Basin Structure of the U.S. Atlantic Margin[1]

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Abstract A detailed magnetic study of the U.S. Atlantic continental margin north of Cape Hatteras delineates the pattern of basins and platforms that form the basement structure. A 185,000-km, high-sensitivity aeromagnetic survey acquired in 1975 over the entire U.S. Atlantic continental margin forms the basis of this study. Magnetic depth-to-source estimates were calculated for the entire survey using a Werner "deconvolution" type method. These depth-to-basement estimates are integrated with multichannel seismic reflection profiles to interpolate basement structures between seismic profiles.

The deep sediment-filled basins along the margin are bounded on their landward sides by blockfaulted continental crust; their seaward sides are marked by the East Coast magnetic anomaly. The trends of the landward sides of these basins vary from 030° in the south to 040° in the north, consistent with a common pole of opening for all of the basins. The ends of these basins are controlled by sharp offsets in the continental crust that underlie the various platforms. These offsets are the result of the initial breakup of North America and Africa and are preserved as fracture zones under the continental rise.

The regions west of the various basins are comprised of platforms of Paleozoic and older crust and embayments of Triassic-Jurassic age. The Long Island platform is a series of ridges and troughs. These troughs are oriented northeastward, parallel with the Baltimore Canyon trough and the Georges Bank trough. The Connecticut Valley Triassic basin has a broad magnetic low associated with it that can be traced across Long Island. A similar magnetic signature is associated with the trough between Martha's Vineyard and Nantucket Island, suggesting that it also may be a Triassic basin. The Salsbury Embayment with its Triassic-Jurassic age sediments lies just west of the Baltimore Canyon trough while the Carolina platform, which has a few smaller Triassic basins within predominantly Paleozoic and older crust, lies landward of the Carolina trough. The area around Charleston is another major embayment of Triassic-Jurassic age, and west of the Blake Plateau is the Florida platform with Paleozoic and older crust.

A magnetic basement high associated with the East Coast magnetic anomaly separates oceanic crust from the deep sediment-filled troughs. The minimum depth of this high ranges from 6 to 8 km and the susceptibility contrast suggests that it is more likely an uptilted block of oceanic crust than a massive intrusive body. The magnetic anomaly probably is produced by a combination of a basement high and an "edge effect," where the edge is between the uptilted block and flat-lying, nonmagnetic sediments to the west.

INTRODUCTION

The U.S. Atlantic continental margin is a Mesozoic and Tertiary sedimentary wedge overlying a basement composed of continental crust, transitional crust, and oceanic crust. The general shape of the margin, as reflected by the 1,000-m depth contour, bears only slight resemblance to the major basement structure, and completely hides the pattern of basins and platforms along the margin (Fig. 1). Multichannel seismic reflection profiles across the margin (Behrendt et al, 1974; Grow and Schlee, 1976; Schlee et al, 1976) show a great thickness of sediments in the basins along the margin. The existence of these basins had been inferred from earlier geophysical studies (Drake et al, 1959; Drake et al, 1968; Emery et al, 1970; Emery and Uchupi, 1972; Mayhew, 1974; Sheridan, 1974).

The structural boundaries and depths of these basins have been estimated by various authors (Drake et al, 1959; Emery et al, 1970; Maher and Applin; 1971; Sheridan, 1974; Schlee et al, 1976), but because of the limited seismic coverage, only a rough determination of their shape has been possible. Additionally, the use of complementary geo-

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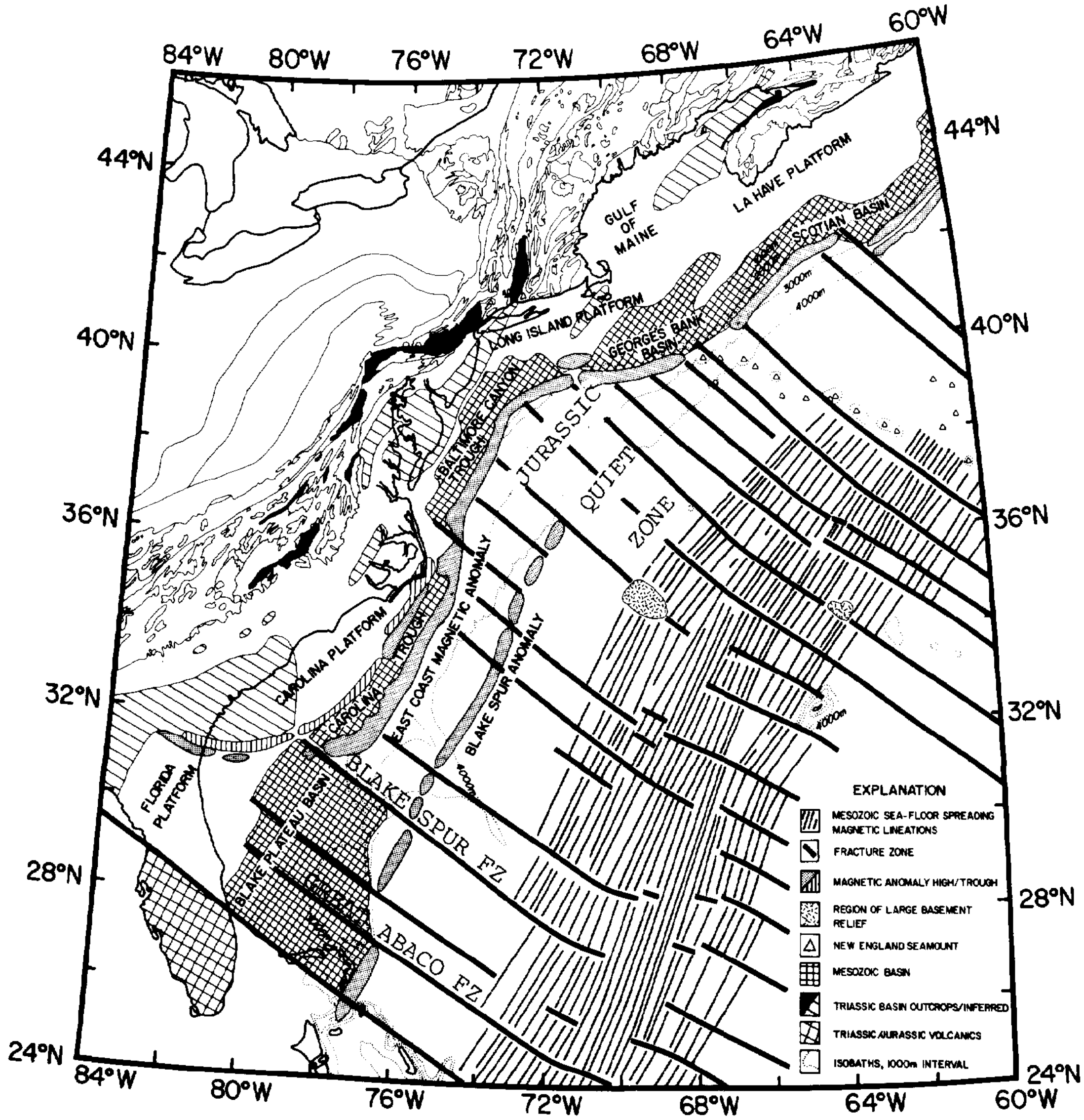

FIG. 1. Western Atlantic continental margin including general structural lineaments of the Appalachian Orogenic System (after King, 1969), Mesozoic sea-floor spreading magnetic lineations and fracture zones (after Schouten and Klitgord, 1977), prominent magnetic lineaments within the Jurassic Quiet Zone, the major sediment-filled troughs of Mesozoic age, and the major platforms which are underlain by continental crust. E.B. = Essaouira Basin.

physical information (magnetic and gravity) has been limited (Emery et al, 1970; Mayhew, 1974; Sheridan, 1974). This paper uses magnetic source depth analyses from a new high-sensitivity aeromagnetic survey over the U.S. Atlantic continental margin, in conjunction with multichannel seismic profiles, to determine the detailed basement structure of the margin. The earlier detailed magnetic study of the Atlantic continental margin by Taylor et al (1968) concentrated on the continental foldbelt region and the continental slope and rise but contained almost no discussion of the continental shelf area and the buried basins. The writers compared magnetic depth estimates and multichannel seismic depth profiles to test the reliability of the magnetic depth analyses. Trends of prominent magnetic sources on adjacent closely spaced magnetic profiles are used to interpolate the locations of the associated basement features between seismic profiles.

DATA SOURCES

1975 Aeromagnetic Survey

As part of the U.S. Geological Survey program to study the U.S. Atlantic continental margin, a 185,000-km high-sensitivity, nonexclusive aeromagnetic survey was flown, compiled and contoured by LKB Resources, Inc. The track coverage (Fig. 2) ranged from a 2.5 × 16-km (1.5 × 10-mi) grid to a 5 × 32-km (3 × 20 mi) grid between the coastline and the 2,000-m depth contour and from a 9.5 × 32-km (6 × 20-mi) grid to a 32.5 × 64.5-km (20 × 40-mi) grid between the 2,000 m and 4,000-m depth contours. The 2.5 × 16-km grid over Georges Bank was flown in

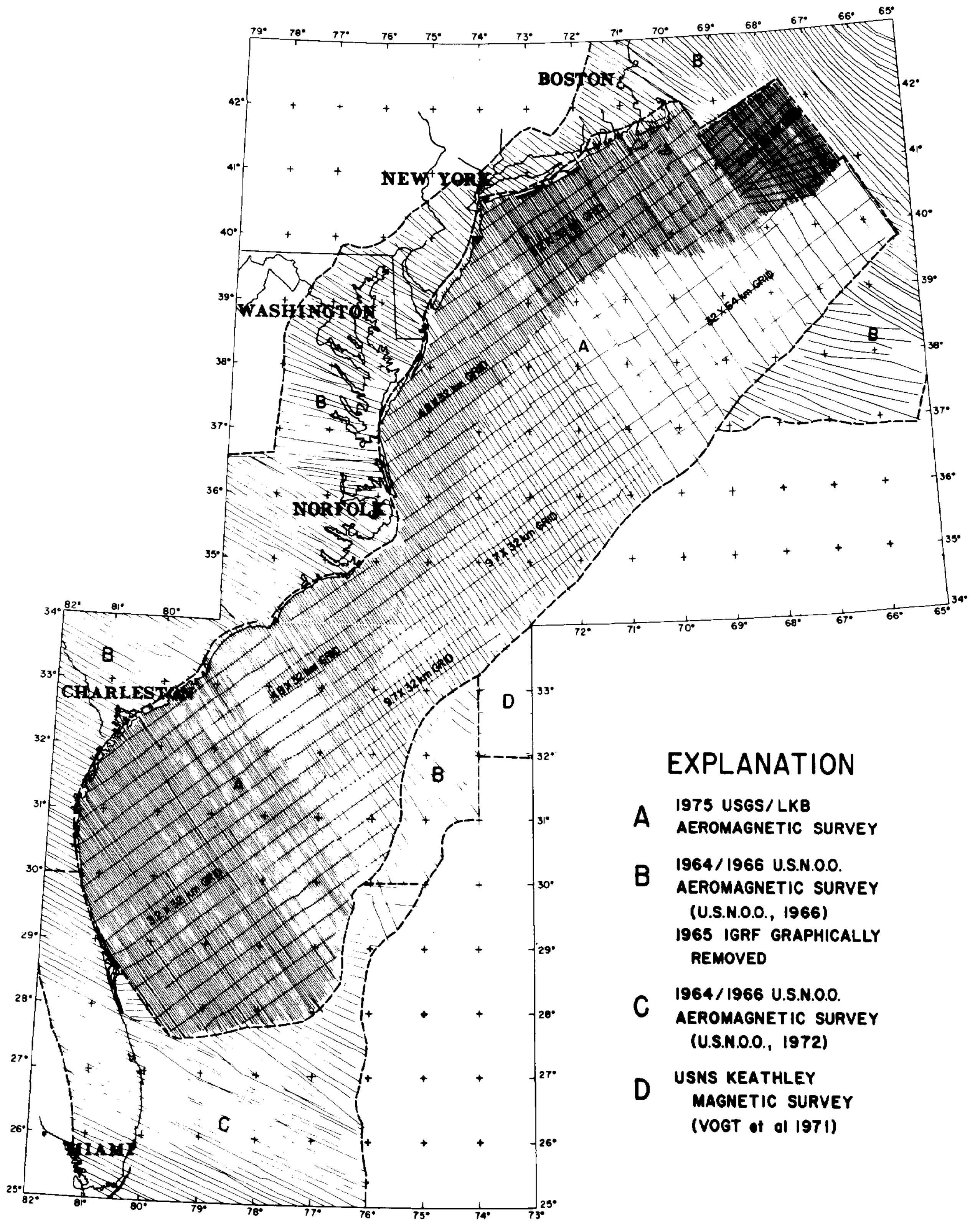

FIG. 2. Track coverage for the aeromagnetic surveys used in this report. The track spacings are indicated in kilometers for Area A.

1966 by Aero Service and the data were recompiled by LKB Resources, Inc. The flight elevation for the survey was about 450 m except for the 2.5 × 16-km grid over Georges Bank, which was flown at about 300 m. A *LORAN* C-doppler radar-VLF (very low frequency) integrated navigation system was used for the 1975 survey. *LORAN* A was used for the navigation of the 1966 survey. A high-sensitivity

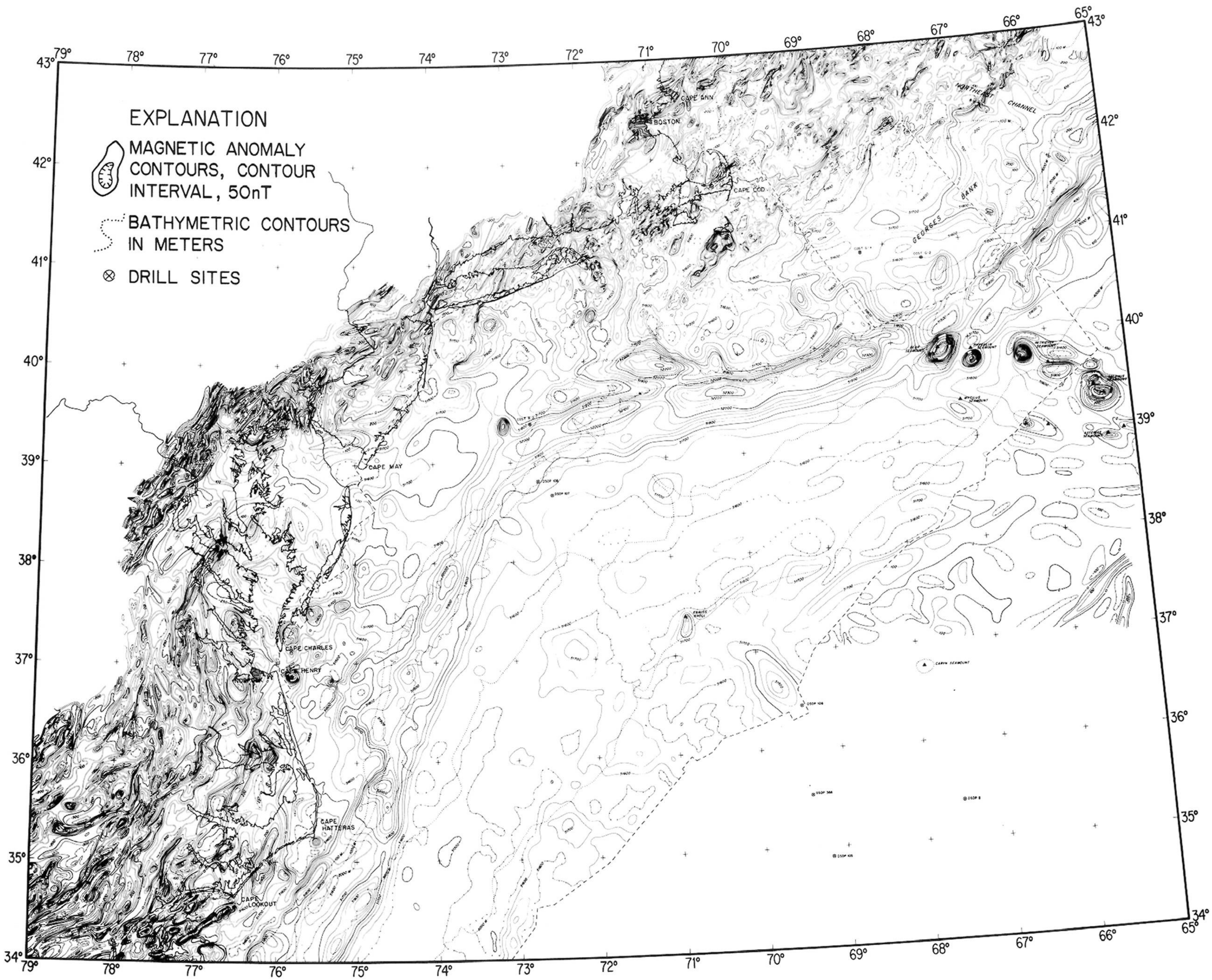

FIG. 3A. Magnetic anomaly contour map on a modified Universal Transverse Mercator projection (central meridian = 75°) with a 50-nT contour interval (Klitgord and Behrendt, 1977). 3A shows area north of 34°N lat. The magnetic contours are based on the track coverage shown in Figure 2.

