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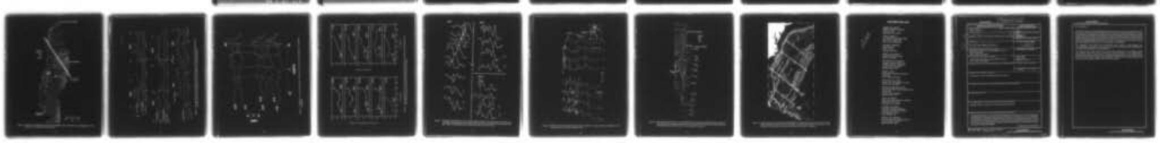

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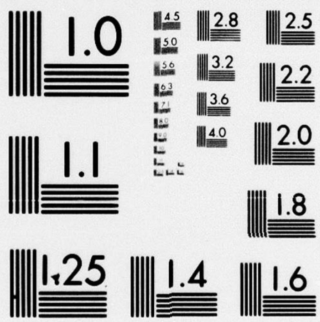

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NORDA Report 16

MAGNETIC PATTERN OF THE WESTERN ATLANTIC SOUTH OF 40°N

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April 1978

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FOREWORD

This report comprises the most comprehensive compilation to date of the magnetic pattern of the ocean floor adjacent to the eastern North American continental margin. The magnetic data were compiled primarily from surveys conducted from 1967 to 1971 by the USNS KEATHLEY, augmented by several smaller-scale surveys. Much of the data, particularly that of the magnetic "quiet zone," have never been published. The magnetic patterns presented will provide a base for further scientific studies, including the opening and early history of the Atlantic and the pre-rift fit of the continents.

C. G. DARRELL
CAPTAIN, USN
COMMANDING OFFICER

EXECUTIVE SUMMARY

The magnetic pattern in the western North Atlantic near the east coast of North America is dominated by a linear region of low magnetic intensities. This magnetic "quiet zone" possesses characteristics of sea-floor spreading: linearity, continuity, and bilateral symmetry with the quiet zone found in the eastern Atlantic. Its small internal anomalies can be shown to have a spatial origin. Some appear linear, but discontinuous, and a degree of correlation can be found over large, intervening distances.

A portion of the quiet zone shows possible subdivision into an inner and outer smooth zone. The inner smooth zone, near the shelf edge, has no counterpart in the eastern Atlantic, and, when considered as the development of a proto-Atlantic, could account for the comparatively greater width of the total western quiet zone. Pre-rift fits of the African and North American continents usually show the African continental margin superimposed on both the inner smooth zone and the unique anomalies of the Blake Plateau which lies to the south. An oceanic origin for the inner smooth zone implies the same origin for a major part of the Blake Plateau.

The magnetic zones show little relationship with present current-shaped seafloor topography, but offsets in the lineations of prominent anomalies attest to displacements in the rock floor beneath the sediments.

The detail of this survey, which shows north-south differences in the magnetic quiet zone, possible fracture locations, and areas of amplitude diversity on the Blake Plateau, provides a good base for many studies, including the characteristics of the underlying rocks, the pre-rift fit of the continents, and for comparison with the magnetic patterns in the eastern Atlantic near the African margin.

ACKNOWLEDGEMENTS

We thank Robert Higgs and Otis Avery of the Magnetics Division, U.S. Naval Oceanographic Office (NAVOCEANO), for the loan of a voluminous amount of original data. We are also grateful to Louis Hemler, Naval Ocean Research and Development Activity (NORDA), for his patience and perseverance in the long and tedious processing of the complex material. B. Grosvenor, R. Edman, and C. Fruik, formerly with NAVOCEANO, prepared the illustrations. Brenda Wells and Linda McRaney typed the manuscripts. To all, our heartfelt thanks.

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

The magnetic pattern of the western Atlantic adjacent to eastern North America is dominated by a parallel region of low magnetic intensities. Here, anomaly peak-to-trough differences of less than 50 gammas (γ) occur in a "smooth" or "quiet" zone some 300-500 km wide, in contrast to the larger differences of 100-300 γ which typify the magnetic field to the east.

Numerous hypotheses have been proposed for the existence of quiet zones and need no further discussion here (Heirtzler and Hayes, 1967; Taylor and others, 1968; Drake and others, 1968; and Drake and Nafe, 1967).

The quiet zone near North America has been found to be one of a pair which lie on opposite sides of the Atlantic (Heirtzler and Hayes, 1967; Drake and others, 1968); the western zone appears to be wider. The proximity of the zones to the continents, their dual nature, and their bilateral symmetry with the mid-Atlantic Ridge argue strongly for their formation by sea-floor spreading as the first and most ancient parts of the Atlantic Ocean.

