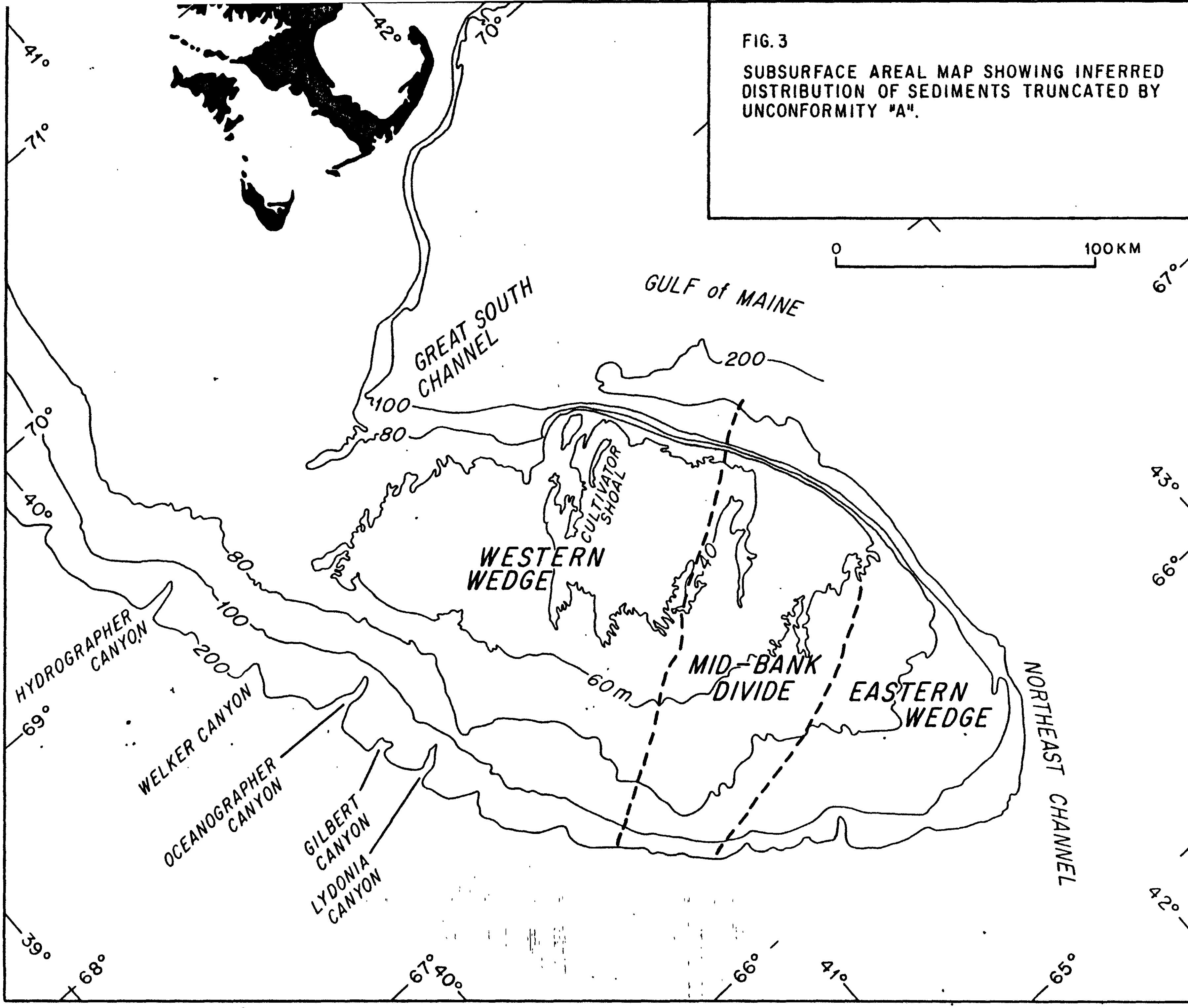


FIG. 3

SUBSURFACE AREAL MAP SHOWING INFERRED DISTRIBUTION OF SEDIMENTS TRUNCATED BY UNCONFORMITY "A".

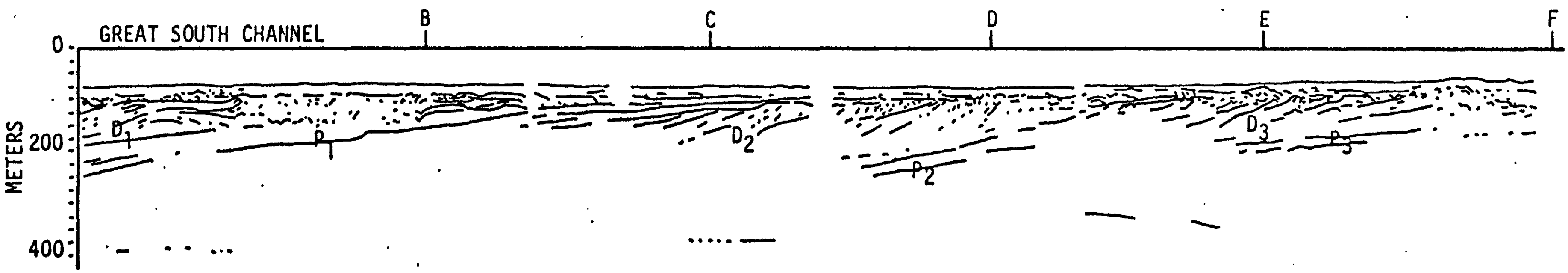


Fig. 4 - Western end of track line Q showing the position of cross lines B,C,D,E,F and the westward shingling of reflectors (see also Plate 4).

F (Plate 1) with line Q (Plate 4), throughout the area west of track line I sediments overlying the "T" sequence dip southwestward into present day Great South Channel.