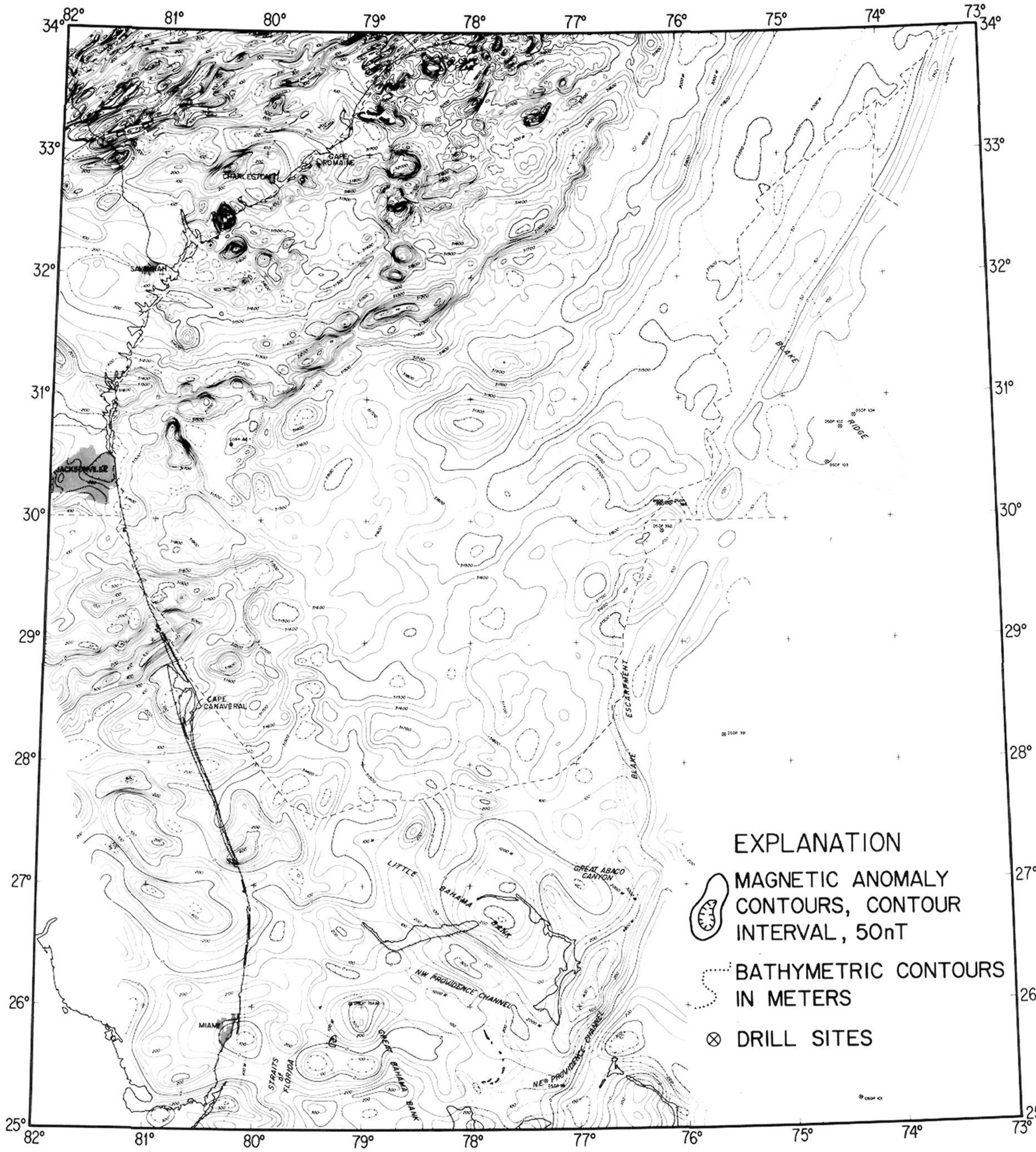

FIG. 3B. Magnetic anomaly contour map on a modified Universal Transverse Mercator projection (central meridian = 75°) with a 50-nT contour interval (Klitgord and Behrendt, 1977). **3B** shows area south of 34°N lat. The magnetic contours are based on the track coverage shown in Figure 2.

magnetometer utilizing optical absorption of energized helium vapor (rubidium vapor for the 1966 survey) was used in the airplane for the survey and at a base station to monitor the diurnal field. Flight lines were reflown when the magnetic noise level was determined to be too high by the base station monitor. The aeromagnetic data, navigational data, and altitude were digitally recorded.

The compilation of the magnetic data included cross-line leveling and regional field removal. The total magnetic field readings were adjusted by utilizing a modified control-line leveling system. This system adjusts the magnetic field values at each flightline intersection to minimize the crossover errors caused by diurnal variations and ground-positioning errors. The resulting adjusted total field data then had the regional field removed using the IGRF 1965 tables (IAGA, 1969) updated to mid-1975 (mid-1966 for the 1966 survey). A datum of 52,000 nanotesla (nT, 1 nT = 1 gamma; 43,850 nT for the 1966 survey) was then added to the magnetic anomalies.

Magnetic anomaly maps were compiled at a contour interval of 2 nT by LKB Resources, Inc. and recompiled by the authors (Klitgord and Behrendt,

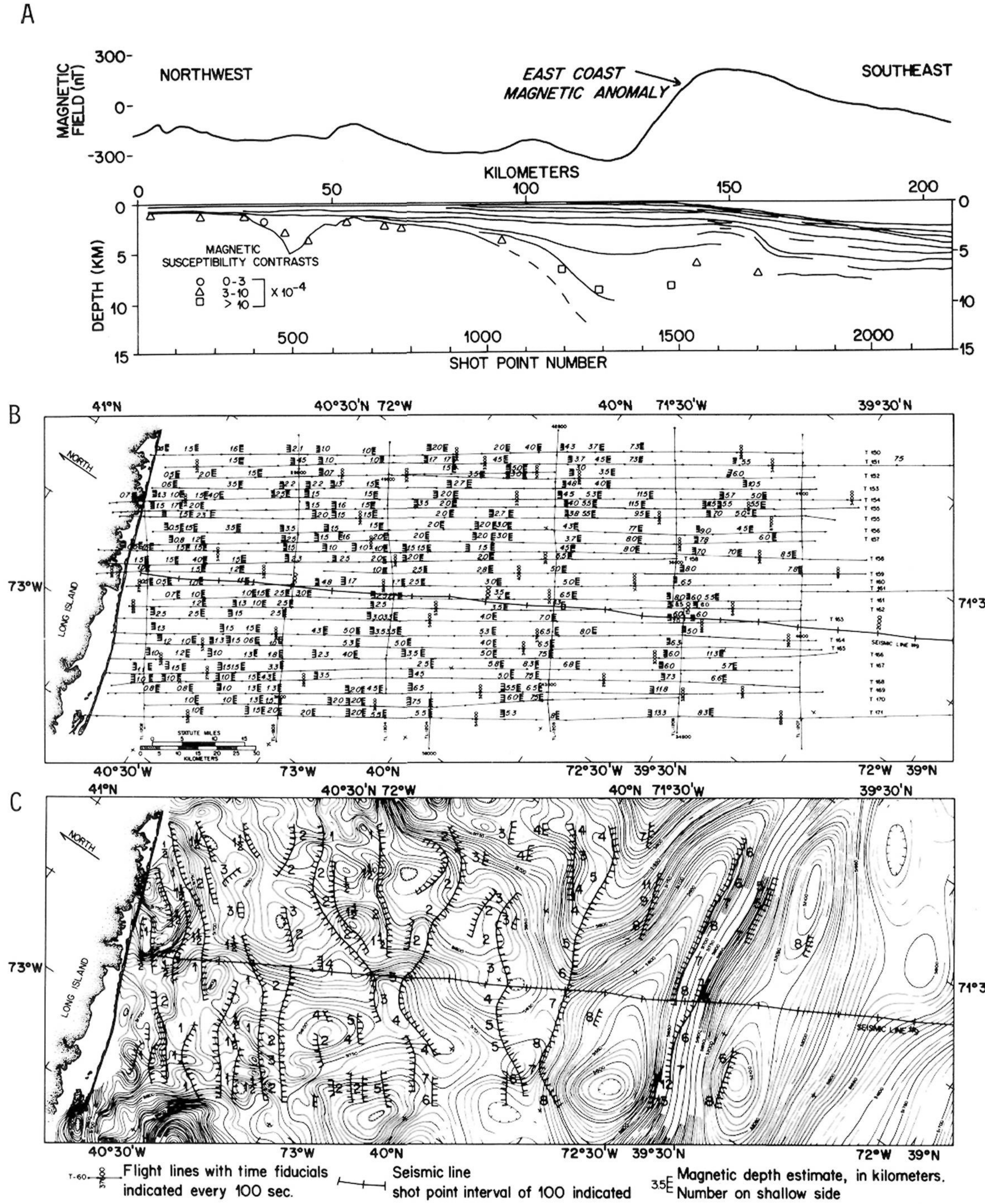

FIG. 4. Example showing the general use of the magnetic depth estimate in the vicinity of seismic line 9: **A**—comparison between magnetic depth estimates and seismic reflection profile; **B**—comparison between magnetic depth estimates on adjacent flight lines; **C**—smoothed version of magnetic depth estimates from **B** superimposed on the magnetic anomalies, contour interval is 10 nT.

1977) at a contour interval of 50 nT (Fig. 3) and a scale of 1:1,000,000. The reliability of these contours is extremely good except in the northeastern deep-water area, where the grid spacing is only 32.5 × 64.5 km (Fig. 2). In this latter area, the contours agree reasonably well with previous aeromagnetic surveys (Taylor et al, 1968). The magnetic contours have been modified in the vicinity of the New England Seamounts, taking into consideration more detailed magnetic surveys by the Naval Oceanographic Office (Walczak, 1963).

1964/1966 Aeromagnetic Survey

Aeromagnetic data from the 1964–1966 U.S. Naval Oceanographic Office survey (U.S. Naval Oceanographic Office, 1966) were used to augment to LKB Resources, Inc. survey (see Fig. 2). This older survey was flown between 1964 and 1966 at flight elevations of about 150 m over water, 450 m over land south of Washington D.C., and 750 m over land north of Washington D.C. The flight lines (Fig. 2) were spaced at about 8-km intervals, with no tie-lines.

The 50 nT magnetic contours south of 30°N lat. were taken from a map previously published by the U.S. Naval Oceanographic Office (1972). North of 30°N lat., the regional field based upon the IGRF 1965 tables was graphically removed by the writers from the total-intensity magnetic maps (U.S. Naval Oceanographic Office, 1966).

U.S.N.S. *Keathley* Magnetic Survey

A small portion of the marine magnetic data collected by the U.S.N.S. *Keathley* (Vogt et al, 1971) is included in figure 3. The magnetic data were collected on a track spacing of 35 km and an average regional field was removed from the total field data.

METHOD OF ANALYSIS OF MAGNETIC DATA

Magnetic Depth-to-Source Estimates

The determination of the depth-to-magnetic basement can be a valuable tool for investigating the structure of sedimentary basins (for example, Vacquier et al, 1951; Dobrin, 1960). In general, the sediments within a basin have very weak susceptibilities compared with those of crystalline/volcanic basement at the bottom of the sediment pile. Therefore, it could be expected that the major source of magnetic anomalies over these basins would be basement structure, susceptibility variations within the basement, and intrusive bodies or extrusive volcanic bodies within the basin.

All the methods for estimating magnetic source depths require assumptions about these sources. Usually the reliability of the depth estimates is closely tied to the validity of these assumptions. When other geophysical data, such as seismic reflection or refraction profiles, or drill-hole data can be used to help limit these assumptions, one can often increase the reliability of these depth estimates. The best method for carrying out the depth estimates will usually be determined by these assumptions and the desired results.

Estimates of the depth to magnetic sources were calculated for the U.S. Geological Survey by International Exploration, Inc., using a Werner "deconvolution" type method (Hartman et al, 1971; Jain, 1976). This method assumes that the sources are either two-dimensional dikes or edges of bodies. The mathematical formula for the magnetic anomaly and horizontal magnetic gradient associated with these two types of sources can be expressed as a truncated expansion (Werner, 1953) having a fixed number of unknowns. These unknowns include the horizontal location of the source, it's depth, susceptibility contrast, and dip.

The magnetic field measurements at a small number of points (e.g., 7), called a sampling window, are used to solve a set of simultaneous equations for the desired unknowns. This window is moved, point by point, across the entire data set; consistency criteria are used for selecting the most reliable source-location estimates. Several passes are made of the data set, each pass having wider sampling intervals and appropriate anti-alias filters, to look at the deeper sources. The number of data

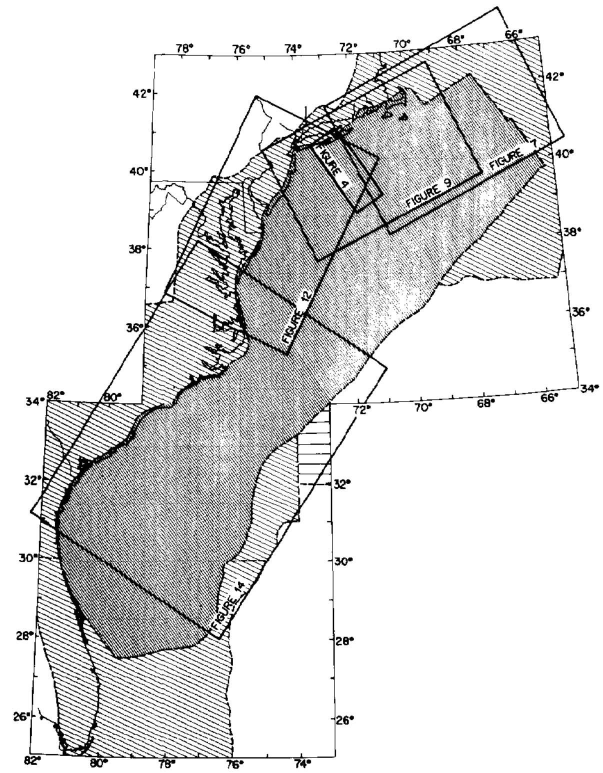

FIG. 5. Location map for areas shown in more detail on other figures. The magnetic surveys shown in Figure 2 are indicated.

points is kept the same for each of the passes and the window is moved with the same distance increment for each pass. As might be expected, the shallower sources producing the shortest wavelength anomalies will be seen by only a few sampling windows because only a few shifts of the window will rapidly bring it beyond a particular magnetic anomaly.

In contrast, the deeper sourced depth estimates, generally associated with the broader wavelength anomalies, will be seen by more sampling windows, but the resolution will be poorer than for the shallow-sourced depth estimates. Each pass of the window produces a set of solutions based on the block edge (interface) model and a set of solutions based on the dike model. Because both sets of solutions are determined from the same data, one or the other must be chosen at any given location; however, the set of solutions chosen along any given profile can be a combination of the two types. In general, for the continental shelf area, the edge solutions were chosen in this study because most of the source bodies appear to be wider than the depth to the source for the basement features and because of the agreement of the solutions with seismic data. Over oceanic crust with its thin source layer, the dike solutions provided a better estimate of the basement depth.