Almost all information about the basement rock from which the small anomalies derive has been obtained primarily from geophysical data such as gravity, magnetics, and seismic refraction and reflection records. There is little direct knowledge of its character because a blanket of sediments ranging up to more than 14 km in thickness (Schlee and others, 1976) covers the entire continental margin and its bordering ocean-basin. At the seaward border of the zone where the sediments are thinner, drillling recovered basalt beneath Upper Jurassic sediments (Ewing and others, 1970), which indicates a time of about 150 MYBP for the close of the quiet zone period. Extrapolation from this age places its beginning at about 180 MYBP. This date is highly uncertain because the location of the continent-ocean boundary has not yet been identified with confidence. Initiation of the rifting process probably began as early as late Triassic, as evidenced by the block-faulting and igneous intrusions which took place in eastern North America at that time.

As yet, some of the most important clues to the history of the early Atlantic have been provided by the wealth of magnetic data.

II. DATA

The comprehensive magnetic surveys presented in this study (Fig. 1) were conducted by USNS KEATHLEY of the U.S. Naval Oceanographic Office (NAVOCEANO) from 1967 to 1971; these have been augmented by data from other surveys by the same office.

The data were computer-processed except where noted, with the removal of the earth's present field based on the International Geophysical Reference Field Tables (IGRF-65). No attempt was made to remove diurnal effects.

Profiles of residual intensities were mechanically plotted on track locations (Fig. 2); only east-west survey lines were utilized.

III. MAGNETIC PROFILES

The profiles in Figure 2 show that the magnetic pattern near the coast is not a simple one. The quiet zone here is wider than that seen near northwest Africa, and moreover, differs within itself from north to south. Although the quiet zone is obvious in Figure 2 because of amplitude contrasts, at this scale (which was chosen to accommodate the larger anomalies), internal details of the zone are scarcely visible. In Figure 3, the small anomalies are shown more clearly through the exaggeration of vertical scales.

First investigations concerned the spatial origin and permanence of the quiet zone anomalies. Because daily variations in the earth's magnetic field often exceed the dimensions of the small anomalies, their effects must be considered, even though the nature of these surveys does not readily allow their removal. A few selected survey profiles were compared with records of daily variations on corresponding days at Fredericksburg, Virginia, and San Juan, Puerto Rico. Figure 4 shows that quiet zone wavelengths are much smaller than those of the daily variations and appear to ride as smaller waves on their crests. It is also obvious that attempts to contour quiet zone data without the removal of diurnal effects would be meaningless. Evaluation of the influence of continental (Fredericksburg) vs. oceanic type (San Juan) variations on the quiet zone anomalies is unproductive.

The spatial origin of the small anomalies is evidenced also by the fact that identical anomalies appear in the same locations on overlapping lines of the KEATHLEY, KELLAR, and MIZAR surveys, even though the data were collected, not only at different times of day, but also in different years.

The sea-floor spreading characteristics of anomaly linearity, continuity, and correlation are minimal within the quiet zone. Some anomalies appear linear, but discontinuous. The most lengthy correlation extends for only about 90 km, although the comparison of several widely spaced profiles in Figure 5 suggests that correlatable relationships may exist over a distance of more than 550 km. Barrett and Keen (in press) have also found lineations in the quiet zone north of the Kelvin Seamount Range.

Because the quiet zone, as outlined by larger anomalies, possesses a linearity and continuity that is consistent with sea-floor spreading tenets, several tests were devised in an effort to detect further uniformities within the zone itself.

A running average of peak-to-trough amplitude was calculated for each track; a few are shown in Figure 6. The results demonstrate an average difference of 25 γ within the zone, which increases slightly to the north and rises gradually, not abruptly, through the "smooth-rough" transition zone to the larger KEATHLEY anomalies (Vogt and others, 1970) to the east.

Plots of running averages that were made for the number of anomalies in a given distance (Fig. 6) also show an increase to the east. If the anomalies are assumed to be reversals, this could denote either a decrease in spreading rate or an increase in reversal rate. Undefined fractures could account for occasional irregularities in the generally similar graph patterns. The argument for reversals in the quiet zone is further advanced by Barrett and Keen (in press), who postulate two narrow zones of reversed polarity near its seaward border in their study area to the north. They also conclude that the observed magnetic field may be matched by a field computed from the basement topography and the Jurassic pole.