Detailed analysis of the western wedge (Line Q, Plate 4) reveals structures resembling foreset bedding. These structures designated D_1, D_2 and D_3 on Figure 4 are sandwiched between more continuous southwest dipping reflectors P_1, P_2 and P_3. The section depicted by Figure 4 represents a shingling of progressively younger sediments westward along line Q. The forest like structures are truncated by more gently dipping erosion surfaces which are in turn overlain by still younger structures, a relationship suggestive of cyclic periods of erosion followed by deposition. Three such cycles of erosion and deposition are evidenced in Figure 4. A similar sequence of events is noted southward along track lines C,D,E and F (Plate 1).

Eastern wedge sediments do not resemble those to the west and are in fact separated from them by the Mid-Bank Divide (Fig. 3). Sedimentary structures of the eastern wedge rest unconformably on older "T" sequence material and resemble a southeastward prograded delta complex. They can be differentiated from the underlying "T" sequence by numerous discontinuous internal reflectors which form an angular relationship to the older more gently dipping sediments below. The eastern wedge thickens southeastward from the Mid-Bank region. Structures composing this wedge are massive features which show no evidence of the cyclic events noted in the western third of Georges Bank. Trackline L (Plate 2) provides a good illustration of the eastern wedge, and its relationship to underlying horizons.

Eastern and Western wedge sediments are separated by a narrow north-south trending zone termed the "Mid-Bank Divide" (Figure 3). The divide area is composed of "T" sequence material, which is truncated 20 to 80 meters below the present sea floor by a ubiquitous unconformity, "A", that truncates all pre-existing bank structures resulting in the separation of Eastern and Western wedge sediments

(Figure 3). Unconformity A is identified on several of the records presented in Plates 1-4.

The shallow unconformity deepens southward, averaging 60-80 m below sea level under the northern bank and 90-120 m below sea level to the south. Unconformity A is incised by many streams (Lines J,K, and L, Plate 2) to depths of 20-40 m. Cross-sections of several of these channels are asymmetric, having long gentle south facing walls but short steeply sloping north facing walls (Line K, Plate 2). Many of the channels have a complex cut and fill history, appearing to have been rechanneled and subsequently filled with younger material. In some instances more recent channeling has incised older channel beds further deepening unconformity A.

The sediment cover blanketing unconformity A is fairly uniform (20-50 m)-- except in areas of localized channel filling or shoaling where the cover may thicken to 80 m. Large areas of the sediment blanket are devoid of internal structure, although the overburden occasionally contains discontinuous, flat lying reflectors.

Modern processes are reworking the sediment veneer forming sand waves and dune-like features which are concentrated in the northern portion of the bank (Figure 1). The data suggests that these large features, such as Cultivator Shoal (Line S, Plate 4) are migrating over former sea floor surfaces, which appear as flat lying reflectors underlying the reworked material.

Summary of Major Shallow Features:

A deep, nearly flat lying reflector (C) is overlain by a sequence of subparallel, continuous, southeast dipping reflectors ("T" sequence). These sediments are thickest in a narrow north-south zone termed the "Mid-Bank Divide" region. West of the Mid-Bank area the "T" sequence is overlain by an extensive wedge of southwest dipping sediment. The wedge thickens westward from the "Mid-

Bank Divide" region and southward across the bank. The northern half of the wedge is thinner than its southern extension, dips more gently to the southwest, and lacks cyclic, sandwiched structures which are observed to the south.

In the eastern third of the bank the "T" sequence is overlain by massive prograded delta like structures. These features thicken southeastward from the "Mid-Bank Divide" region and do not contact the western wedge material.

The bank has been truncated by an erosion surface 20-80 m below the present sea floor. This ubiquitous unconformity is a complex surface incised by stream channels. Sediments above the unconformity form a nearly uniform blanket of sediment. Numerous episodes of cutting and filling are indicated by reflectors within the sediment blanket. The present sea floor nearly parallels the shallow unconformable surface, except where modern processes are reworking small portions of the sediment blanket.

Geologic Significance:

Georges Bank has long been recognized as a remnant of the coastal-plain, nearly isolated from the surrounding continental shelf by erosion of the Gulf of Maine, Great South Channel and Northeast Channel (Garrison, 1970; Ballard and Uchupi, 1974; Emery and Uchupi, 1965; Knott and Hoskins, 1968). Bank morphology is generally attributed to late Tertiary erosion as modified by glacial events. Estimates of Pleistocene deposition on Georges Bank vary from a few meters to the five major periods of glacial deposition proposed by Knott and Hoskins (1968).

Reflector C has previously been identified as the Cretaceous-Tertiary boundary (Emery and Uchupi, 1965) and is described as a gently southward dipping erosion surface. The thick sequence of sub-parallel, southeast dipping reflectors termed the "T" sequence in this discussion is reported to be up to 270 m of Tertiary strata, overlying the Cretaceous-Tertiary boundary, by Emery and Uchupi (1965).

Inferences drawn from minisparker data indicate that Georges Bank is a compound feature resulting from erosion of the Tertiary coastal-plain followed by deposition of an extensive sedimentary sequence on the western flank of a coastal-plain divide. Oldale et al. (1974), stated, "Toward the end of Tertiary time, during the Pliocene and possibly continuing into early Pleistocene time, a major episode of subaerial erosion took place. Streams eroded the inner part of the coastal-plain sedimentary wedge to form an interior lowland, the Gulf of Maine, and a large cuesta, Georges Bank. Northeast and Great South Channels were the water gaps for streams draining the interior lowland". The "Mid-Bank Divide" region is inferred to be the southern extension of the divide recognized in the Gulf of Maine by Oldale and Uchupi (1970).