Susceptibility contrasts within the basement can affect the depth analyses. Large-scale sharp variation in the susceptibility, such as at contacts be-

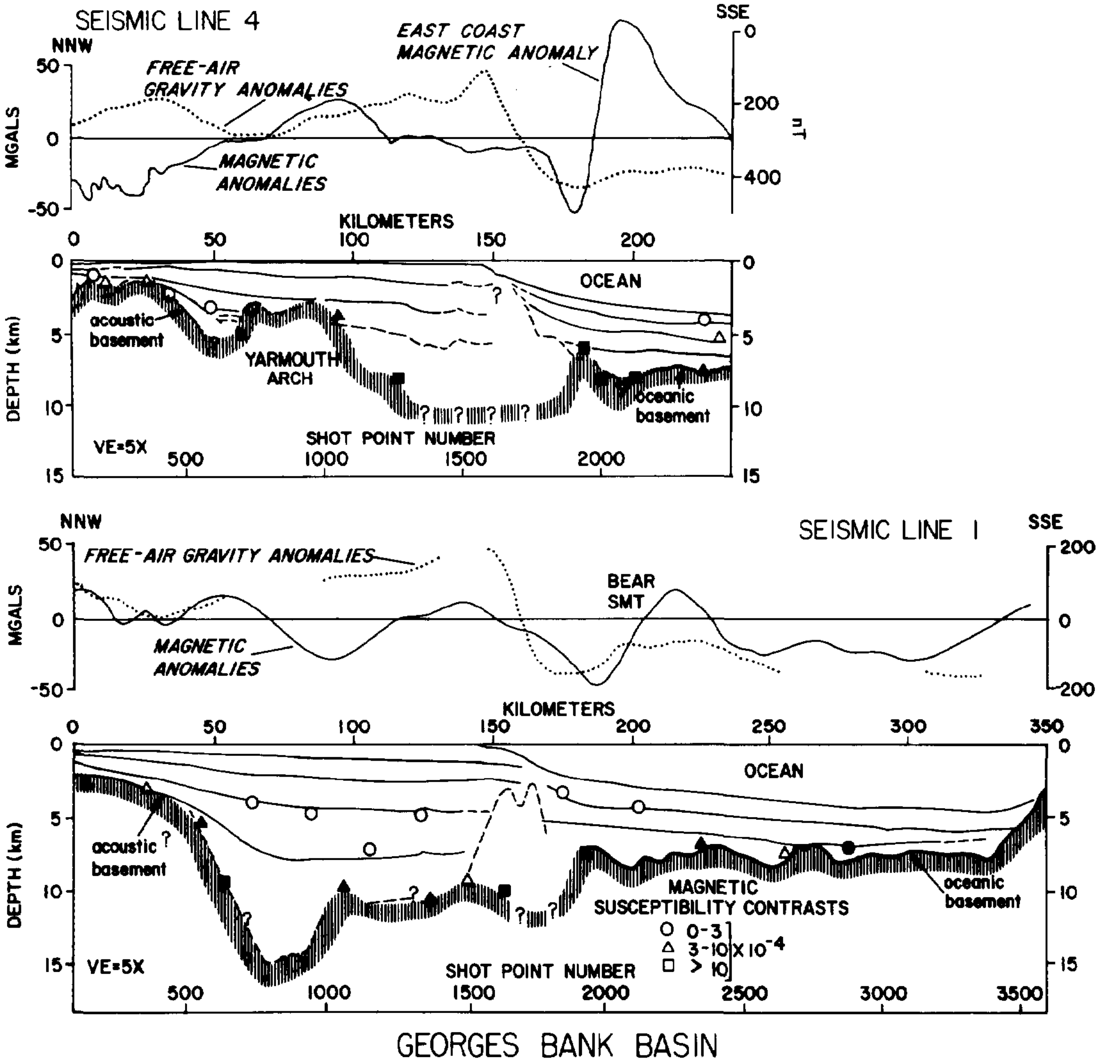

FIG. 6. The comparison between magnetic depth-to-basement estimates and multichannel seismic lines 4 and 1 (Schlee et al, 1976; Grow and Schlee, 1976) over the Georges Bank basin. See Figure 7b for their locations. The heavy lines are prominent seismic horizons; these lines are dashed where the horizon is indefinite. The magnetic basement is shaded. Where the depth to basement is unknown, a set of question marks (?) is used. The reliable magnetic depth estimates are shown. Depth estimates that have more than 50 solutions have been filled in. Seismic line 4 did not cross the area for which magnetic depth estimates were calculated. The magnetic depth estimates have been projected onto the seismic line in the appropriate positions relative to the magnetic anomalies.

tween rock types, will look like edges or dikes and reliable depth estimates can be calculated by the above method. Moderately long wavelength variations (i.e., those that take place gradually over a long distance—for example, the susceptibility variations associated with a broad metamorphic contact zone) could produce erroneously deep depth estimates. Fortunately, comparison with seismic reflection data and with the many adjacent magnetic profiles for consistent solutions, plus the existence of reliable shallow depth estimates, will usually result in the discarding of most of these erroneous deep estimates. Depth estimates greater than approximately 20 km can be immediately discarded because this depth is probably below the Curie point isotherm (Vacquier and Affleck, 1941).

Depth estimates have been categorized by susceptibility contrasts and the number of solutions that determined the estimate. Susceptibility contrasts have been designated as weak for 0-3 $\times$ 10^{-4} (C.G.S. units), moderate for 3-10 $\times$ 10^{-4}, and strong for $>10 \times 10^{-4}$. This division tends to separate the sources within the sediments ($<3 \times 10^{-4}$) from the basement sources and to separate the sources at the edges of the basins ($>10 \times 10^{-4}$) from the other sources. The depth estimates with greater than 50 solutions have been indicated by filled symbols (Figs. 6, 8, 10, 11, 13) to earmark the sources of the most prominent anomalies.

The depth analyses just described were carried out using the digital data on the entire 185,000 km track coverage of the 1975 LKB Resources, Inc.

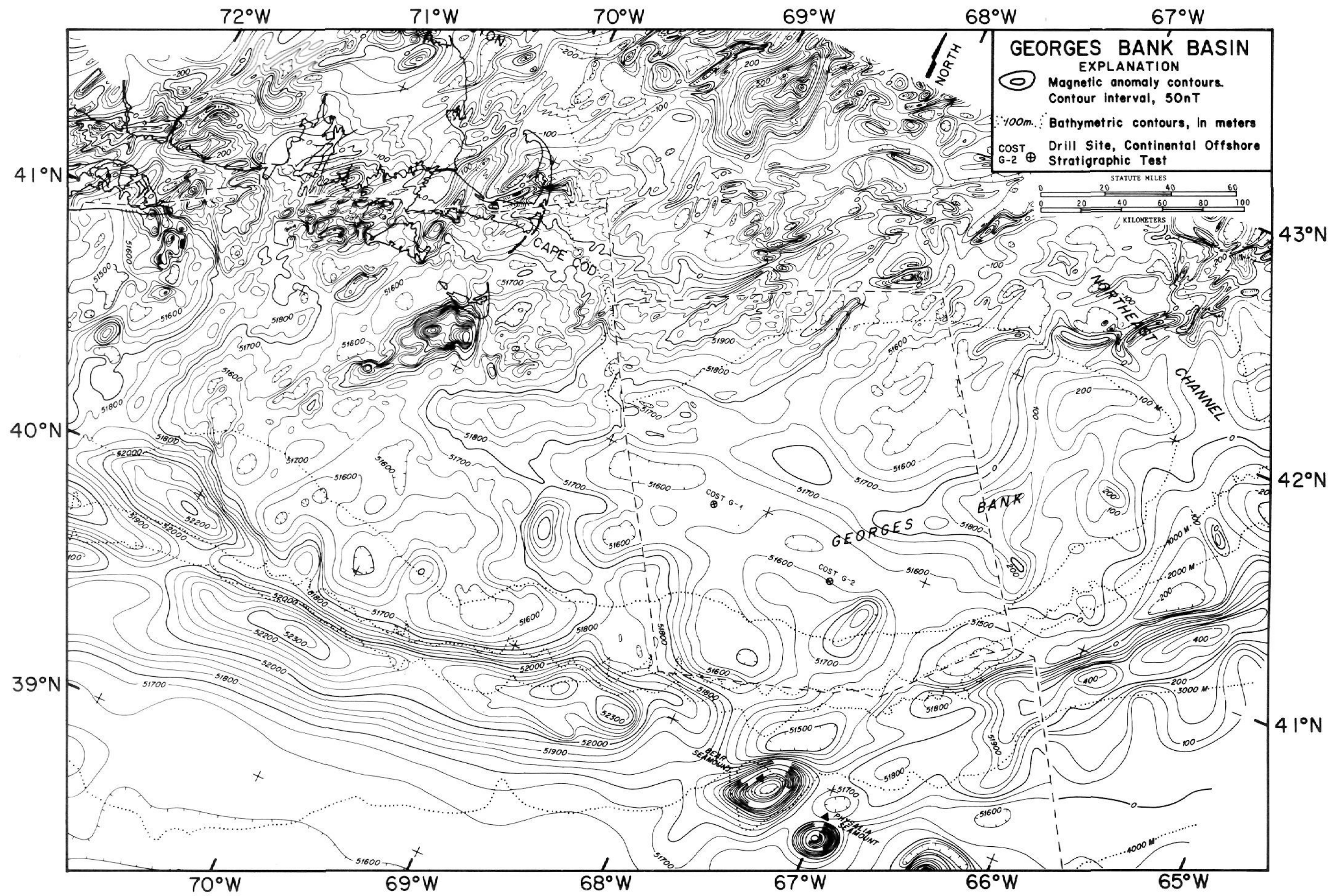

FIG 7A. Magnetic anomaly contour map for the Georges Bank basin region. Contour interval is 50 nT.

aeromagnetic survey and the 1966 Aero Services aeromagnetic survey. Interpretation of these depth analyses included the comparison of adjacent profiles for compatibility. The validity of the above method and its assumptions for this area were checked by examination of the results from adjacent magnetic profiles (Figs. 7b, 9b, 12b, 14b), the linearity of the magnetic anomalies on the contour map (Figs. 3, 7a, 9a, 12a, 14a), and a comparison between the magnetic data and the seismic reflection profiles (Figs. 6, 8, 10, 11, 13).

Example: Seismic Line 9

The results of the magnetic depth estimate calculations in the vicinity of seismic line 9 (Figs. 4, 9) provide an example of the general method utilized for all of the magnetic profile interpretations and for the integration with the seismic profiles. Seismic line 9 crosses the Long Island platform and the northern end of the Baltimore Canyon trough, traversing both shallow and deep basement structures.

The magnetic depth estimates along the flight lines adjacent to seismic line 9 are shown on Figure 4b. These depth estimates are assumed to be associated with basement (in this region, basement probably corresponds to the base of the Mesozoic sediments). They represent the set of depth estimates which are compatible with the seismic reflection data (Fig. 4a) and which are consistent on adjacent magnetic profiles (Fig. 4b). The agreement in the areal location of depth estimates on adjacent profiles is typical for the whole margin. The scatter in the estimated depths is commonly found to be about 20%, probably reflecting noise in the data, influence from adjacent magnetic anomalies, non two-dimensionality of the sources, and other variations in the sources from our assumed dike or interface models. The depth estimates (Fig. 4b) were averaged and rounded off to the nearest kilometer to produce the depth-to-basement location maps presented here (Figs. 4c, 7b, 9b, 12b, 14b). The quality of the depth estimates and desired results did not warrant a sophisticated smoothing of the results.

The comparison between the magnetic depth estimates and the seismic reflection data (Fig. 4a) was produced by projecting the depth estimates onto the seismic line, using the trends in the depth locations from Figure 4b. The troughs centered at shotpoints 500 and 1500 are clearly distinguished by both the magnetic depth estimates and the seismic reflection data. The peak in the magnetic basement near shotpoint 1600 is characteristic of the indications of

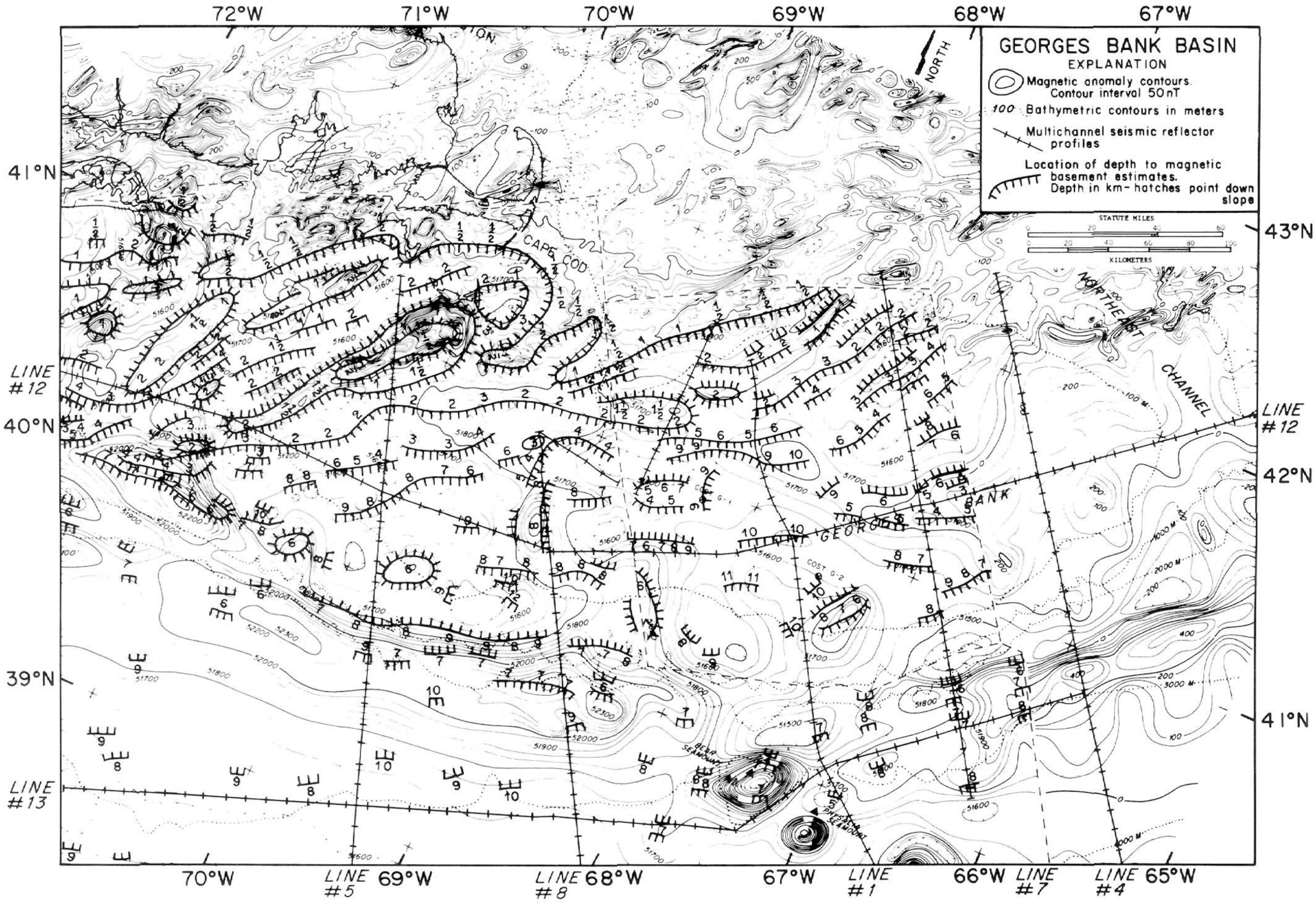

FIG. 7B. Location of magnetic depth estimates for the Georges Bank basin. The background contours are the 50-nT magnetic anomaly contours. Multichannel seismic lines are identified by numbers along the map margins.

a basement high beneath the East Coast magnetic anomaly which we found along most of the margin. The seismic structures directly above this peak have been inferred to be caused by a carbonate bank or reefal deposits (Schlee et al, 1976), and probably represent acoustic basement in this region on most of the multichannel seismic profiles.

The magnetic anomalies which are associated with the magnetic depth estimates (Fig. 4c) are very linear seaward of shotpoint 1100 on seismic line 9, while the anomalies landward of this point (on the Long Island platform) are more three dimensional. The more chaotic magnetic anomaly pattern on the platform is typical of the other platforms, and only the broader basement features such as the trough at shotpoint 500 can be identified with reasonable confidence. Within the major basins, the longer wavelength magnetic anomalies have fewer associated depth estimates, and it is easier to interpret them in terms of the source structure.

RESULTS

Our study of the U.S. Atlantic continental margin has been sub-divided into a series of areas, focusing on the individual basins and platforms which are found along the margin (Figs. 1, 5). These regions have been identified as the Georges Bank Basin (Fig. 7), the Long Island platform (Fig. 9), the Baltimore Canyon trough (Fig. 12), and the Carolina platform (Fig. 14). Our analyses of the Blake Plateau Basin are not complete, but they will be included in our discussion using preliminary results with some of the area included in Figure 14. For each area, we will discuss the magnetic anomaly lineations, compare the seismic reflection data with the magnetic depth estimates, compare the magnetic depth estimates on adjacent profiles, and, finally, discuss the depth to basement contour maps.

Comparison Between Magnetic Profiles

The agreement among depth estimates on adjacent magnetic profiles (Figs. 7b, 9b, 12b, 14b) is very good. This consistency of the depth estimates adds to the reliability of the results. The linearity of these sources and the linearity of the magnetic anomalies (Figs. 3, 7a, 9a, 12a, 14a) show that most of the sources are longer in extent than their depth, so the two-dimensionality assumption is reasonably accurate. The depth estimates near the ends of the anomalies commonly have to be discarded and a rough correction has to be made for the anomalies that were crossed obliquely by the flight lines. The variation in depth between an estimate for the same source on adjacent profiles may reflect the limits of the resolution of the method, the influence of noise on the estimates, the fact that the anomalies are not two dimensional, and other deviations in the actual source from our assumed dike or interface models. The depth estimates also indicate that many of the "edges" are not horizontal. Because these depth estimates are only for the top edges of the source blocks, we have little information concerning the depth to basement between the edges. The depths on these maps are given to the nearest 1/2 kilometer for the shallower estimates and to the nearest kilometer for the deeper estimates, reflecting the lack of resolution for these deeper estimates.