Strike calculations, which were made on a few linear anomalies in the zone, show an average direction of N23° E south of Cape Hatteras, which changes northward to N18° E for a short distance, then to N40° E. These changes correspond to the curvature of the coastal bight north of Cape Hatteras. A line may be drawn which approximates the points where anomaly strikes change to N40° E; its direction is about N55° W, which may be inferred as the spreading direction.

Larger anomalies define both borders of the quiet zone. The seaward or younger boundary is marked along the entire length by the KEATHLEY sequence. Following the nomenclature of Larson and Pitman (1972), who later discovered this same sequence in the Pacific, "M25" has been designated as the quiet zone border anomaly. In addition to good identification, the smooth-rough transition zone between the quiet zone on the west and the KEATHLEY sequence to the east is observed to occur with three repetitive expressions (Fig. 7).

The landward boundary is more complex. The large east coast anomaly (Taylor and others, 1968) approximates the shelf edge, although they do not always coincide. At 26°N, this anomaly seems to bifurcate, becoming two parallel anomalies which continue south for a time to about 31°N. Here, the landward branch, accompanied by a large minimum, curves westward into the continent, while the seaward branch becomes obscure.

The profiles show that the quiet zone in that area may be divided into two parts, separated by the Blake Spur anomaly (Taylor and others, 1968). This anomaly extends northeastward from the topographic Blake Spur to about 34° N and possibly southward for a short distance along the seaward side of the Blake Plateau. Its existence north of 34° N is uncertain, although a few large and seemingly random anomalies may be its continuation. The "inner smooth zone" thus formed between the Blake Spur and east coast anomalies contains at least two small linear anomalies with peak-to-trough amplitudes of 30-50 γ and wavelengths of 50-100 km; both measurements are slightly larger than those in the rest of the quiet zone. This singular band of small anomalies which borders the shelf has not, as yet, been found in the eastern quiet zone or anywhere else in the Atlantic. Comparison of the widths of the quiet zones on both sides of the ocean show that the inner smooth zone could account for the greater width of the western zone.

This division of outer and inner smooth zones differs from that of Rabinowitz (1974), who proposes a separation of the quiet zone into continental and oceanic components based on gravity data. His boundary, which he calls anomaly "E", falls in the small anomalies of the inner smooth zone just west of the Blake Spur anomaly.

The magnetic pattern differs north and south of about 34°N. North of this point, recognition of the inner smooth zone and the Blake Spur anomaly is questionable. Part of the problem may have a mechanical origin: the decreased angle between the east-west tracks and the strike changes which take place in the bight make identification of the small inner smooth anomalies problematic. Too, anomaly verification is often difficult in a bight.

Seismic profiles (Schlee and others, 1976), however, now show that an oceanic basement underlies this projected continuation of the inner smooth zone. The seaward extension of multi-channel U.S. Geological Survey seismic lines across the continental shelf, slope, and rise by single-channel seismic lines to DSDP Hole 105 show a gently undulating, hummocky, acoustic basement which can be traced from the drill hole where it lies under 1.13 km of sediment to within 65 km of the base of the continental slope, where it is lost under more than 7.5 km of cover.

To the south, the inner smooth zone abruptly terminates at the northern edge of the Blake Plateau, which lies in its path. Reconstructions of the original fit of North America and northwest Africa by Bullard (1965), Dietz (1970), and Le Pichon and Fox (1971) produce an overlap, not only of the Blake Plateau, but also of the inner smooth zone. Therefore, if the inner smooth zone is oceanic, the same could be implied for the Blake Plateau. This agrees with proposals which hold that the Blake-Bahama carbonate platforms were laid down on subsiding Mesozoic oceanic crust (Dietz, 1970).

In Figure 8, selected profiles constructed from aerial magnetic survey lines (Taylor and others, 1968) show the changes which take place in the anomalies from the edge of the continent, across the shelf, and out to sea; the inner smooth zone wavelengths and amplitudes appear to be more like those of the outer quiet zone. Upward continuation studies by Taylor and others (1968) also argue against their origin from deeply buried continental rocks, and show that it would take unreasonable depths of more than 15 km to flatten continental anomalies to the small amplitudes found in the quiet zone.