Late Tertiary-Quaternary erosion modified the coastal-plain in the Georges Bank area much more than has previously been recognized, removing much of the Tertiary section west of the divide. The western lowland is presently choked with an extensive sedimentary sequence which has filled the water gap and has buried the cuesta remnant on the western flank of the divide. Filling occurred during several (at least 3) episodes of erosion (P_1-P_2-P_3) followed by deposition (D_1-D_2-D_3). The sequence of 5 Pleistocene events described by Knott and Hoskins (1968) is in-fact, the sedimentary sequence filling Great South Channel (note plot of Knott and Hoskins line on Figure 5). It is important to recognize that much of the western half of Georges Bank is composed of material which post-dates the formation of the western lowland.

The eastern boundary of the old Great South Channel water gap may be indicated by an abrupt change in topography along the northern flank of the modern bank. Slightly west of Cultivator Shoal, the character of the bank edge changes from a distinct break in slope to a ramp-like feature (Figure 1). To the south, Lydonia, Gilbert, Oceanographer, Welker and Hydrographer Canyons probably mark major outlets of the wide stream complex which formed the western lowland.

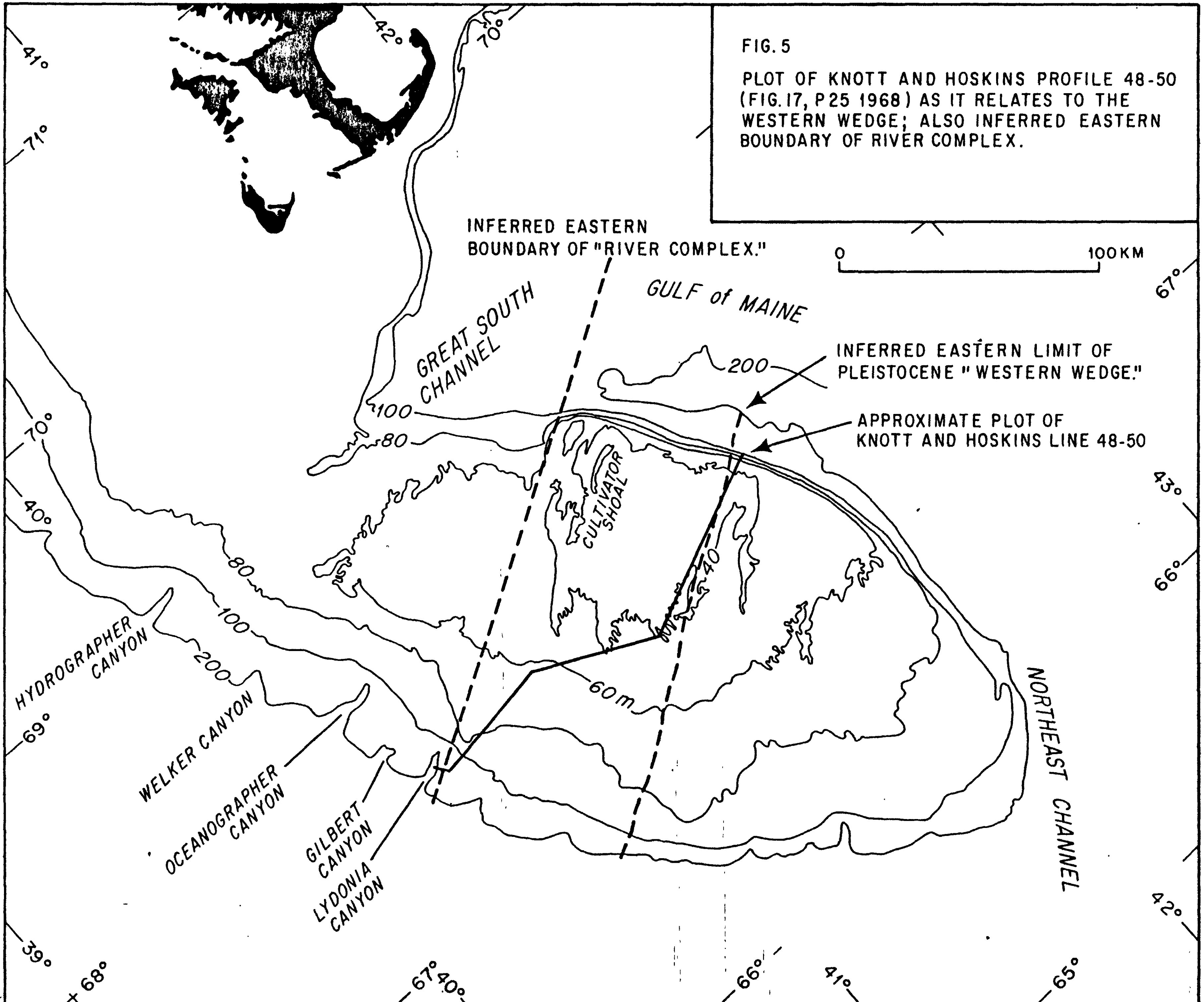


FIG. 5

PLOT OF KNOTT AND HOSKINS PROFILE 48-50 (FIG. 17, P25 1968) AS IT RELATES TO THE WESTERN WEDGE; ALSO INFERRED EASTERN BOUNDARY OF RIVER COMPLEX.

Schlee et al. (1975) believe the canyons were eroded in late Tertiary and Quaternary time, by streams carrying copious amounts of sediment to the upper slope, "during glacial stages when sea level stood at the present shelf edge," (Schlee et al., 1975; p. 9). Note the position of Lydonia Canyon as it relates to the north bank ramp (Figure 5). A line extending from the eastern edge of the ramp to Lydonia Canyon (Figure 5) intersects trackline E mid-way between cross lines O and Q. A feature resembling a west facing valley wall appears on the seismic record near this point (Plate 1). The late Tertiary-Quaternary water gap of the western lowland is inferred to have extended eastward to these features (Figure 5).