Comparison Between Magnetic and Seismic Data

The magnetic depth-to-basement estimates along the seismic lines were compared with the seismic depth sections (Figs. 6, 8, 10, 11, 13) to minimize the ambiguities in the magnetic depth estimates. On the landward side of the deep, sediment-filled basins, multichannel seismic reflection profiles across the margin (Grow and Schlee, 1976; Schlee et al, 1976) show an acoustic basement that appears to be composed of large blocks of continental(?) crust rather than many intrusive bodies. This interpretation would be compatible with the assumption that major magnetic anomaly sources are the edges of bodies. On the seaward side of the East Coast magnetic anomaly, the hyperbolic acoustic signature of the acoustic basement (Schlee et al, 1976) and the seismic refraction data from the region (Emery et al, 1970; Mayhew, 1974; Sheridan, 1974) indicate that the acoustic basement is oceanic crust. In general, the dike solution depth estimates are more compatible with the seismic data for the oceanic crust because the source layer is fairly thin. In the areas where the acoustic basement was thought to be continental crust, the "edge" solutions of the magnetic depth estimates having reasonably high susceptibility contrasts were consistent with the location of acoustic basement.

There are some features that are found on the magnetic/seismic depth comparisons for all the seismic profiles. A consistent set of weak susceptibility solutions within the sediment column is associated with prominent seismic horizons (e.g., the long shallow horizon seen on line 9 [Fig. 8]). In a previous

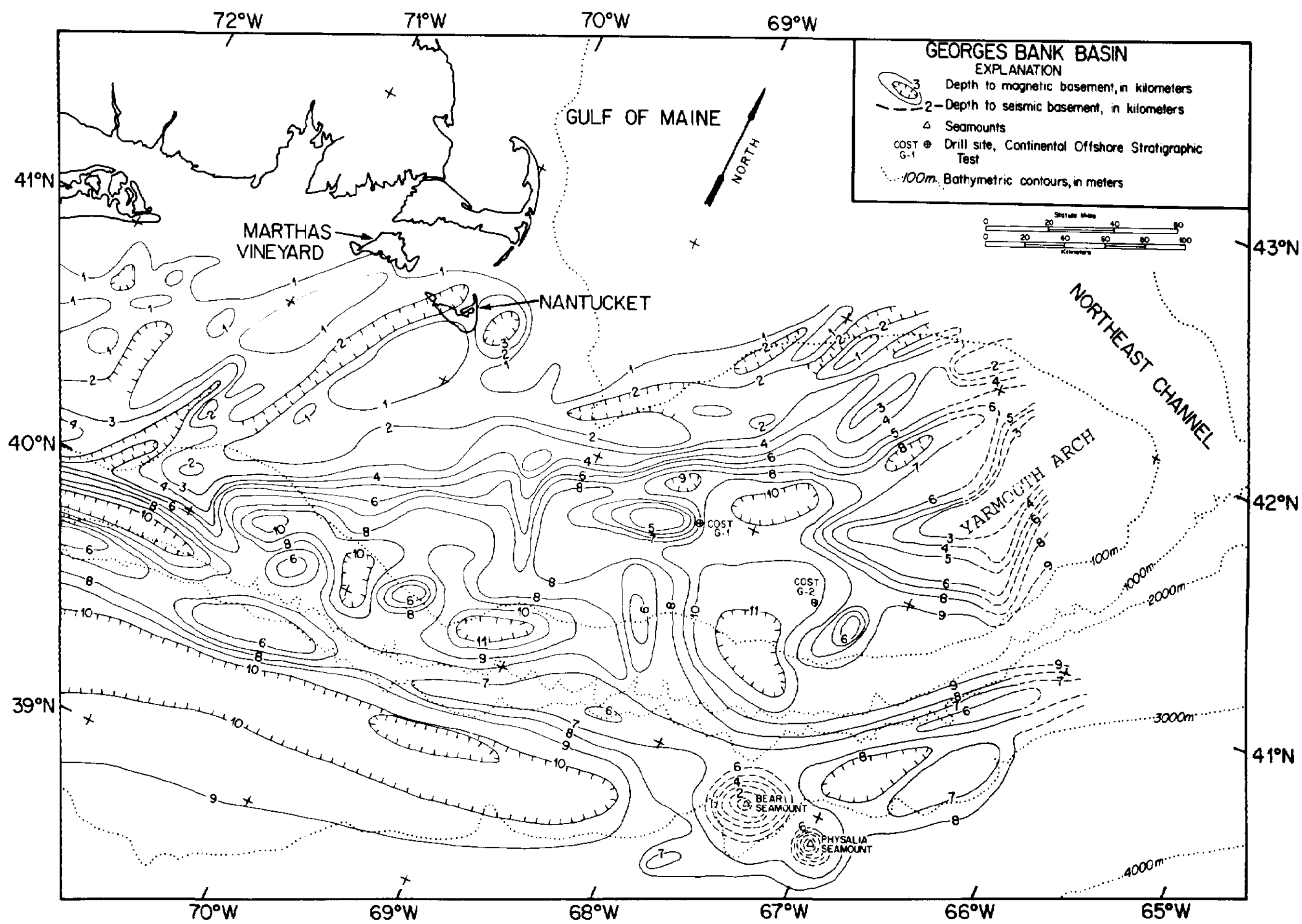

FIG. 7C. Depth-to-basement contours for the Georges Bank basin based on the magnetic depth estimates shown in Figure 7B. The depth-to-basement contours are in kilometers; the contour interval is 1 km. Hachures point down slope.

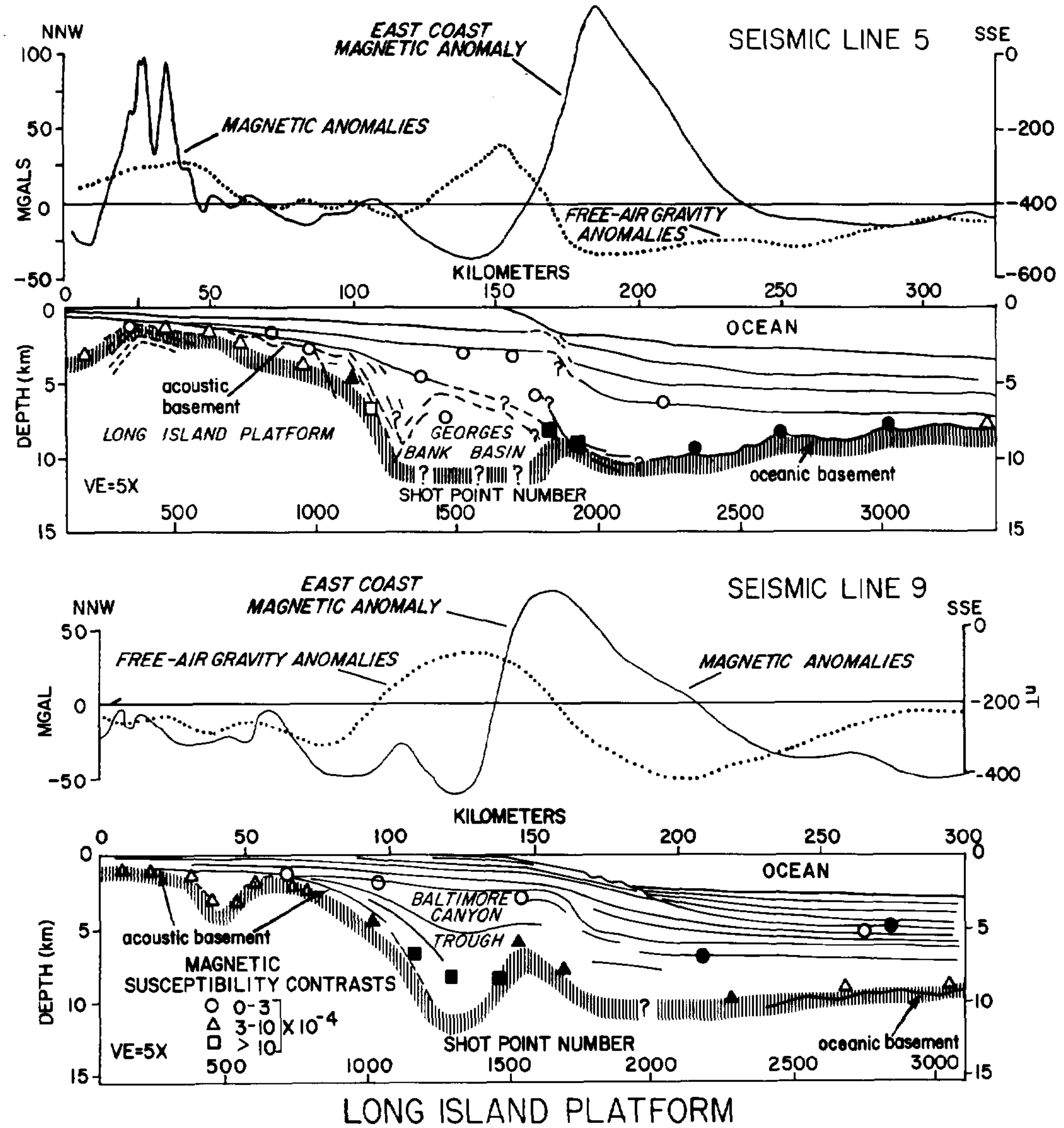

FIG. 8. Comparison between magnetic depth-to-basement estimates and multichannel seismic lines 5 and 9 (Grow and Schlee, 1976) over the Long Island platform. See Figure 9B for locations. Symbols are the same as in Figure 6.

study of high-resolution aeromagnetic data on the U.S. Atlantic continental margin, Steenland (1977) found a very shallow magnetic basement. This basement may have been the same layer as the one associated with the weak susceptibility contrasts that are found within the sediment column. The small susceptibility contrasts of these shallow depth estimates suggest that they are not produced by crystalline/volcanic rock. The consistent appearance of these solutions on adjacent magnetic profiles and their association with prominent seismic horizons suggest that they are real, but further discussion of them would be extraneous to the subject of basement structures.

Associated with the landward edges of the deep, sediment-filled troughs are intermediate to strong susceptibility contrast solutions that have depths which are progressively deeper towards the center of the basins. On the seaward side of the East Coast magnetic anomaly, where seismic reflection data (Grow and Schlee, 1976; Schlee et al, 1976) and seismic refraction data (Mayhew, 1974; Sheridan, 1977) indicate that the acoustic basement is probably oceanic crust, the associated magnetic depth estimates show weak to moderate susceptibility contrasts. Between the two above-mentioned zones are the deep, sediment-filled basins and the East Coast anomaly. Many deep magnetic depth estimates (>10 km) are found in this region, and a narrow set of shallow depth estimates (6 to 8 km) is obtained from beneath the East Coast magnetic anomaly. These facts indicate a peak in the magnetic basement between the oceanic crust and the deep troughs (Figs. 6, 8, 10, 11, 13). A high susceptibility contrast (>10 $\times$ 10^{-4}) is usually associated with the landward edge of this magnetic high. The seismic profiles do not show any identifiable structures below this magnetic basement high, but in most places, above this high is a disturbed seismic zone that has been interpreted as carbonate rocks (Schlee et al, 1976).

Depth-to-Basement Maps

Depth-to-basement maps for the Atlantic margin were compiled for each of the basins and platforms (Figs. 7c, 9c, 12c, 14c). Although these maps are based on the depth-to-magnetic basement estimates, the control provided by the magnetic/seismic comparisons in the selection of reliable magnetic depth estimates results in a map of basement depths that is compatible with the available multichannel seismic reflection data. The controls for these contours are the depth-to-magnetic basement locations and multichannel seismic reflection profiles shown on Figures 7b, 9b, 12b, and 14b. For each of the areas to be discussed, the depth-to-basement maps (Figs. 7c, 9c, 12c, 14c) are used in conjunction with the magnetic/seismic comparisons (Figs. 6, 8, 10, 11, 13), providing an aerial and cross-sectional view of each region.

Georges Bank Basin

The Georges Bank sediment pile masks a large variation in basement depth. The sediment pile overlaps the shallow basement of the Long Island platform (Garrison, 1970) on the northwest, and that of the Gulf of Maine (Ballard and Uchupi, 1972) on the north. The main part of the bank is underlain by a deep trough (Schultz and Grover, 1974) with possible sediment thicknesses of more than 8 km (Schlee et al, 1976). The Yarmouth arch protrudes into the trough from the northeast, splitting it into two basins. On the seaward side of Georges Bank, oceanic crust at a depth of 7 to 8 km extends from the deep ocean basin almost to the East Coast magnetic anomaly (Schlee et al, 1976). Two published multichannel seismic reflection profiles (Fig. 6) cross Georges Bank (USGS seismic line 1, Schlee et al, 1976; USGS seismic line 4, Grow and Schlee, 1976). Seismic line 4 crosses the northeast end of the bank over the Yarmouth arch, and seismic line 1 crosses the central part of Georges Bank over the deepest part of the Georges Bank Basin.

The magnetic anomalies over Georges Bank (Figs. 3, 7a) reflect the variations in basement depth (Kane et al, 1972) and demonstrate the linearity of many of the basement features. Shallow magnetic depth estimates (<4 km) are obtained over the landward edges of the Georges Bank Basin. Intermediate magnetic depth estimates (4 to 6 km) are associated with the Yarmouth arch and several smaller intrusive(?) bodies within the basin. Magnetic depth estimates of 7 to 8 km are generally found seaward of the East Coast magnetic anomaly, over oceanic crust. The

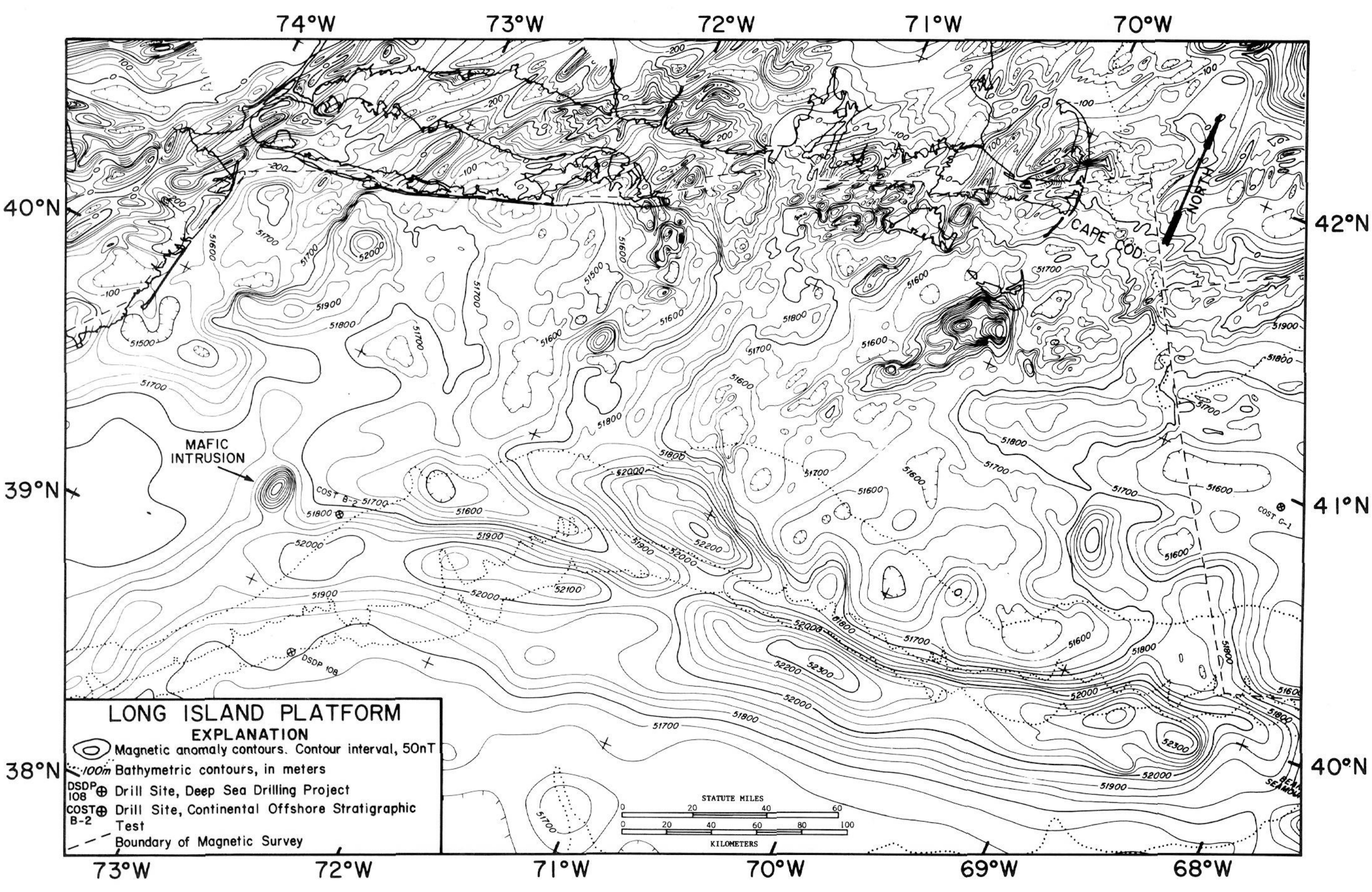

FIG. 9A. Magnetic anomaly contour map for the Long Island platform region. Contour interval is 50 nT.