Given the apparent relationship of the Blake Plateau and the inner smooth zone as shown by the fit of the continents, absence of their counterparts in the eastern Atlantic suggests a different and separate history. Vogt (1973) has proposed that the inner smooth zone bordering North America may stem from a proto-Atlantic formed by early sea-floor spreading, with a subsequent "jump" of the ridge. Assuming that the coast anomaly represents an intrusive body which marks the edge of the continent, he postulates that this anomaly, together with its component which is sometimes found near the African shelf (Rona, 1970), and the Blake Spur anomaly in the western Atlantic may derive from surviving slivers of the early magmatic intrusion into the new rift. This would explain the nonappearance of the inner smooth zone near the African coast and the discrepancy in the distances from the present ridge to each continent, but it does not explain the unique magnetic pattern of the Blake Plateau.

In Figure 9, profiles across the Plateau show irregular anomalies that correlate poorly and bear little similarity to other anomaly patterns seen in this survey. On the whole, anomaly wavelengths are larger than those in the other areas, and peak-to-trough amplitudes exceed those in the quiet zone.

The appearance of greater magnetic intensities in the landward and southern areas of the Plateau could possibly denote the presence of underlying continental rocks, a possibility which might be resolved by a more accurate pre-rift fit of the continents.

Of still unknown significance is the fact that the truncation of the inner smooth zone, the curving of the landward branch of the east coast anomaly into the continent, and the disappearance of its seaward branch all occur in the same vicinity. The quiet zone to the east does not share these complications, but continues its southerly path to the Bahamas beside the scarp which marks the eastern edge of the Plateau.

IV. OTHER GEOLOGIC IMPLICATIONS

As a whole, the magnetic pattern of the zones in the western Atlantic seems to bear little relationship to the present current-shaped topography. The zones cut across most bathymetric structures (Fig. 10), although a few major features seem to approximate the spreading direction. Offsets in the lineations of larger anomalies indicate the probable presence of fracture zones. Although the Blake Spur anomaly continues unbroken across the prominent Blake-Bahama Ridge, it is displaced just south of that structure, and a conspicuous offset occurs in the western edge of the quiet zone in the vicinity of Abaco Canyon. Similar offsets are found in the KEATHLEY anomalies to the east. Although it is difficult to trace fractures across the quiet zone, the presence of similar offsets on both sides of the zone supports the concept of two left-lateral offsets in the basement beneath it, whose direction generally parallels the early spreading direction (Sheridan and Porter, 1971).

The locations of other interruptions and certain irregularities which occur in the magnetic lineations imply that some of the topographic canyons may be similarly related to fracture zones or other basement dislocations, particularly in the Hatteras and Abaco Canyon areas. The Blake Spur anomaly is uniquely accompanied by two other large anomalies only where it crosses these canyons. The east coast anomaly lineation is also disturbed, not only in these canyon areas, but also in the Hudson and other canyon vicinities in the coastal bight north of Cape Hatteras. Possible basement structural controls of these canyons may have persisted despite deep burial under the sediments through long, slow, continuous movement. This mechanism is suggested by the fact that the east coast is not totally seismically quiescent; many earthquakes have been recorded, even in recent times (King, 1970), including one in the vicinity of Baltimore Canyon.

Support from other data for these speculations is mostly lacking; seismic refraction data which could best support or disprove hypotheses for deeply buried basement structures are sparse and widely spaced.

V. CONCLUSIONS

Further interpretation and understanding of the magnetic pattern of the sea floor near eastern North America and the early history of the Atlantic Ocean involves study from two aspects. Because of its intermediate position between the continent and the marine areas where sea-floor spreading origins are more obvious, its history is linked to both. Its inception is intricately bound to complex events on the continent which immediately followed the final rifting.

As half of the first Atlantic sea floor, the details of its distinctive areal patterns may be compared with those of its counterpart in the eastern Atlantic. Its unique characteristics include north-south anomaly amplitude differences in the quiet zone; possible fractures, which are shown by dislocations in anomaly lineations; differentiation in anomaly amplitudes on the Blake Plateau; and changes in lineation strikes. One such change in strike has already been noted in the eastern Atlantic (Hayes and Rabinowitz, in press). The identification and matching of these features on both sides of the ocean will further reinforce the argument for a sea-floor spreading origin of the quiet zones. In addition, the details of the magnetic pattern in the western Atlantic will provide a sound base for a more accurate pre-rift fit of the continents.