The genesis of the eastern delta complex is not clear because no structural reversal occurs at the base of the complex. Southeast-dipping Tertiary material in the "Mid-Bank" region becomes younger to the southeast and overlying deltaic sediments could represent an episode of Tertiary progradation. Outbuilding is known to be important in the construction of the continental shelf west of Georges Bank (Garrison, 1970). If the deltaic sediment does indeed represent progradation during the formation of the coastal-plain, the eastern half of Georges Bank is simply a remnant of the coastal-plain cuesta truncated in a manner which exposes progressively younger portions of the Tertiary section eastward across the bank. In this instance, streams draining the interior lowland east of the divide simply breeched the cuesta in the area of the modern Northeast Channel and did not form a wide lowland east of the mid-bank region.

If one is inclined to insist on similar histories for both water gaps, the deltaic sequence must represent filling in a wide eastern lowland, cut in Tertiary material by streams flowing east of the divide.

Certain inferences can be drawn from the seismic data in the absence of positive age dates for the sedimentary units of Georges Bank. Late Tertiary events in the bank region involved two drainage systems which flowed from an interior lowland, breeched the cuesta and removed Tertiary material from the bank area. The two drainage systems are inferred to have differing histories because the genesis of the eastern delta complex seems dissimilar to that of the western fill sequence. Sediments choking the western lowland appear to represent cyclic upbuilding, interrupted by erosion, while those of the eastern complex are massive prograded structures, lacking evidence of cyclic events. Few outlet canyons are found along the shelf break south of Northeast Channel. This evidence supports the belief that the eastern half of Georges Bank is primarily composed of Tertiary coastal-plain sediments, which include the delta complex.

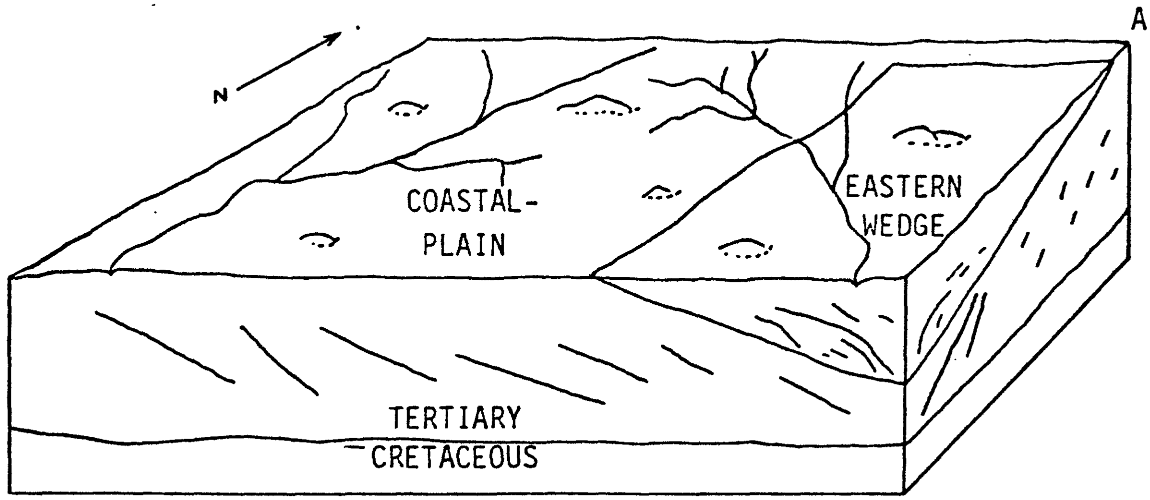
Present bank morphology is a rather recent feature, having formed after the filling of the Great South Channel lowland. Marine planation truncated bank structures late in bank history creating an unconformable surface, nearly parallel to the present sea floor. Pre-existing morphology was erased by this event, and sedimentation post-dating the planation, has masked the underlying features. The surface of marine planation was later modified by subaerial erosion, as evidenced by the channels incising it. Post-planation sediments reveal a complex history of channel filling and cutting.

Inferred Geologic History:

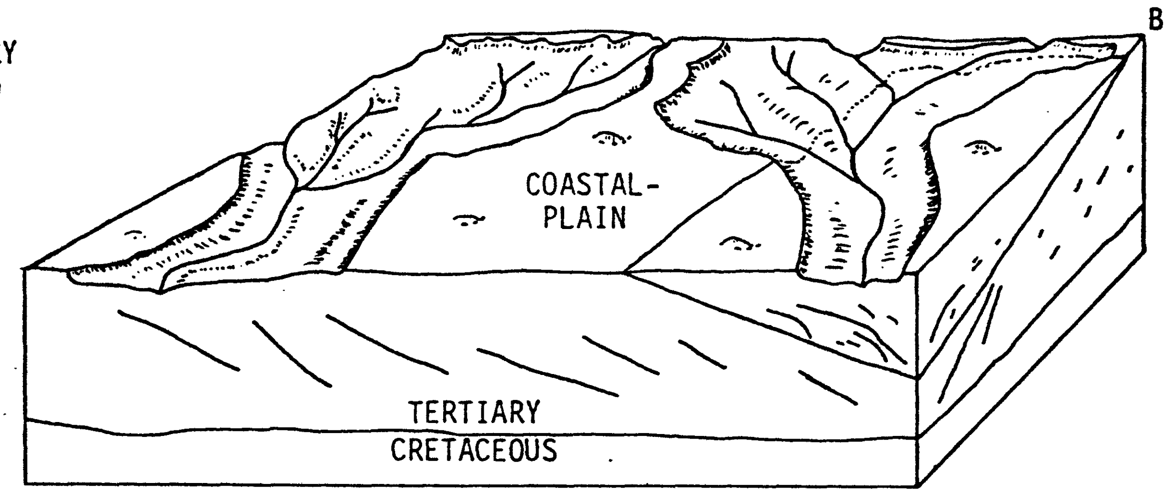
During Cretaceous and most of Tertiary time the continental shelf was formed by upbuilding and outbuilding on the continental margin (Garrison, 1970). Deposition was interrupted at the beginning of the Tertiary Period by and episode of extensive erosion which is now represented by the unconformity at the top of the Upper Cretaceous coastal-plain deposits (Oldale et al., 1974). The Lower Tertiary section was deposited over the unconformity as a southeastward thickening