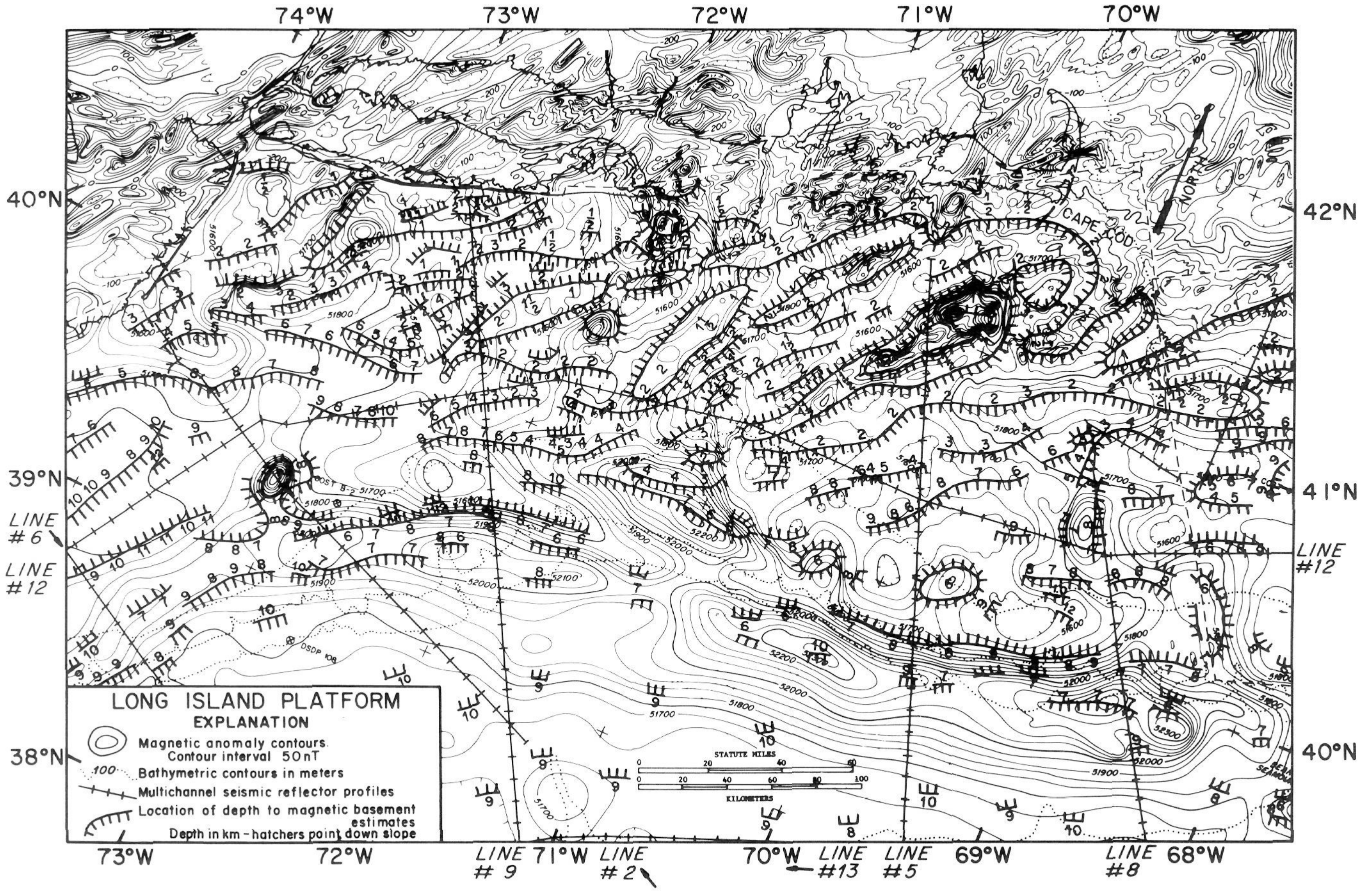

FIG. 9B. Location of magnetic depth estimates for the Long Island platform. Symbols are the same as in Figure 7b.

deepest magnetic depth estimates (>10 km) are located just landward of the East Coast magnetic anomaly.

The structure of the Georges Bank Basin (Figs. 1, 7) trends 030° to 040°, roughly parallel with the Baltimore Canyon trough and the general trend of the western Atlantic continental margin. The northwest side of the trough appears to be composed of block-faulted basement that rapidly deepens between the Long Island platform (<3 km) and the axis of the trough. The southwestern end of the trough terminates near 40°N lat., 70°W long., at the East Coast magnetic anomaly. Two magnetic features at this point may be caused by intrusive bodies (buried seamounts?) that reach a minimum depth of about 6 km. Northeast of these intrusive bodies, the trough deepens abruptly at about 40.5°N lat., 69°W long. The trough then branches—a shallow part going on the north side of the Yarmouth arch, and the deeper part continuing south of the arch towards the Scotian Basin. Near 40.8°N lat., 67.3°W long., there appears to be another buried seamount having a minumum depth of about 6 km.

The seaward edge of the Georges Bank Basin is marked by the East Coast magnetic anomaly. This anomaly is discontinuous at the southwestern end of the Georges Bank Basin and where Bear Seamount intersects the anomaly. Northeast of Bear Seamount, the East Coast magnetic anomaly is fairly narrow (~35 km) and separates the shallow (7 to 8 km) oceanic crust from the deep basin (8 to 12 km). The anomaly southwest of Bear Seamount is much broader (~50 km) and trends approximately east to west. A magnetic basement high that has a large susceptibility contrast (>20 × 10^{-4}) is associated with the east to west part of the East Coast magnetic anomaly. This high has a minimum depth of 6 to 7 km and a deeper (>10 km) basement to the north and south.

Long Island Platform

The Long Island platform has a fairly shallow acoustic basement, which is broken into a series of ridges and troughs. Single-channel seismic reflection profiles show that the top of the basement dips seaward (Garrison, 1970; McMaster, 1971; Emery and Uchupi, 1972). The existence of a few small basins was suggested by Ballard and Uchupi (1972); these basins can be seen on multichannel seismic reflection profiles (Grow and Schlee, 1976; Schlee et al, 1976). The platform is crossed by only two published multichannel seismic profiles (Fig. 8); therefore, a reasonable determination of the orientation of the troughs or of the extent of the platform by this means is precluded.

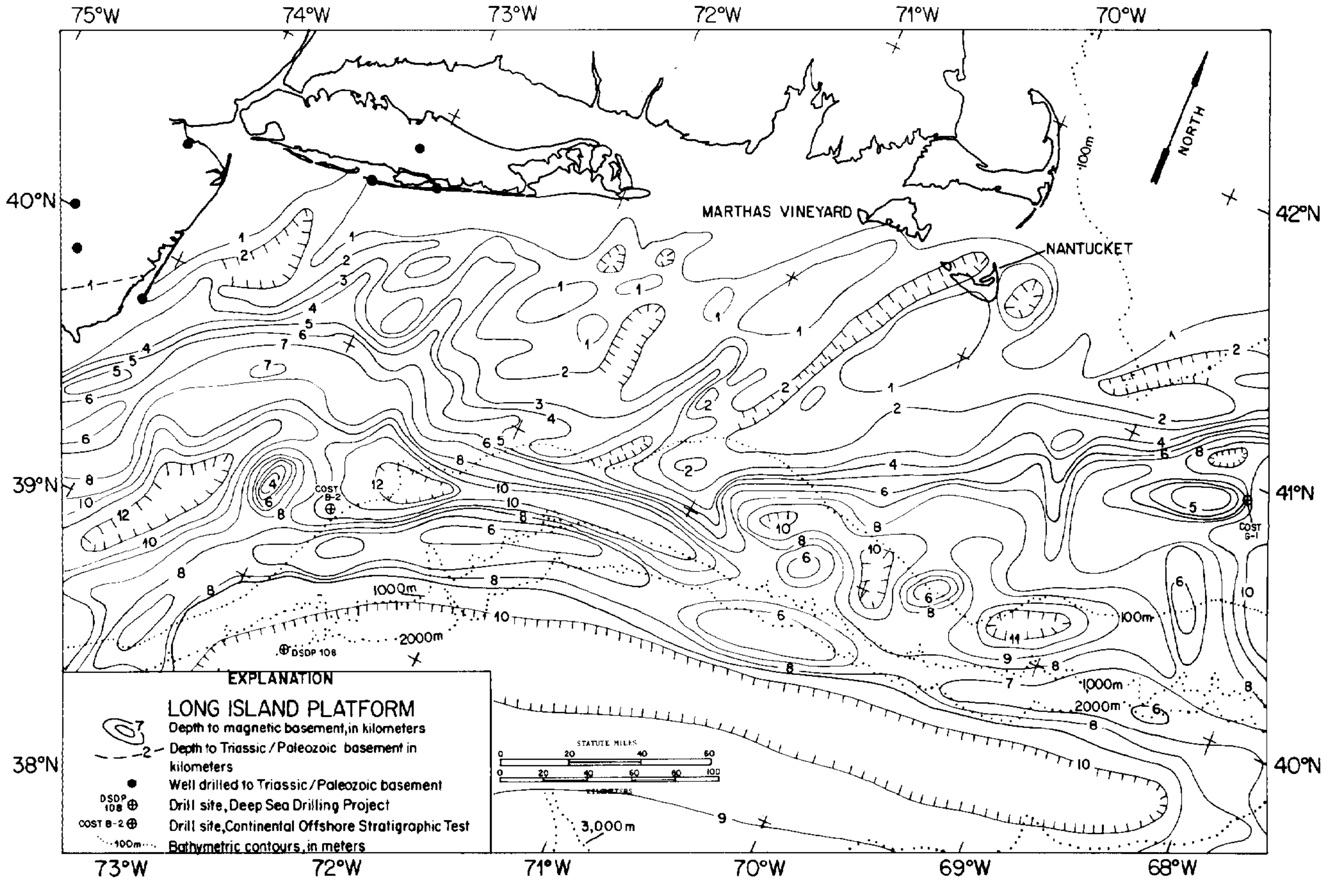

FIG. 9C. Depth-to-basement contours for the Long Island platform based on the magnetic depth estimates shown in Figure 9B. The symbols are the same as in Figure 7C.

This region of shallow basement is clearly distinguished by the magnetic field (Figs. 3a, 9a) which has many more short wavelength anomalies than does that over the deep sediment-filled basins. There are at least four small basins which trend parallel with the Baltimore Canyon trough and the Georges Bank Basin (Fig. 9). Seismic line 5 (Fig. 8) crossed two of these troughs, and seismic line 9 (Fig. 8) crossed one of them. The generally high-amplitude, short-wavelength character of the magnetic anomalies (Figs. 3, 9a) is fairly typical of the continental crust under New England. The platform probably is composed of blocks of continental crust that were compressed by the Appalachian orogeny and then faulted apart by the Triassic and Jurassic rifting.

At least two of the troughs in the Long Island platform are probably Triassic and Jurassic basins. The broad magnetic low at about 40.5°N lat., 73.5°W long. (Fig. 9a) is a continuation of the low over the Connecticut Valley Triassic and Jurassic basin, indicating that this basin continues beneath Long Island. Well data also show the location of this basin beneath Long Island (Wheeler, 1938). A similar magnetic signature is associated with the basin between Martha's Vineyard and Nantucket; Minard et al (1974) suggested that this basin was Triassic. The other small troughs also may be Triassic and/or Jurassic in age.

A rapid increase in the depth-to-magnetic basement (Fig. 9) marks the southern and southeastern edges of the Long Island platform. South of Long Island, this edge is at about 40°N lat. where the depth increases from about 4 km to more than 8 km into the Baltimore Canyon trough. The change in depth along this zone is quite variable because this is where the basement highs of the Long Island platform are truncated and the small basins broaden and deepen into the Baltimore Canyon trough. Farther east, at about 40°N lat., 71°W long., a large magnetic high is associated with the southwestern end of the Nantucket basement high. This magnetic anomaly (Fig. 9a), which appears to be an offset part of the East Coast magnetic anomaly, separates the Long Island platform (<3 km depth) from the northeastern end of the Baltimore Canyon trough (>8 km depth). This region has the most rapid drop in basement depth from the Long Island platform to an adjacent basin. Along the southeastern edge of the Nantucket basement high, the deepening of the basement is more gradual into the Georges Bank Basin. The drop takes place in four steps (or blocks). The two upper steps closest to the Nantucket basement high have large linear magnetic anomalies associated with them.

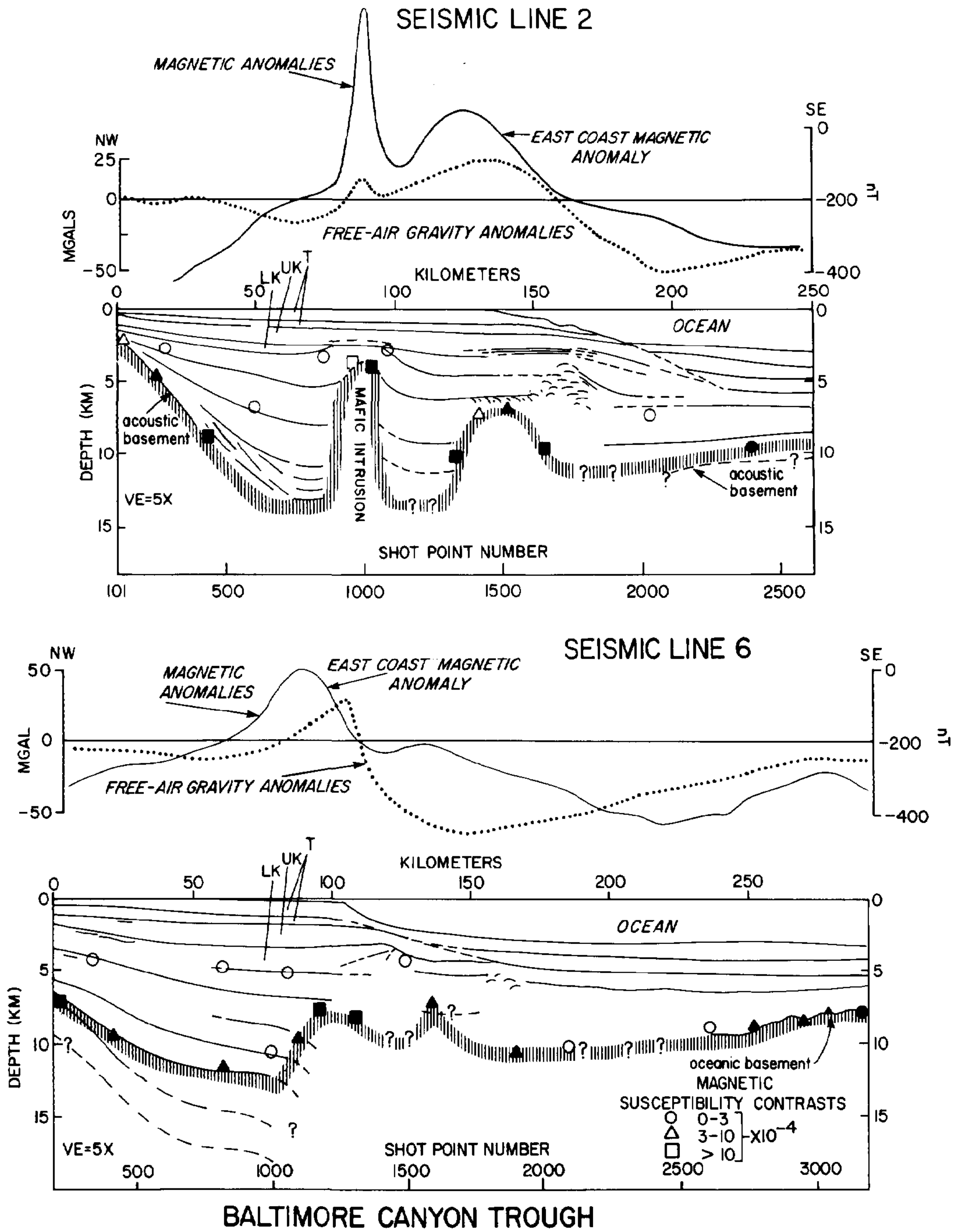

FIG. 10. The comparison between magnetic depth-to-basement estimates and multichannel seismic lines 2 and 6 (Schlee et al, 1976; Grow and Schlee, 1976) over the Baltimore Canyon trough. See Figure 12B for their locations. The symbols are the same as in Figure 6.