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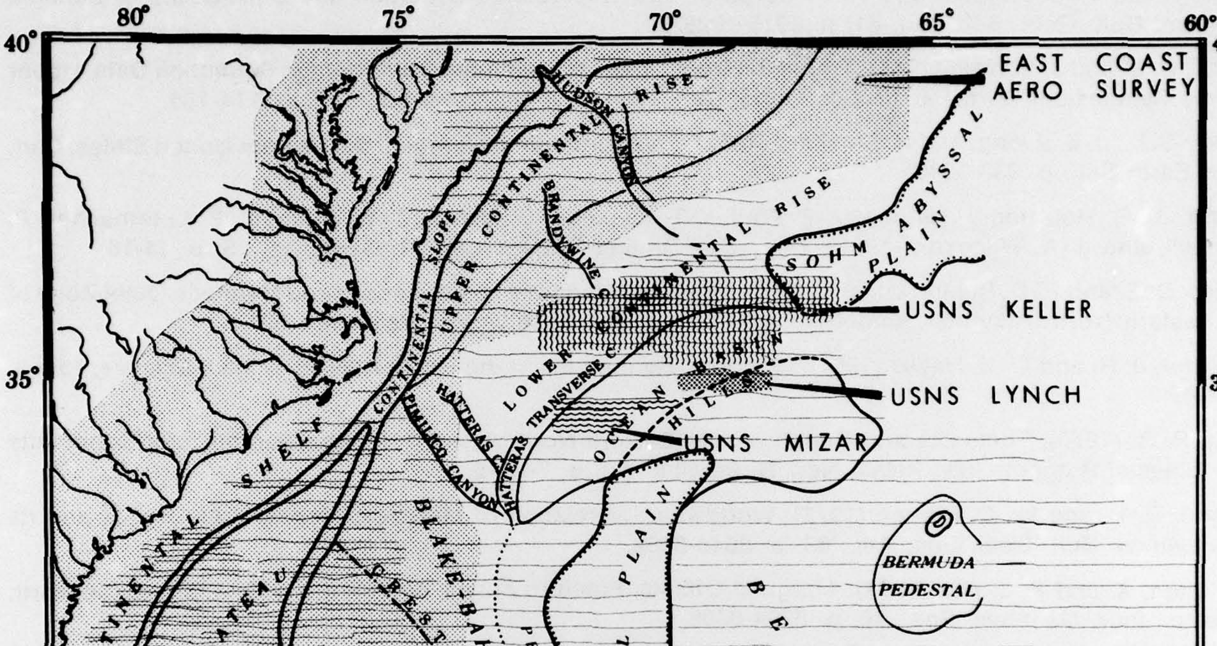

Figure 1. USNS KEATHLEY tracks and other surveys near the east coast of North America.