Figure 6 (A,B,C,D,E,F) showing inferred development of Georges Bank in sequential 3 dimensional block diagrams (not to scale).

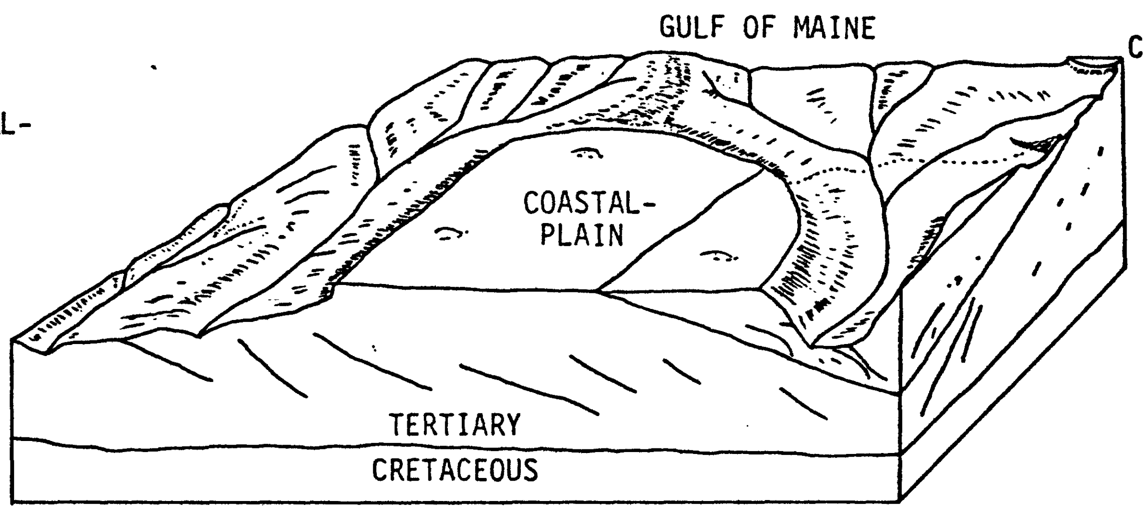
TERTIARY COASTAL-PLAIN AND EARLY DRAINAGE