Baltimore Canyon Trough

The continental margin between Long Island and Cape Hatteras contains two major offsets in the continental crust that form a large embayment into continental North America. Along the coastline of New Jersey and Delaware, drill holes reached Triassic or Paleozoic basement at a depth of 1.5 to 2 km (Brown et al, 1972). Beneath the continental shelf is a deep, sediment-filled trough (Drake et al, 1968; Emery et al, 1970) called the Baltimore Canyon trough. Multichannel seismic reflection profiles (Figs. 10, 11) indicate that the basement deepens into the Balitmore Canyon trough in a series of faulted blocks (Schlee et al, 1976). This trough contains more than 12 km of sediments and is oriented along 030°.

Magnetic anomalies over the Baltimore Canyon Trough (Figs. 3, 12a) in general have very broad wavelengths, suggesting a source depth of more than 8 to 10 km. The exceptions are a few circular highs

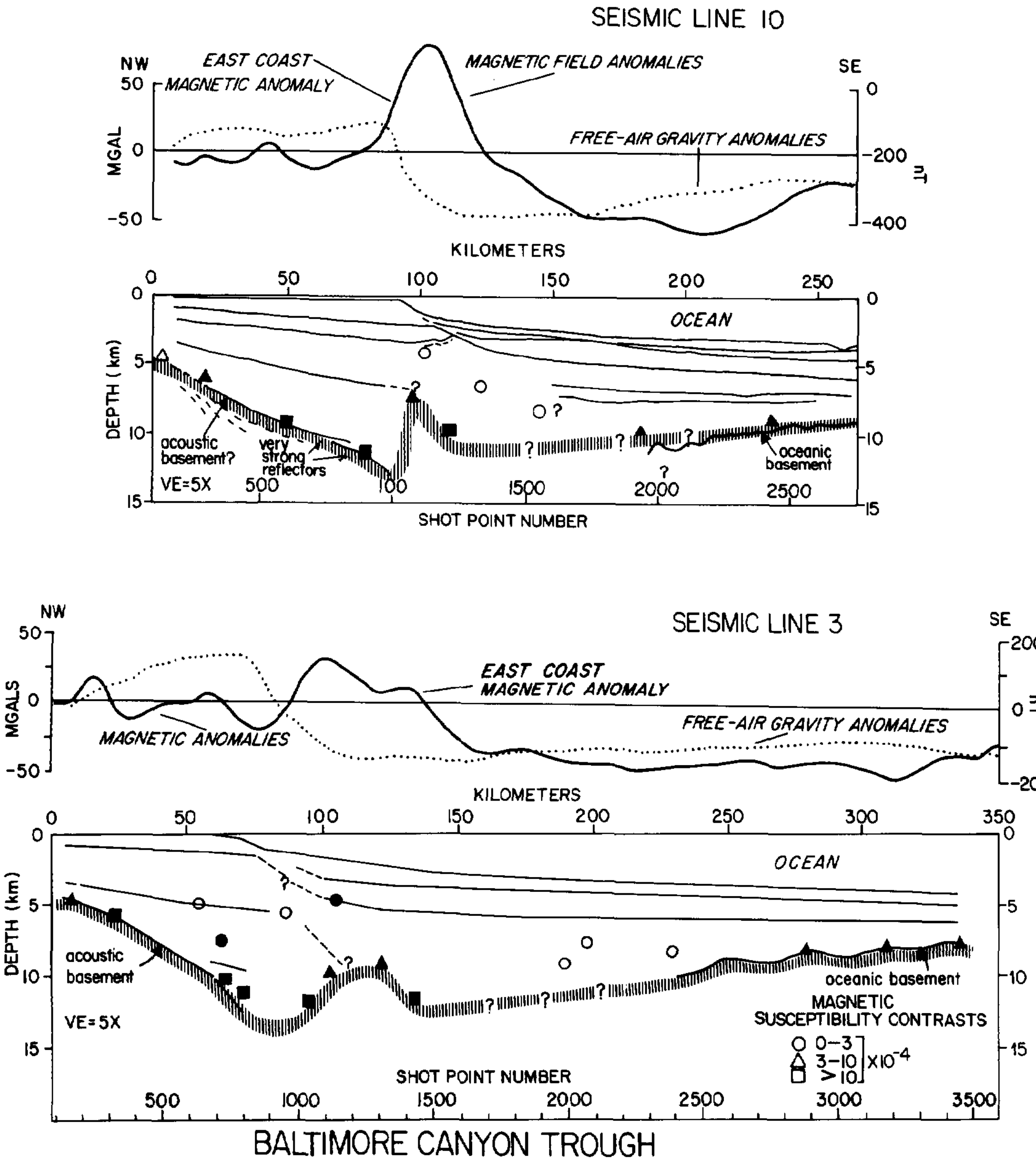

FIG. 11. The comparison between magnetic depth-to-basement estimates and multichannel seismic lines 10 and 3 (Schlee et al, 1976) over the Baltimore Canyon trough. See Figure 12B for their locations. Symbols are the same as in Figure 6.

which are probably intrusive bodies. The magnetic depth estimates (Figs. 10, 11, 12b) get progressively deeper in the seaward direction until reaching the East Coast magnetic anomaly. Nearshore, the magnetic basement drops off rapidly from about 2 km (in agreement with drill-hole information) to about 6 km near the beginning of the multichannel lines. These estimates reach a maximum depth of greater than 10 km just landward of the East Coast magnetic anomaly.

A few intrusive bodies are associated with the Baltimore Canyon trough. The most conspicuous of these bodies is the mafic intrusion at about 39.3°N lat., 73°W long. (Fig. 12a; Schlee et al, 1976). Minimum magnetic depth estimates are about 3.5 km for this body, which has a susceptibility contrast of about 25×10^{-4} with the surrounding sediments. The other major intrusive bodies indicated by the magnetic data are near Cape Charles and Cape Henry. They are near the edge of the Baltimore Canyon trough and may be intruded into older continental crust.

The magnetic depth estimates are of particular interest near the shelf break and the East Coast magnetic anomaly because the seismic technique has not been able to penetrate more than a few kilometers in this region. Several depth estimates have been obtained in this region, ranging from about 7 km to

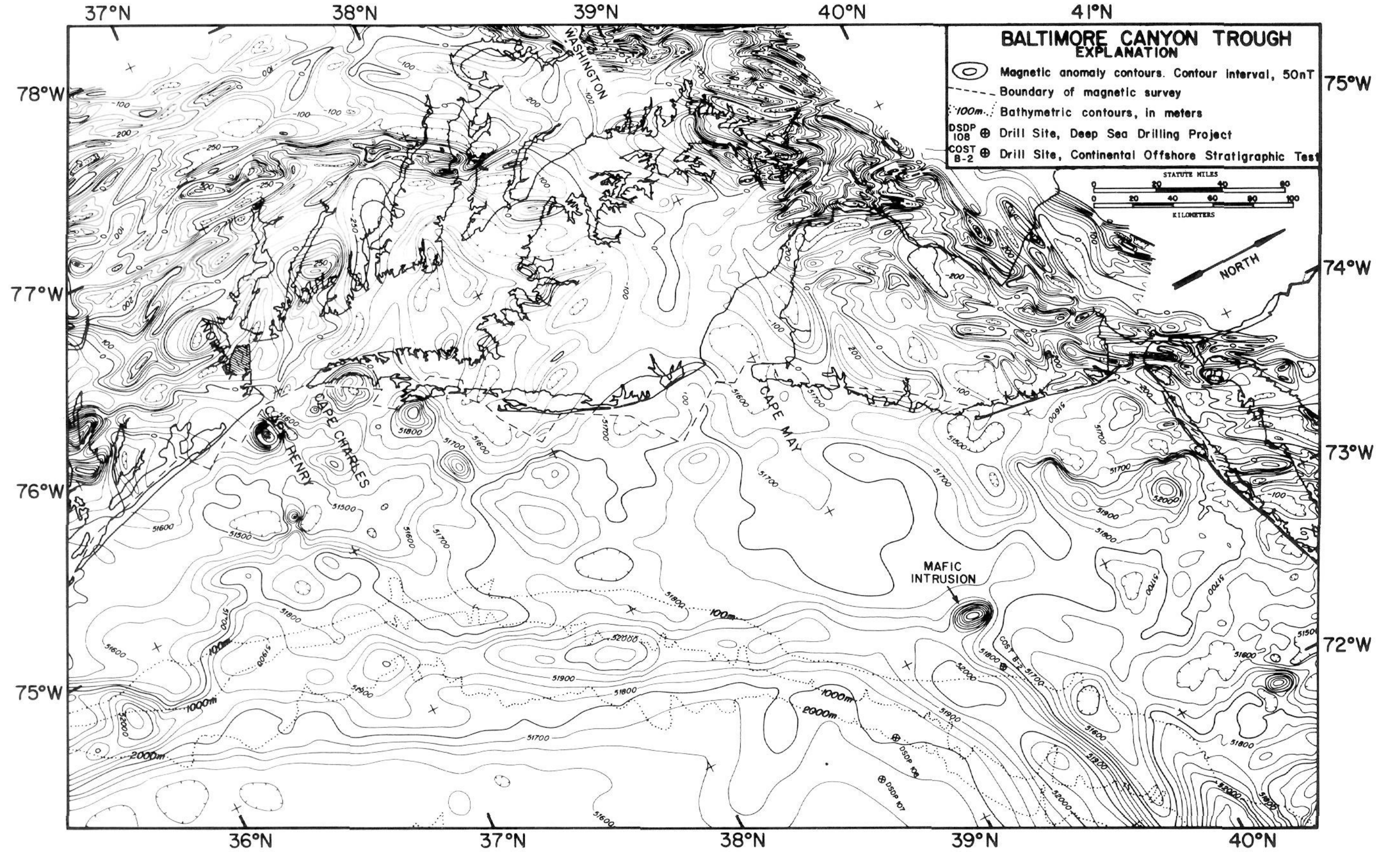

FIG. 12A. Magnetic anomaly contour map for the Baltimore Canyon trough region. Contour interval is 50 nT.

more than 12 km; the deeper depth estimates are well landward or seaward of the East Coast magnetic anomaly. Many of the shallower depth estimates are at about the same location as the truncation of prominent seismic reflectors (Figs. 10, 11). The susceptibility contrasts are about 10×10^{-4}, lower than the contrast for the other intrusive bodies ($>25 \times 10^{-4}$). Basement is at a depth of about 10 to 12 km on the seaward side of the East Coast magnetic anomaly, and the magnetic depth estimates suggest that the basement shallows to an average depth of 8 km beneath this anomaly.

The Baltimore Canyon trough is composed of three basins (Fig. 12c) of different widths and depths. The broadest and deepest basin is on the north, and the narrowest and shallowest basin is on the south. The landward edges of these basins have the same trend and have fairly abrupt offsets to the west. The most southern part of the Balitmore Canyon trough terminates at the Carolina platform, and the most northern part terminates at the Long Island platform. Each of these offsets probably marks an initial offset in the continental crust as Africa and North America separated about 185 m.y.B.P. These offsets were propagated as transform faults in the adjacent oceanic crust (Fig. 1).

Carolina Platform and Trough

The Carolina platform is the region of shallow, Triassic and older crust which lies between the Baltimore Canyon trough and the Blake Plateau Basin (Fig. 1). The Carolina trough is just seaward of the platform and is the narrowest of the deep sediment-filled basins which are found along the entire U.S. Atlantic continental margin. The East Coast magnetic anomaly marks the seaward edge of the Carolina trough, and the Brunswick magnetic anomaly (Fig. 13), described by Taylor et al (1968) as the inner branch of the East Coast magnetic anomaly, marks the seaward edge of the platform.

Magnetic anomalies (Fig. 14a) and magnetic depth estimates (Fig. 14b) suggest that the crust of the Carolina platform is similar to that of the Long Island platform. A number of Triassic basins have been noted on the platform (King, 1969; Brown et al, 1972; Marine and Siple, 1974), and the whole southern part of the platform appears to be a region of Triassic and Jurassic material similar to the Salsbury Embayment (Popenoe and Zietz, 1977). The shallow depth estimates are confined to the region landward of the Brunswick anomaly (Figs. 13, 14b), a magnetic anomaly which is a prominent peak north of 33.5°N lat., a prominent trough with a small peak between 33.5°N lat., 36.5°W long., and 31°N lat., 80°W long., and a peak and trough west of 80°W long.

At the boundary between the Carolina trough and platform, there is a small basement trough and high which are associated with the Brunswick magnetic anomaly. These two features can be seen in both the

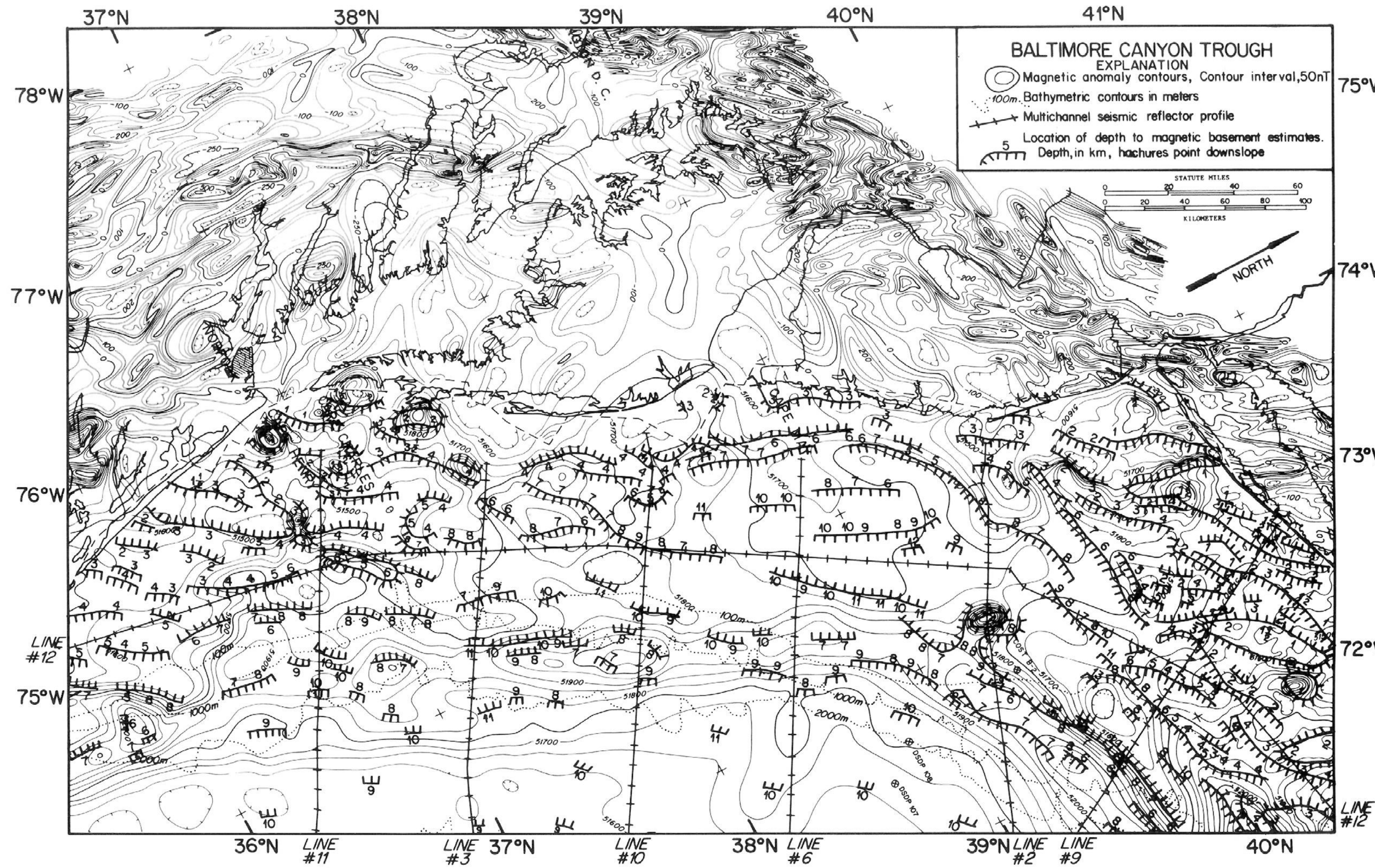

FIG. 12B. Location of magnetic depth estimates for the Baltimore Canyon trough. Symbols are the same as in Figure 7A.