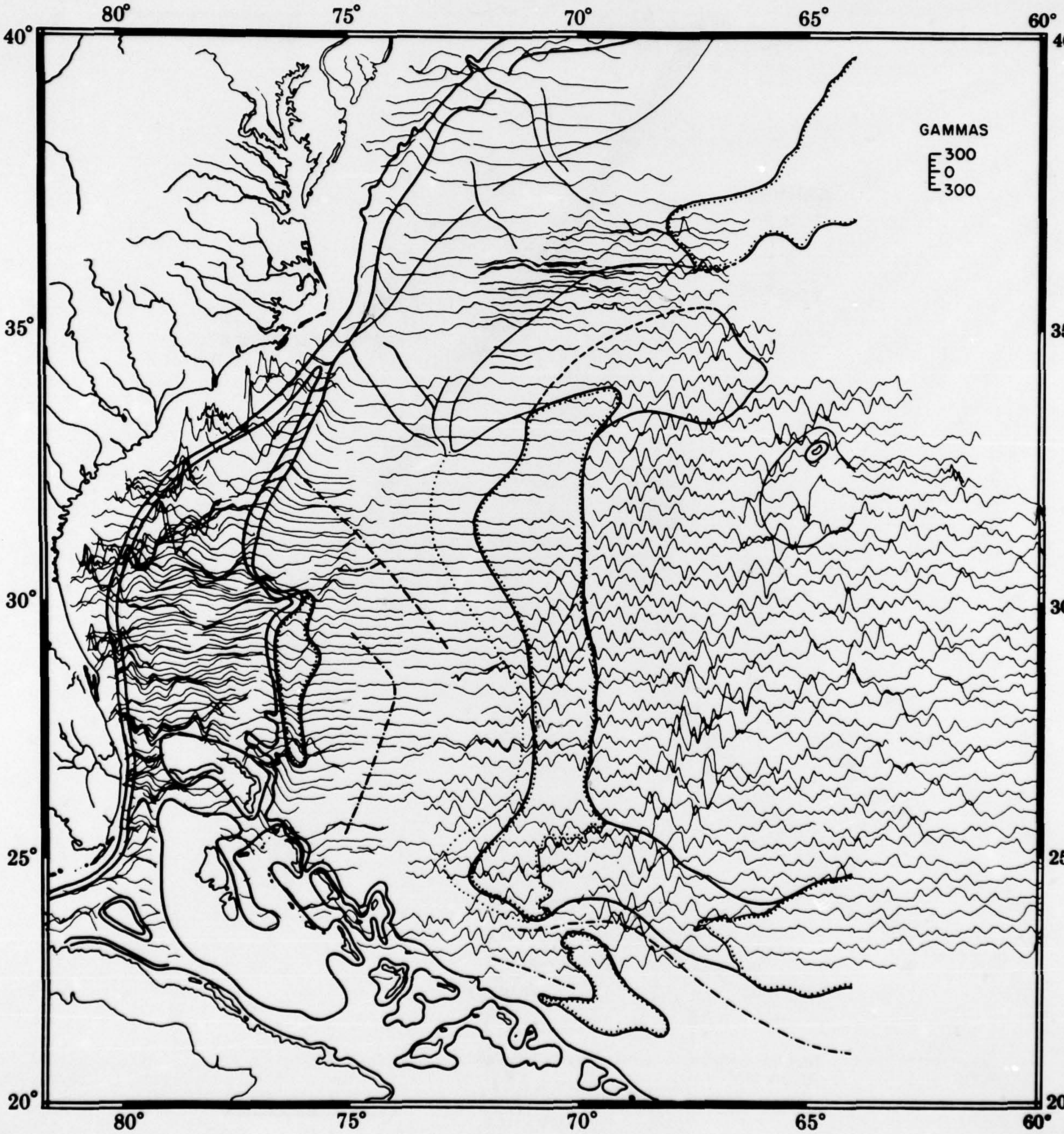

Figure 2. Profiles of residual magnetic intensities plotted on the tracks shown in Figure 1.