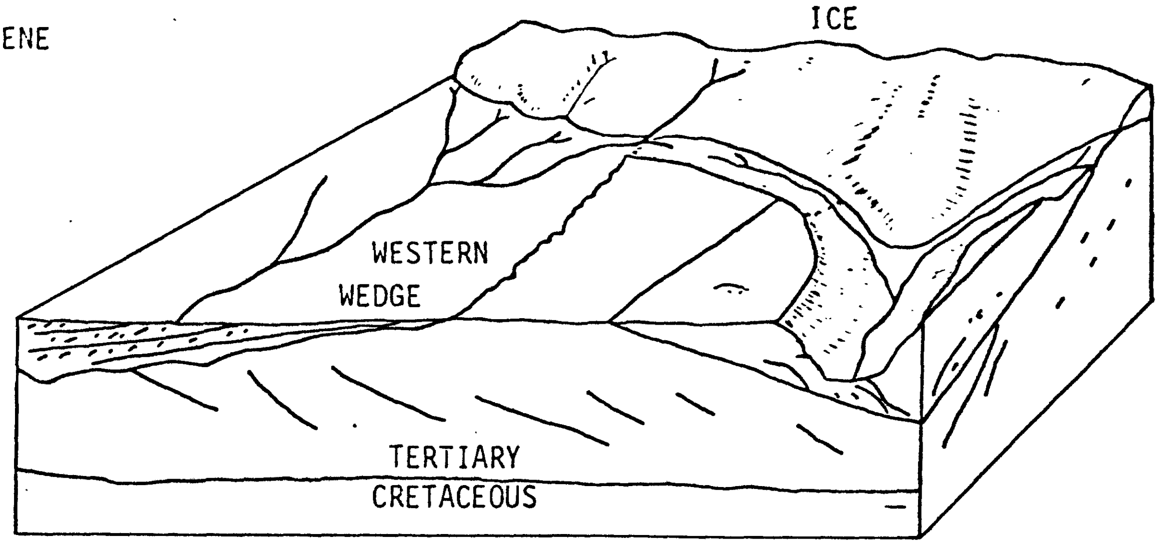
MID-LATE TERTIARY INTERIOR LOWLAND DEVELOPMENT



LATE TERTIARY-EARLY PLEISTOCENE REMOVAL OF COASTAL-PLAIN

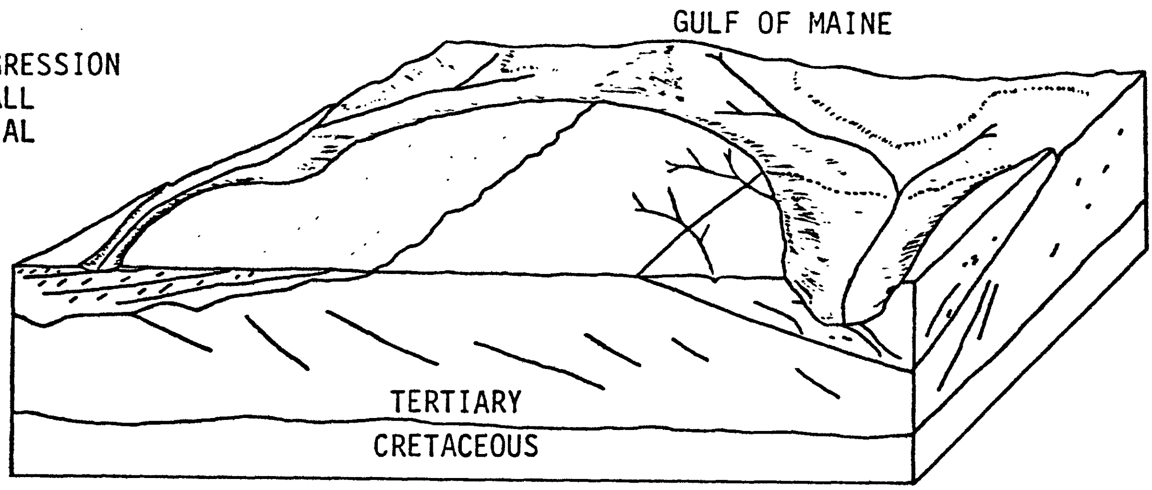


EARLY-LATE PLEISTOCENE
FILLING OF WESTERN
LOWLAND



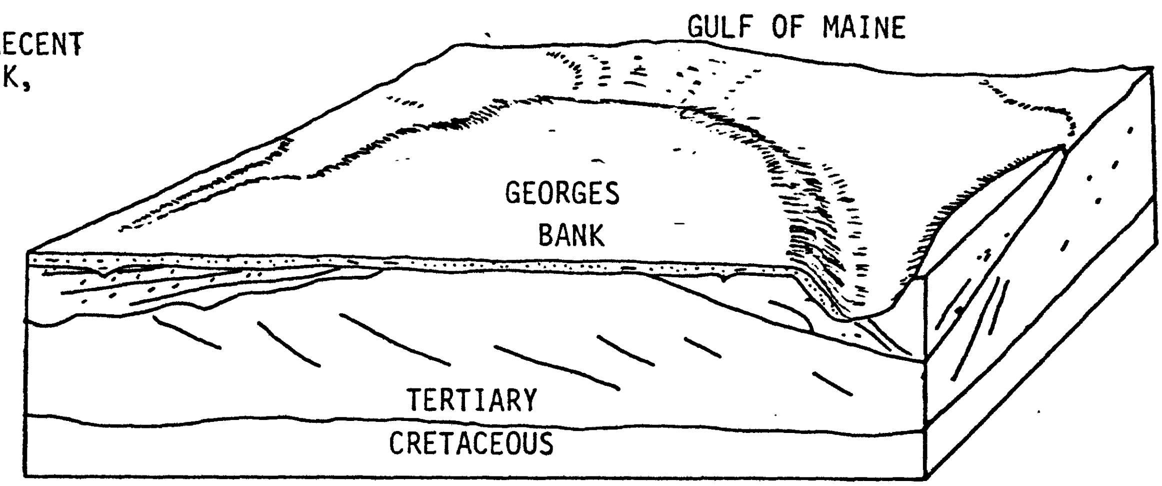
D

PRE-LAST ICE TRANSGRESSION
OF THE SEA PLANES ALL
STRUCTURES, SUBAERIAL
EROSION FOLLOWS



E

LATE PLEISTOCENE-RECENT
DRIFT BLANKETS BANK,
PRESENT MORPHOLOGY
FORMS



F

sediment wedge. Younger Tertiary material is inferred to have prograded over the wedge, as it did south of Long Island (Garrison, 1970). The Cretaceous was buried by at least 270 m of Tertiary strata during shelf building (Emery and Uchupi, 1965). Some time in the late Tertiary, possibly during Pliocene time, an interior lowland formed in the Gulf of Maine area (Oldale et al., 1974).

As the Gulf of Maine deepened, a drainage divide formed and two southward flowing drainage systems developed on the coastal-plain, east and west of the present bank (Figure 6 A). Further erosion in the Gulf of Maine and on the flanks of the divide removed coastal-plain material surrounding the bank area and produced a cuesta cut in Tertiary strata (Figure 6 B). By early Pleistocene time, much of the Tertiary material composing the western flank of the cuesta is inferred to have been removed by fluvial and glacial erosion (Figure 6 C). Hydrographer, Welker, Oceanographer, Gilbert and Lydonia Canyons probably formed, during low stands of sea level, as drainage outlets for a river complex flowing through the western lowland.

Drainage on the eastern flank of the cuesta probably removed much less of the Tertiary section. Erosion in the water gaps was confined to Tertiary coastal-plain material, and did not reach the Cretaceous boundary.

Early Pleistocene glacial events deepened the Gulf of Maine and supplied great amounts of sediment to the Great South Channel lowland. The lowland was choked during Early and Middle Pleistocene time by episodic introduction of glacial material washed from the interior lowland (Figure 6 D). Prior to the final Pleistocene ice advance a transgression of the sea planed the bank removing an undetermined amount of Pleistocene and Tertiary material (Figure 6 E). Subaerial erosion during the last glaciation modified the unconformity. Numerous stream channels incise the planatation surface in the northeast corner of the bank (Figure 7). The channels decrease in number eastward across this area and probably represent the remains of a major late Pleistocene drainage system which flowed eastward to Northeast Channel from the Pleistocene bank surface. Subaerial exposure lasted long enough to produce the complex cut and fill relationships common in the Late Pleistocene material blanketing the unconformity (Figure 6 F). Southward drainage appears to have been reestablished in Great South Channel where late Pleistocene channeling has removed older Pleistocene material.