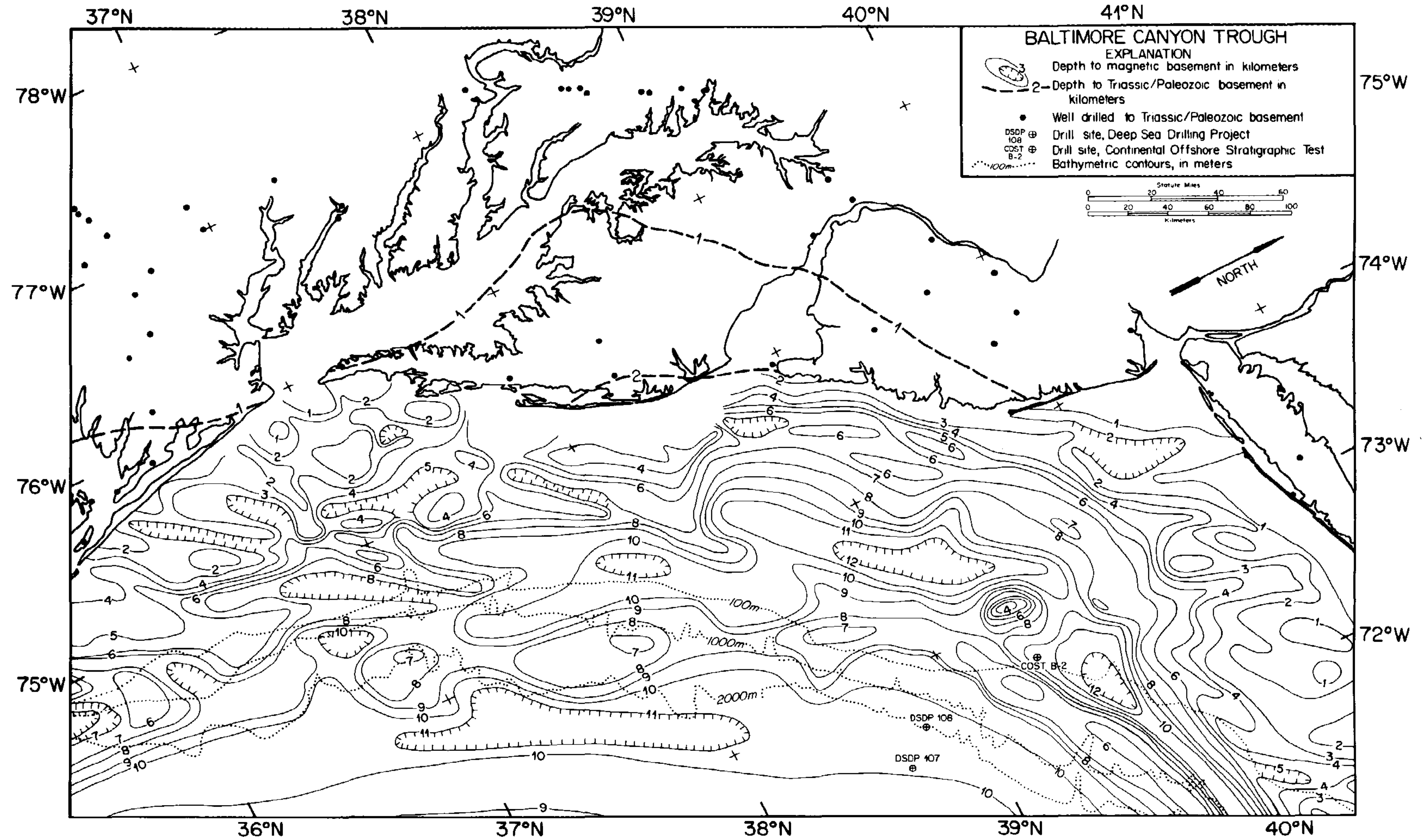

FIG. 12C. Depth-to-basement contours for the Baltimore Canyon trough based on the magnetic depth estimates shown in Figure 12B. Symbols are the same as in Figure 7B.

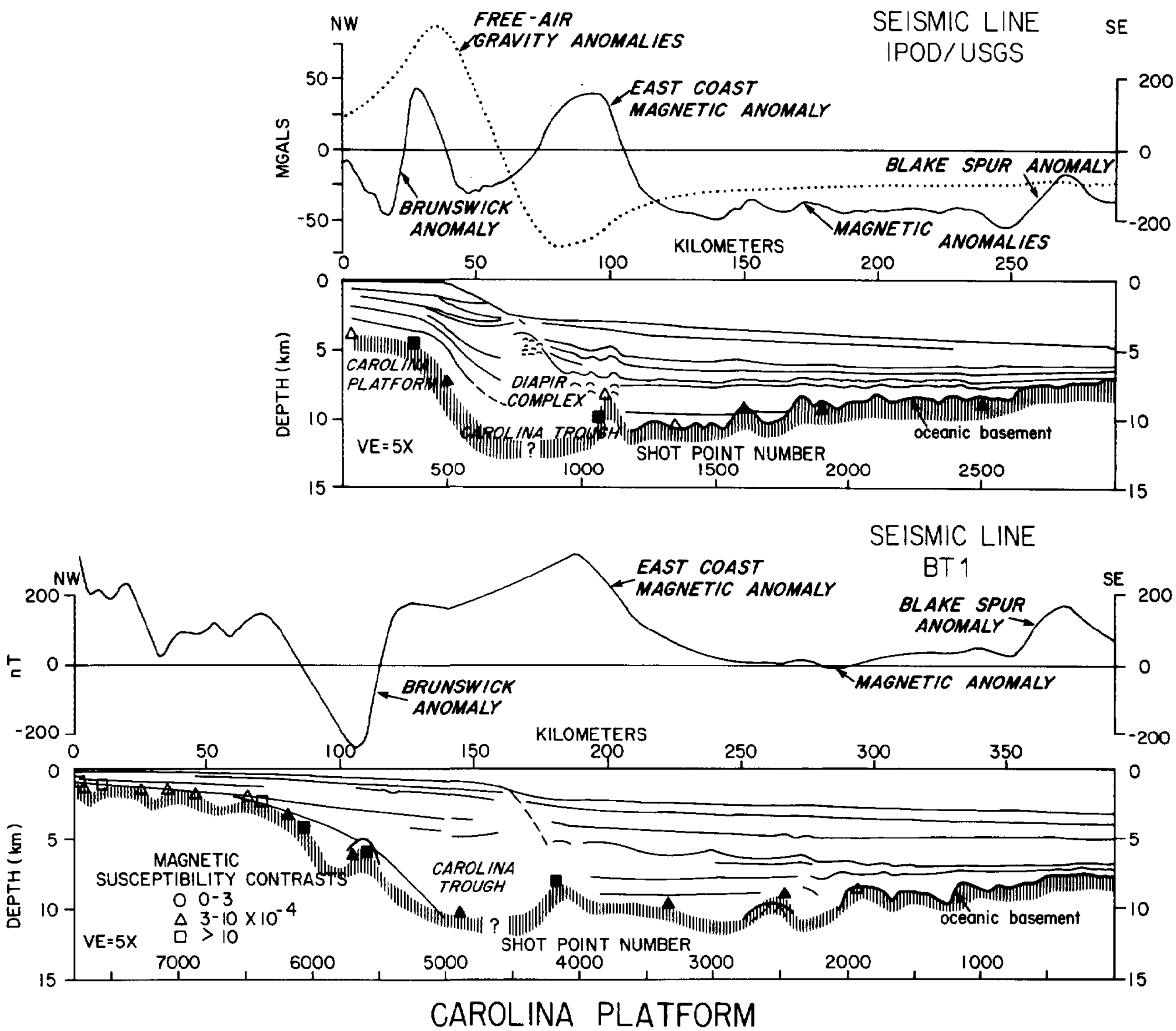

FIG. 13. Comparison between magnetic depth-to-basement estimates and multichannel seismic lines IPOD/USGS and BT-1 (Grow and Markl, 1977; Dillon et al, 1978) over the Carolina platform. See Figure 14B for their locations. Symbols are the same as in Figure 6.

magnetic data and seismic data for line BT1 (shot point 5800 and 5600, Fig. 13). This basement high and trough is found along the entire edge of the Carolina platform south of 34°N lat. (Figs. 14b, 14c) and is similar to the source of the Brunswick magnetic anomaly within Georgia suggested by Popenoe and Zietz (1977) to be Triassic or Early Jurassic in age. Additional multichannel seismic profiles across this region (Fig. 14b) also indicate the presence of this ridge and trough (Dillon and Paull, 1978). Just south of the Brunswick anomaly and west of the COST GE-1 well (Fig. 14a), there is another small basin (Fig. 14c) centered at 30.5°N lat., 80.5°W long. inferred from magnetic depth estimates. It is a triangular-shaped basin about 50 km across, probably of Triassic age, and the main target area for the OCS lease sale 43 (Dillon et al, 1975).

The Carolina trough is the narrowest of the marginal basins and forms one of the most lineated features on the entire U.S. Atlantic margin. As with the basins to the north, its landward edge is probably block-faulted continental(?) crust, while its seaward edge is marked by the East Coast magnetic anomaly.

Blake Plateau Basin

The Blake Plateau Basin is the largest of the sediment-filled basins on the U.S. Atlantic continental margin. The existence of the thick sequence of sediments beneath the plateau has been known for a long time (Hersey et al, 1959; Sheridan et al, 1966; Emery and Uchupi, 1972; Sheridan, 1974), but the base of the sediment pile has been hard to define with either seismic refraction data. This basin was formed during the Jurassic rifting of Africa from

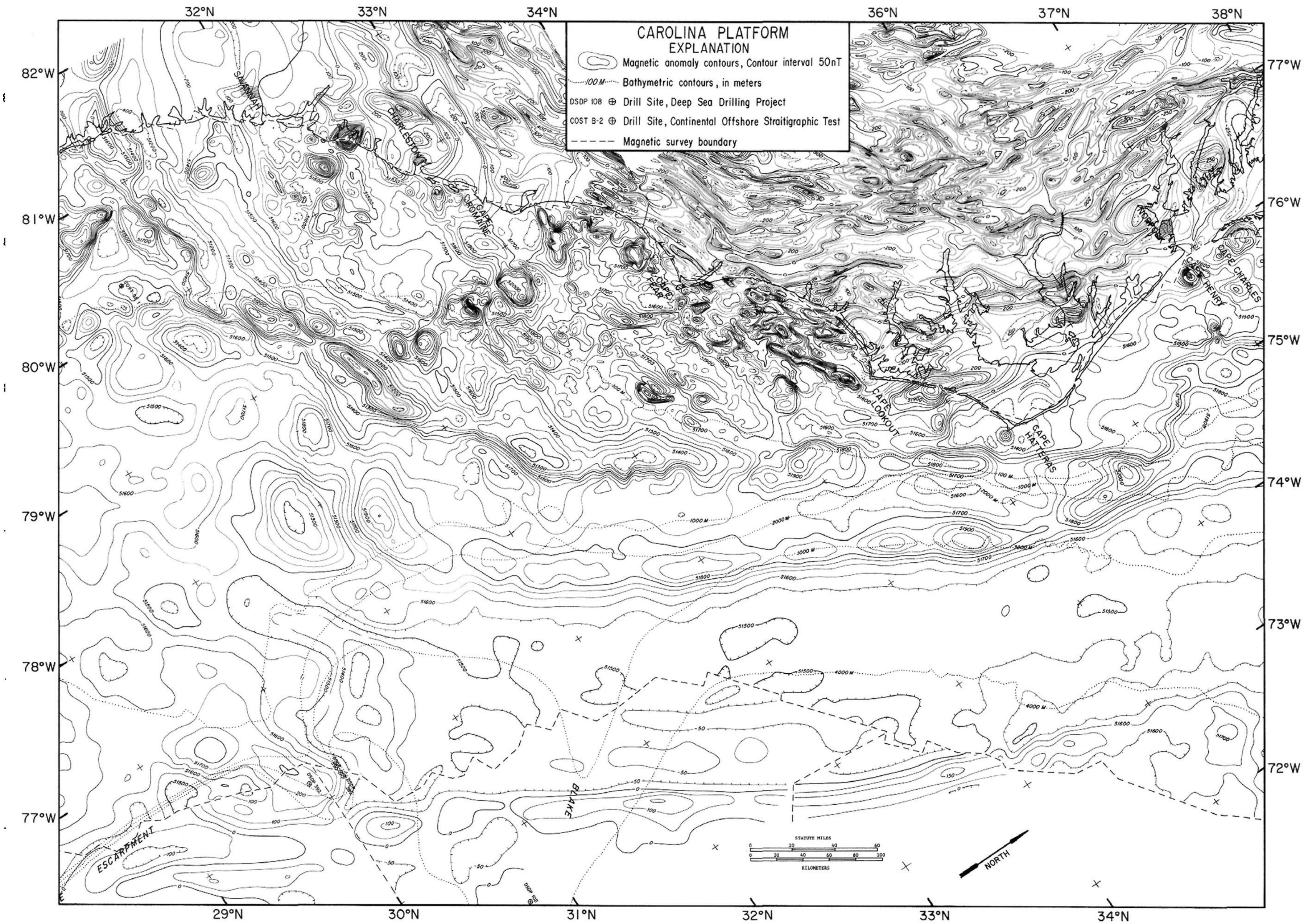

Figure. 14A. Magnetic anomaly contour map for the Carolina platform region. Contour interval is 50 nT.

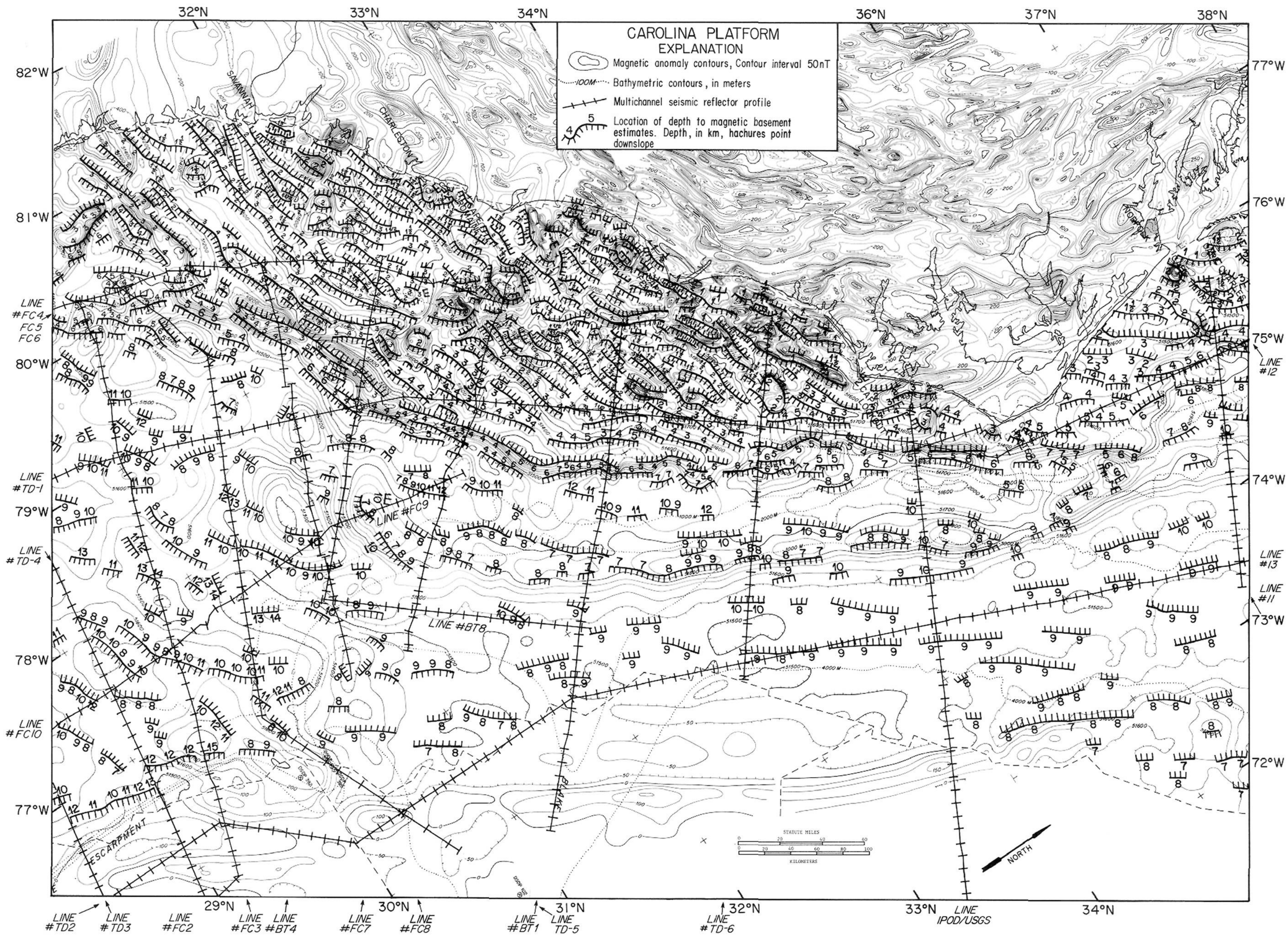

FIG. 14B. Location of magnetic depth estimates for the Carolina platform. The symbols are the same as in Figure 7B.