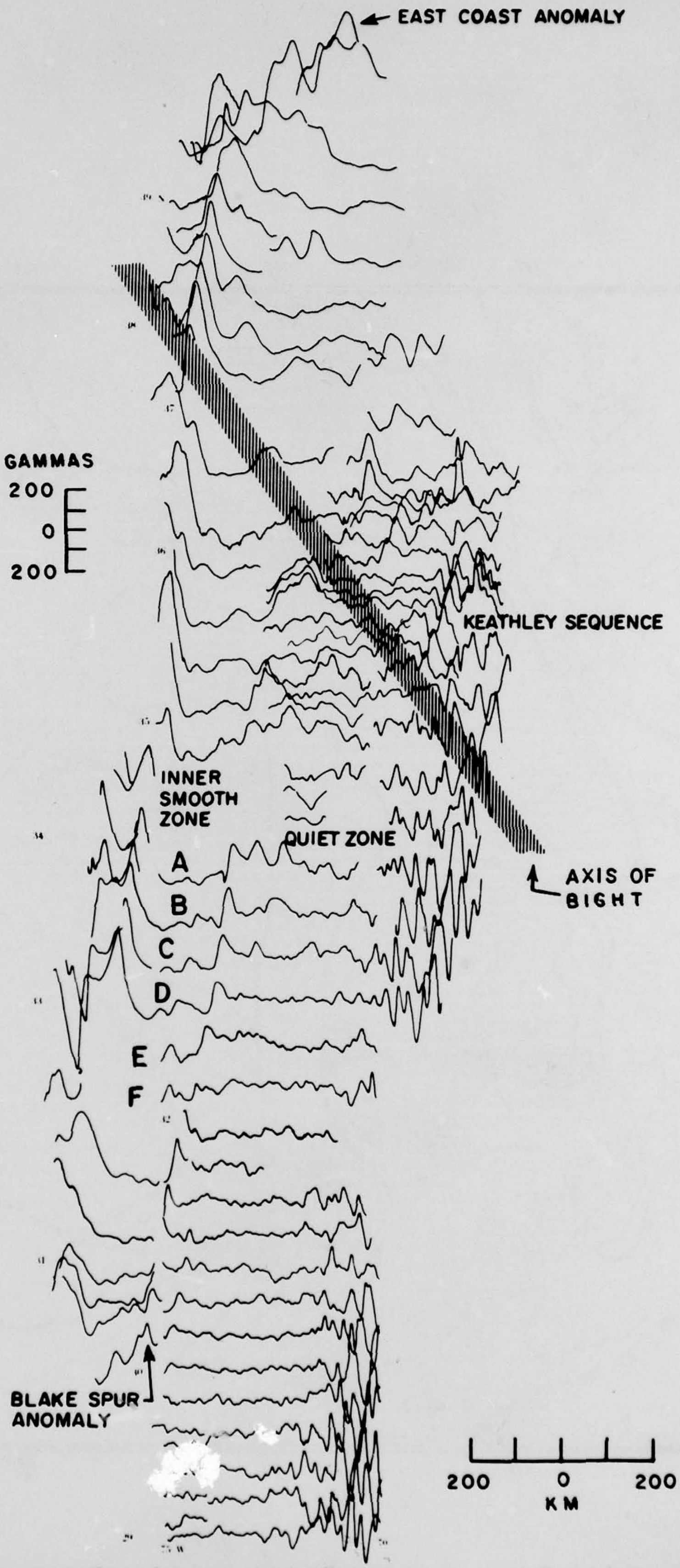

Figure 3. Details in the magnetic quiet zone and adjacent areas, amplified by the exaggeration of the gamma and north-south distance scales.

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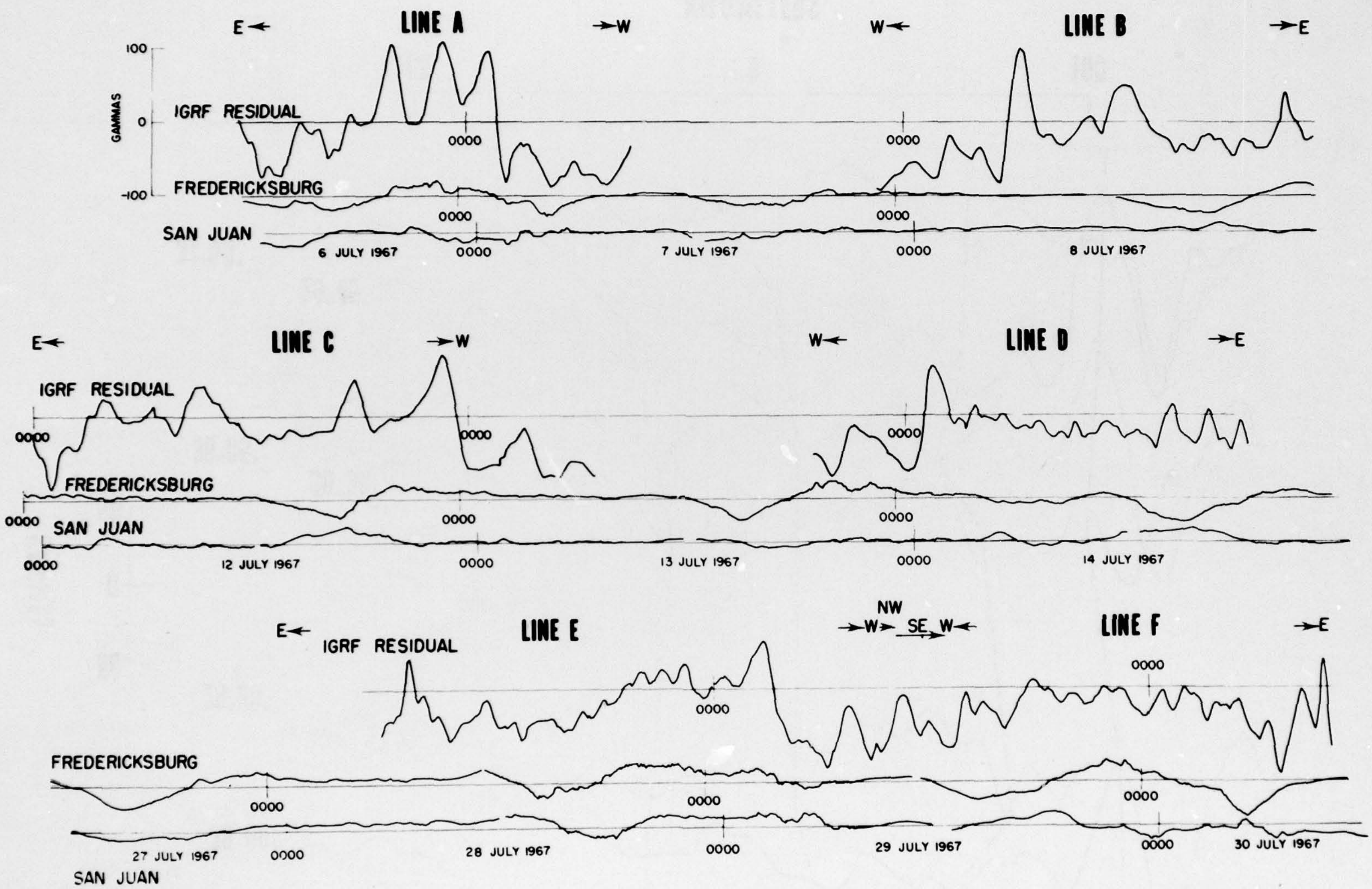

Figure 4. Comparison of time-true magnetic profiles with records of daily variations at Fredericksburg, VA, and San Juan, PR; all times shown are UTM, shifted for longitude differences.