Submergence of the bank, as the last ice retreated, resulted in reworking of the thin late Pleistocene blanket. Modern shoaling is a continuation of the submarine reworking process. The minisparker data does not reveal evidence of ice override or deformation along the north slope of the bank. The north bank edge appears to be an erosional feature, blanketed by younger material. Ice contact features may have been removed from the areas surveyed in this study by late Pleistocene marine planation, or ice may never have reached the bank. Seismic records covering the Great South Channel area also lack evidence of ice occupation. Sediments inferred to be of Pleistocene age in this report appear to have been deposited as outwash south of the ice sheets.

Environmental Implications:

Potential geologic hazards have been observed throughout the upper 20-80 meters of bank sediment. Sediments blanketing the marine planation surface are acoustically complex containing reflectors inferred to represent several episodes of channel cutting and filling. Materials devoid of internal structure, appearing to represent reworked or disturbed sediment, are observed throughout the sediment blanket. The sediments are quite variable and sediment characteristics change dramatically over short distances. Large shoal structures appear to be migrating over the sea floor in response to modern reworking processes. The highly variable sediment blanket caps several shallow unconformities where angular sediment relationships could pose stability problems.

Unfortunately the distrbution and environmental significance of many of these features cannot be assessed in this report, because correlation of small scale feature is precluded by the broad trackline spacing of the survey. The variablility of bank sediments requires detailed seismic coverage of specific areas of concern for proper environmental evaluation. As an example, structural control of channel erosion is hinted at along Line K (Plate 1) where asymmetric channels are noted. The morphology of these channels would indicate that streams flowing parallel to the strike of underlying strata eroded, preferentially, down dip faces of more resistant sediments. Seismic coverage is insufficient to establish the trend of channel axes in the area, so the true nature of this stream erosion remains questionable. The geotechnical properties of the various stratigraphic units, channel fill materials and buried sedimentary features recognized in the data cannot be determined without an extensive sampling and analytical program designed to test their slope stability, differential compaction, surficial erosion potential, bearing capacities and shear strengths.

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PLATE I

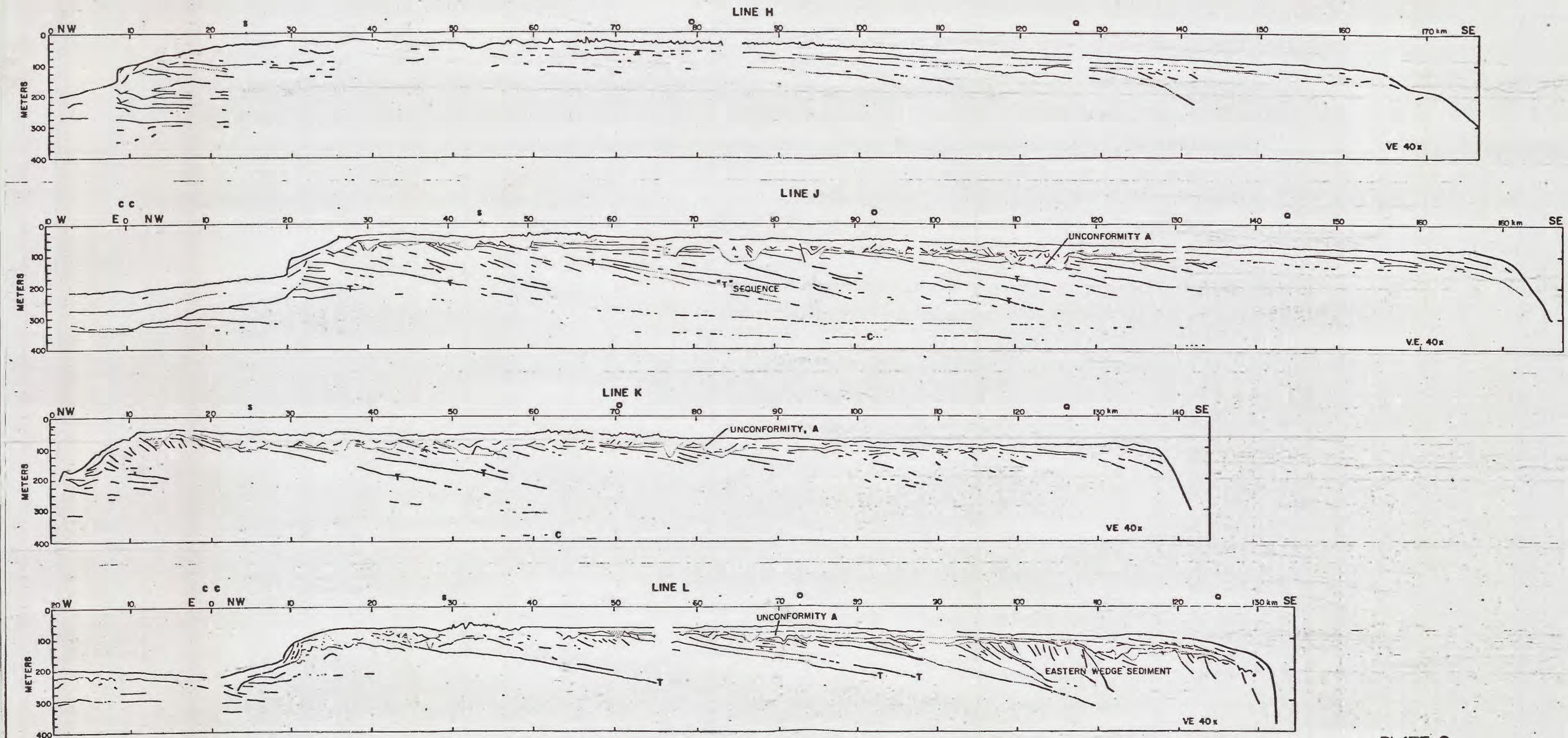
LINE H
NW
SE
METERS
VE 40x
LINE J
W
E
NW
SE
UNCONFORMITY A
"T" SEQUENCE
METERS
V.E. 40x
LINE K
NW
SE
UNCONFORMITY, A
METERS
VE 40x
LINE L
W
E
NW
SE
UNCONFORMITY A
EASTERN WEDGE SEDIMENT
METERS
VE 40x