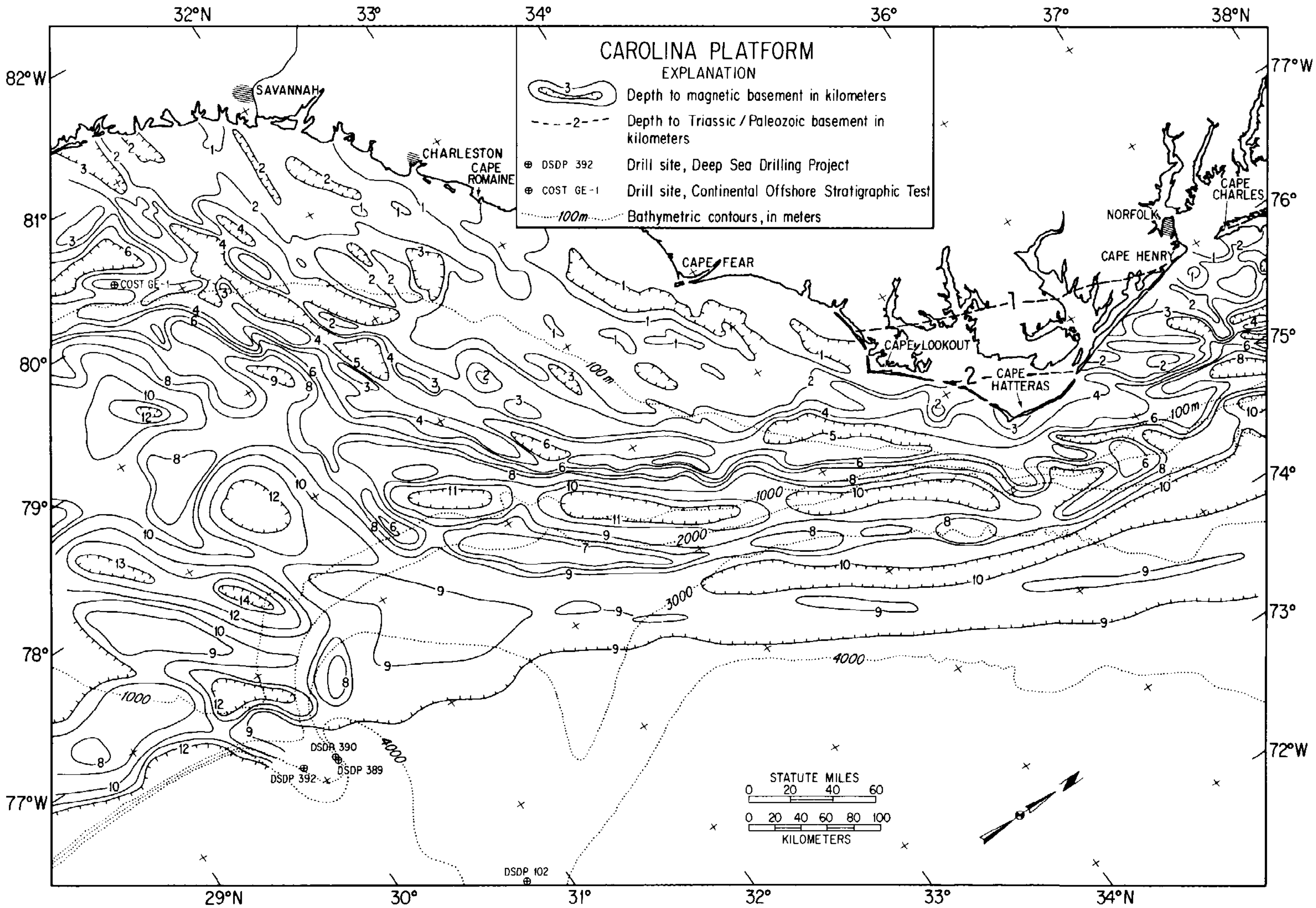

FIG. 14C. Depth-to-basement contours for the Carolina platform based on the magnetic depth estimates shown in Figure 14B. Symbols are the same as in Figure 7C.

North America and is bounded by the Blake Spur fracture zone on the north, the Blake Escarpment on the east, the Florida platform and the Triassic embayment on the west, and the Bahama platform on the south (Fig. 1).

The Blake Plateau Basin is segmented by two fracture zones which can be traced from the offsets in the landward edge of the basin into the deep sea and offsets in the seafloor spreading magnetic anomalies (Fig. 1). The shallowest part of the basin is found between the Bahamas and the southernmost fracture zone within the basin (called the Great Abaco fracture zone by Sheridan, 1974). This is the portion of the basin which has the Florida platform (Barnett, 1975) at its landward edge. The northern two thirds of the basin is the deepest, with more than 10 to 12 km of sediment (Sheridan, 1974), and it has the Triassic basin at 40.5°N lat., 80.5°W long. at its landward edge.

The magnetic depth estimates for the Blake Plateau Basin clearly define the landward edge (Fig. 14b, c) but are very hard to interpret within the basin. There is a scatter in the depth estimates for the deep portion of the basin from 9 km to 14 km (Fig. 14b). The reconstructions of the North Atlantic (Le Pichon et al, 1977; Klitgord and Schouten, 1977) indicate that crust under the Blake Plateau was formed at the same time as oceanic crust was formed to the north. The region may be similar to the Gulf of California where the magma does not extrude onto the seafloor but is intruded within the overlying sediment column, with the magnetic depth estimates picking out these various sills within the sediments.

DISCUSSION

Comparisons of multichannel seismic reflection profiles and magnetic depth estimates (Figs. 6, 8, 10, 11, 13) show that the use of magnetic depth estimates for interpolating between seismic lines is reasonable. The linear block-faulted nature of the landward edges of the various basins is ideal for the Werner deconvolution method of determining magnetic depth estimates. Although some errors exist in the nonunique depth estimates determined by such a method, the results do provide a good regional picture of the relative depths in various areas. The primary reason for this success is the relatively nonmagnetic property of the flat-lying sediments above the basement.

The structure of the Atlantic continental margin consists of a series of platforms and basins (Fig. 1; Maher and Applin, 1971; Emery and Uchupi, 1972; Jansa and Wade, 1975) stretching from the Bahamas to Nova Scotia. From south to north, these features are the Blake Plateau Basin, the Carolina trough, the Carolina platform, the Baltimore Canyon trough, the Long Island platform, the Georges Bank Basin, the LaHave platform, and the Scotian Basin. The platforms have a Paleozoic or older continental basement while the basins probably have a mixture of continental and rift stage crust, covered by Triassic or younger sediments.

The platforms have a distinctive high-amplitude, short-wavelength magnetic pattern which reflects the shallow basement. They also contain smaller basins which have been interpreted as Triassic in age (see Ballard and Uchupi, 1972; Minard et al, 1974; Popenoe and Zietz, 1977) and which have broad magnetic lows associated with them. These platforms tend to be terminated sharply, and the ends probably mark the location of continental to continental transform faults which appeared when Africa and North America split up about 185 m.y.B.P. The seaward edges of these platforms have long and linear magnetic anomalies associated with them. Along the Carolina platform, this large magnetic anomaly is the inner anomaly described by Taylor et al (1968), where their East Coast magnetic anomaly bifurcates near Cape Hatteras (Figs. 3, 14a). Small offsets of the Long Island platform/Gulf of Maine result in a series of en echelon linear magnetic anomalies. The magnetic data along the LaHave platform are fairly sparse but do suggest the presence of a conspicuous magnetic anomaly along the edge of the platform (e.g. Rabinowitz, 1974).

Deep, sediment-filled troughs are found along the entire continental margin from the Bahamas to Newfoundland. The orientation of the axes of all of these troughs suggest that they were all formed by a rifted system having the same pole of rotation. This axial orientation and the orientation of the landward edges of the troughs vary from about 030° in the south to about 050° in the north off Nova Scotia, but the orientation of the seaward edges departs from this pattern. The lengths of the troughs are determined by the locations of the prominent offsets in the continental crust (i.e., the ends of the platforms).

The prominent East Coast magnetic anomaly (Drake et al, 1968; Taylor et al, 1968) is found at the seaward edge of all of the deep, sediment-filled troughs north of the Blake Spur fracture zone. The two major gaps in the East Coast magnetic anomaly are at the southeastern edge of the Long Island platform (where the deep basins pinch out) and at the intersection of the New England Seamounts where the large intrusive body of Bear Seamount drastically alters the magnetic field and the basement shape. The major offsets in the anomaly (Fig. 1) are at offsets in the continental crust along the intersections of associated fracture zones with the margin (Klitgord and Schouten, 1977). A magnetic basement high is indicated by the magnetic depth estimates for the area around the East Coast magnetic anomaly. Oceanic basement can be traced on multichannel seismic profiles almost to the seaward edge of this anomaly (Grow and Schlee, 1976; Schlee et al, 1976), whereas a thick sediment layer (>10 km) is often found just landward of the anomaly.

Seismic reflection profiles over the region of the East Coast magnetic anomaly are characterized by a disturbed zone. An acoustic basement that could be attributed to crystalline/volcanic basement has not been found (Schlee et al, 1976). A ridge feature has been reported at the location of the East Coast mag-

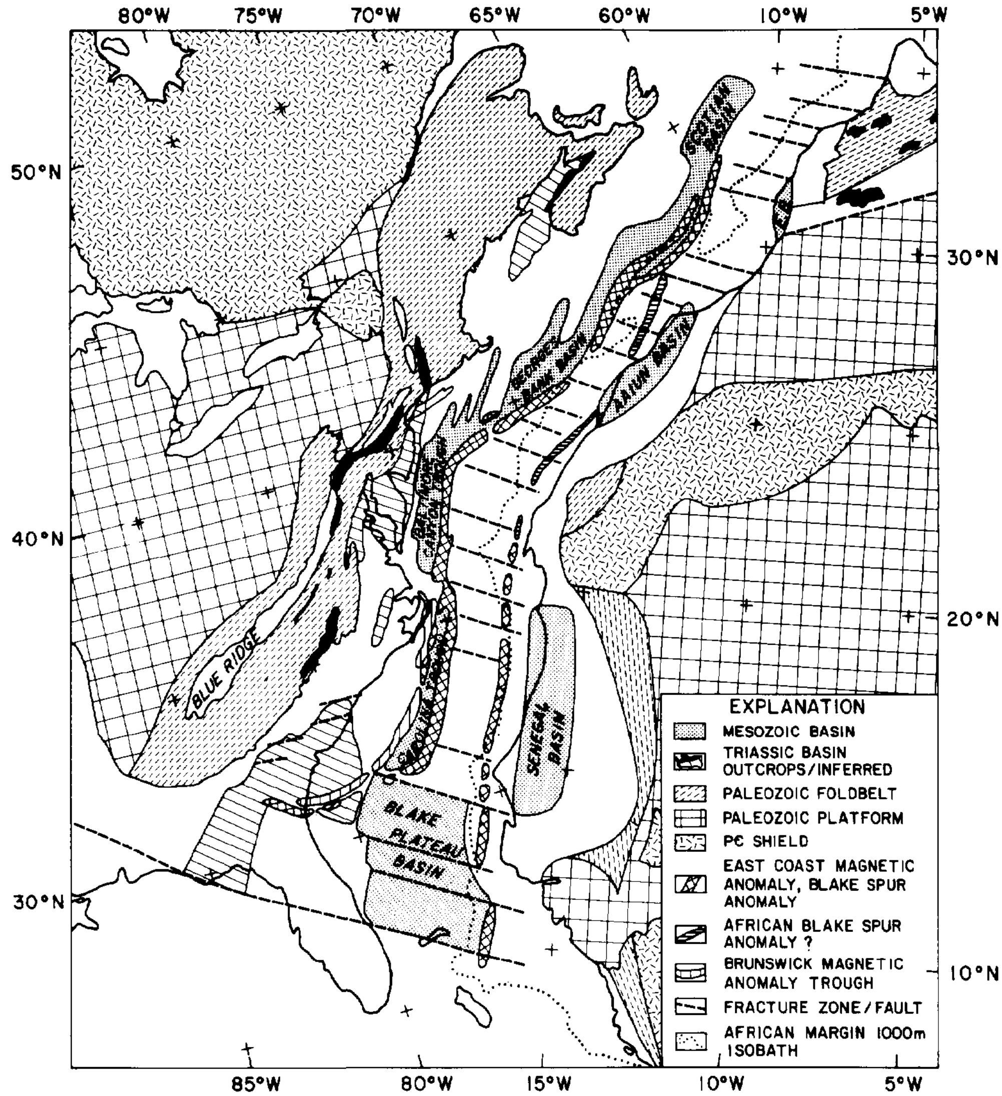

FIG. 15. Reconstruction of the North Atlantic at the time of the Blake Spur anomaly (~175 m.y.B.P.; after Klitgord and Schouten, 1977). Locations of the major sediment filled basins of Mesozoic age are indicated for the African and North American margins.

netic anomaly (Drake et al, 1959; Taylor et al, 1968; Emery et al, 1970; Sheridan, 1974; Schlee et al, 1976; Uchupi et al, 1977). This feature has been interpreted as a basement ridge at a depth of 2–4 km (Drake et al, 1959; Emery et al, 1970; Uchupi et al, 1977), but multichannel seismic reflection data indicate that it is probably composed of carbonate rocks (Sheridan, 1974; Schlee et al, 1976). Magnetic data suggest a basement ridge at about 6 to 8 km, which could be the feature upon which the carbonate rocks accumulated. This interpretation is similar to that suggested by Sheridan (Fig. 8, *in* Sheridan, 1974). The susceptibility contrast of this basement high is much lower than that found for intrusive bodies along the margin (e.g., $>25 \times 10^{-4}$ for the mafic intrusion in the Baltimore Canyon trough). We believe that it is more likely an uptilted block of oceanic(?) crust, the steep landward edge of the block forming the seaward edge of the deep, sediment-filled troughs. The prominent East Coast magnetic anomaly would then reflect a combination of a basement high and an edge effect (Keen, 1969), where the edge is between an oceanic(?) type crust and flat-lying sediments.

The widths of the major basins along the margin range from about 50 km (the Carolina trough) to about 350 km (Blake Plateau Basin), the other three troughs (Baltimore Canyon trough, Georges Bank Basin, and the Scotian Basin southwest of Sable Island) each having a width of about 100 km. This large variation in widths may be a result of the initial rifting process or the later sediment-loading patterns. If the initial rifting stage is important, then the basin pattern on the African side should be related to that of the western Atlantic margin. The broadest basins on one side should be matched by the narrowest basins on the other, with the offsets in the edge of continental crust at the time of rifting controlling the locations.

Reconstructions of the north-central Atlantic (Klitgord and Schouten, 1977; LePichon et al, 1977) show that at least 200 km of oceanic crust still existed between Africa and North America at the time (~175 m.y.B.P.) that the eastern edge of the Blake Plateau was against the continental(?) crust of the Guinea marginal plateau (Fig. 15). This reconstruction places the Blake Plateau adjacent to the part of west Africa that has almost no marginal basin, whereas the small Carolina trough runs parallel with the Senegal Basin (Aymé, 1965), the largest Mesozoic basin on the west African margin. North of Cape Blanc (Africa)/Cape Hatteras (North America), the basin pattern on the African side is not as well known, but basins do exist—the small Aaiun Basin and the Essaouira Basin (Dillon and Sougy, 1974; Van Houten, 1977). The Cape Blanc Paleozoic platform is adjacent to the Baltimore Canyon trough, and the Aaiun Basin is adjacent to the Georges Bank Basin. This relation between the basins on the two margins suggests that there may be a direct correlation between the basin widths on the two sides, but the information concerning the basin sizes on the African margin is too vague.

The locations of the basins and oceanic crust at about 175 m.y.B.P. (Fig. 15) provides evidence for the type of crust beneath some of the basins. The Blake Plateau crust must have been formed by means of at least 200 km of extension at the time that oceanic crust was being generated to the north. This crust could have been rift-stage-type crust or oceanic crust. The nonlinear magnetic anomaly pattern associated with the Blake Plateau is very different from the linear magnetic anomalies associated with oceanic crust just north of the plateau and east of the East Coast magnetic anomaly (Figs. 3, 14a). This nonlinear pattern suggests more of a rift-stage-type crust for the Blake Plateau and a more random location of the zone of intrusion/extrusion than is found for oceanic crust.

CONCLUSIONS

Detailed magnetic studies of the U.S. Atlantic continental margin have yielded valuable information concerning the structure of the margin. The pattern of platforms and deep, sediment-filled troughs is brought out by the magnetic anomaly contour maps and magnetic depth analyses. The integration of magnetic data with multichannel seismic reflection profiles provides a limit on the number of interpretations of the magnetic data and allows the interpolation of basement structures between seismic profiles.

The general basement structure is controlled by sharp horizontal offsets in the continental crust, which were formed during the initial rifting stage. The edges of the platforms are marked by large linear magnetic anomalies. The landward edges of the troughs are of a block-faulted construction; they trend parallel with the basin axes and are formed by an opening about the same pole of rotation. The seaward edges of the basins are identified by the prominent East Coast magnetic anomaly which may be caused by an uptilted block of oceanic(?) crust adjacent to the flat-lying, relatively nonmagnetic sediments within the deep, sediment-filled trough. The major basins are found to be segmented into smaller basins whose locations are controlled by the initial offsets in the continental crust.

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