PLATE 2

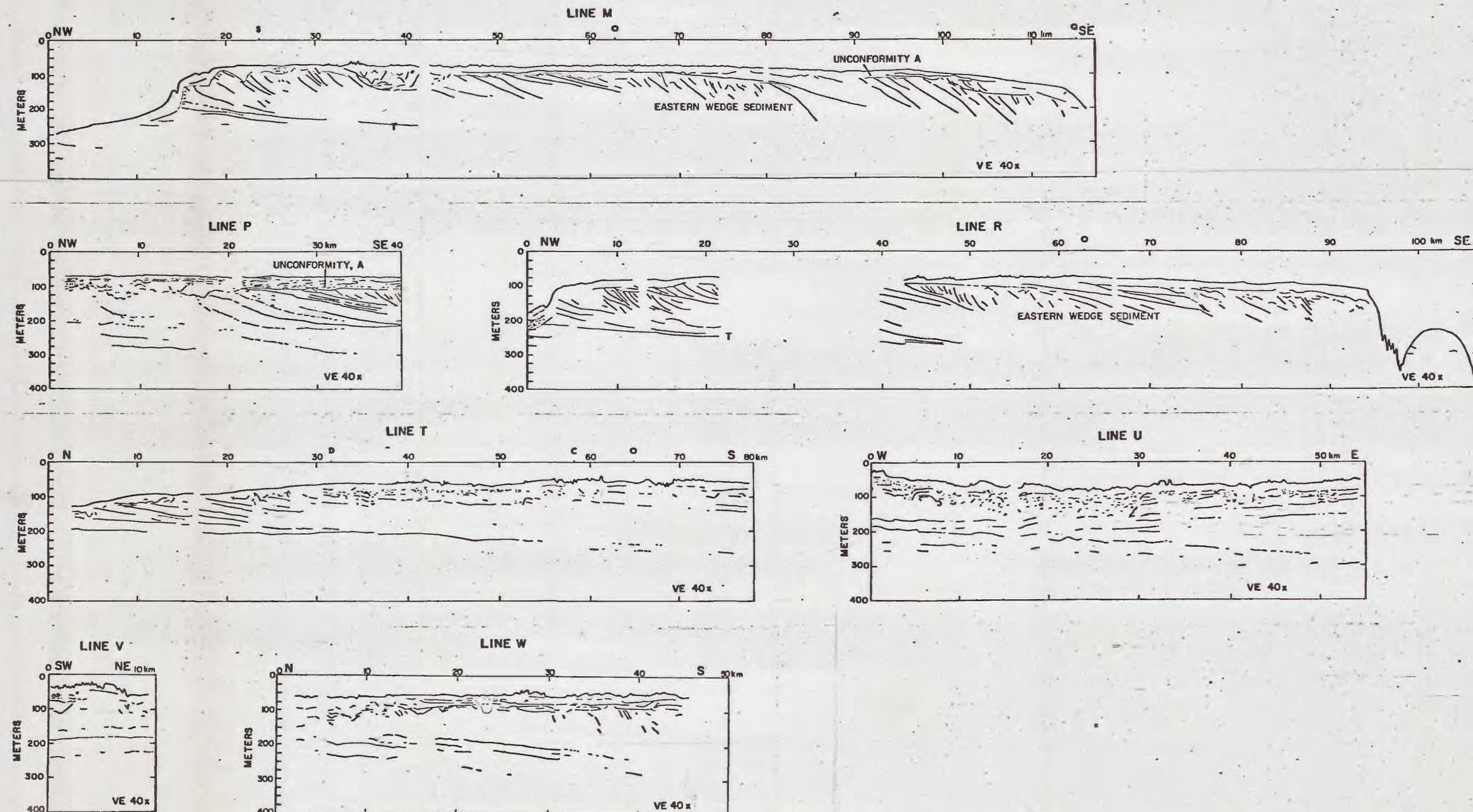
LINE M
NW
SE
UNCONFORMITY A
EASTERN WEDGE SEDIMENT
METERS
VE 40x
LINE P
NW
SE
UNCONFORMITY, A
METERS
VE 40x
LINE R
NW
SE
EASTERN WEDGE SEDIMENT
METERS
VE 40x
LINE T
N
S
METERS
VE 40x
LINE U
W
E
METERS
VE 40x
LINE V
SW
NE
METERS
VE 40x
LINE W
N
S
METERS
VE 40x

PLATE 3


LINE O
W
E
310 km
UNCONFORMITY A
WESTERN WEDGE SEDIMENT
EASTERN WEDGE SEDIMENT
METERS
VE 40 x
LINE Q
UNCONFORMITY A
CORSAIR CANYON
270 km
VE 40 x
LINE S
CULTIVATOR SHOAL
WESTERN WEDGE SEDIMENT
UNCONFORMITY A
EASTERN WEDGE SEDIMENT
180 km
VE 40 x

PLATE 4