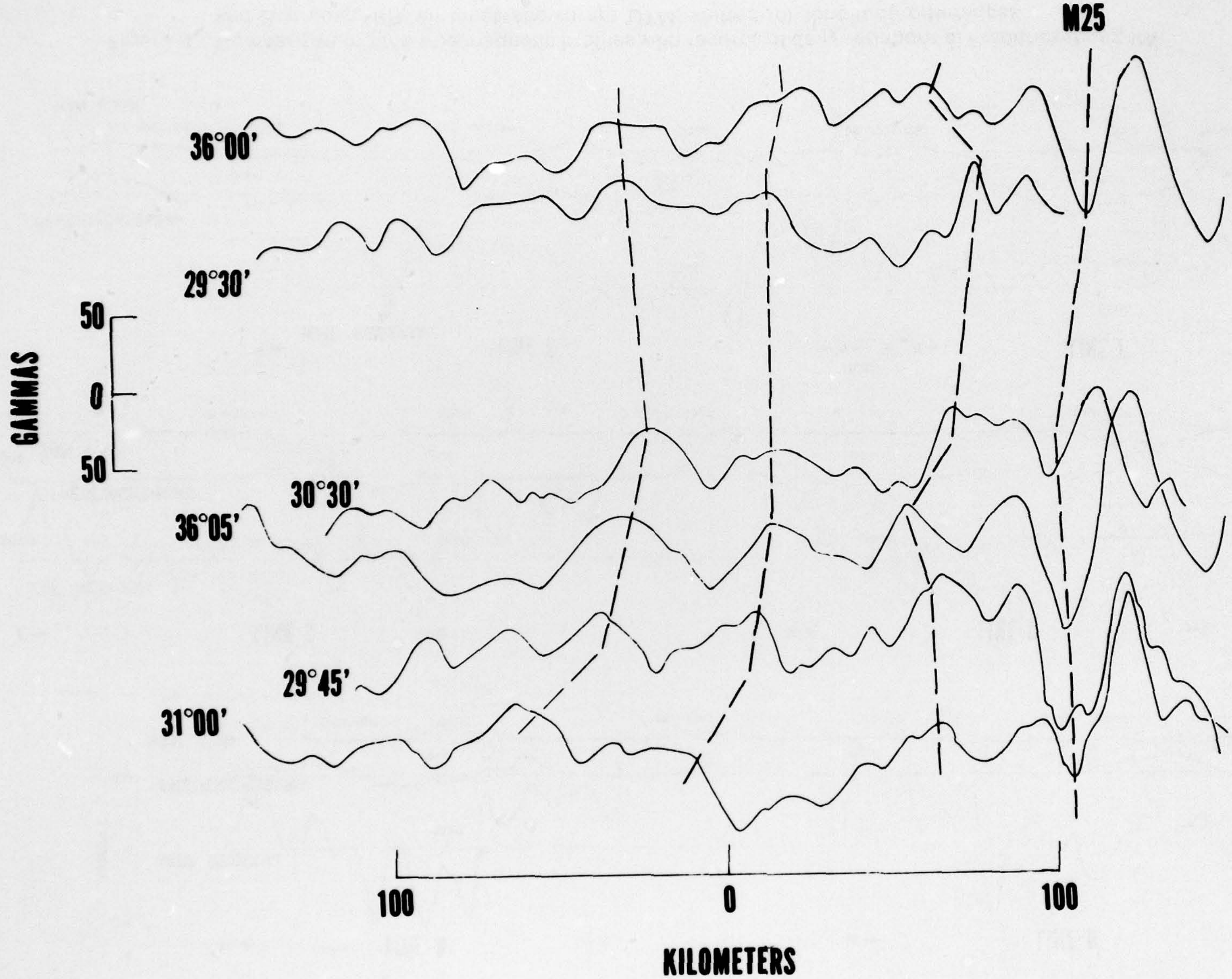

Figure 5. Correlation in quiet zone profiles; north-south order has been rearranged to accentuate similarities.

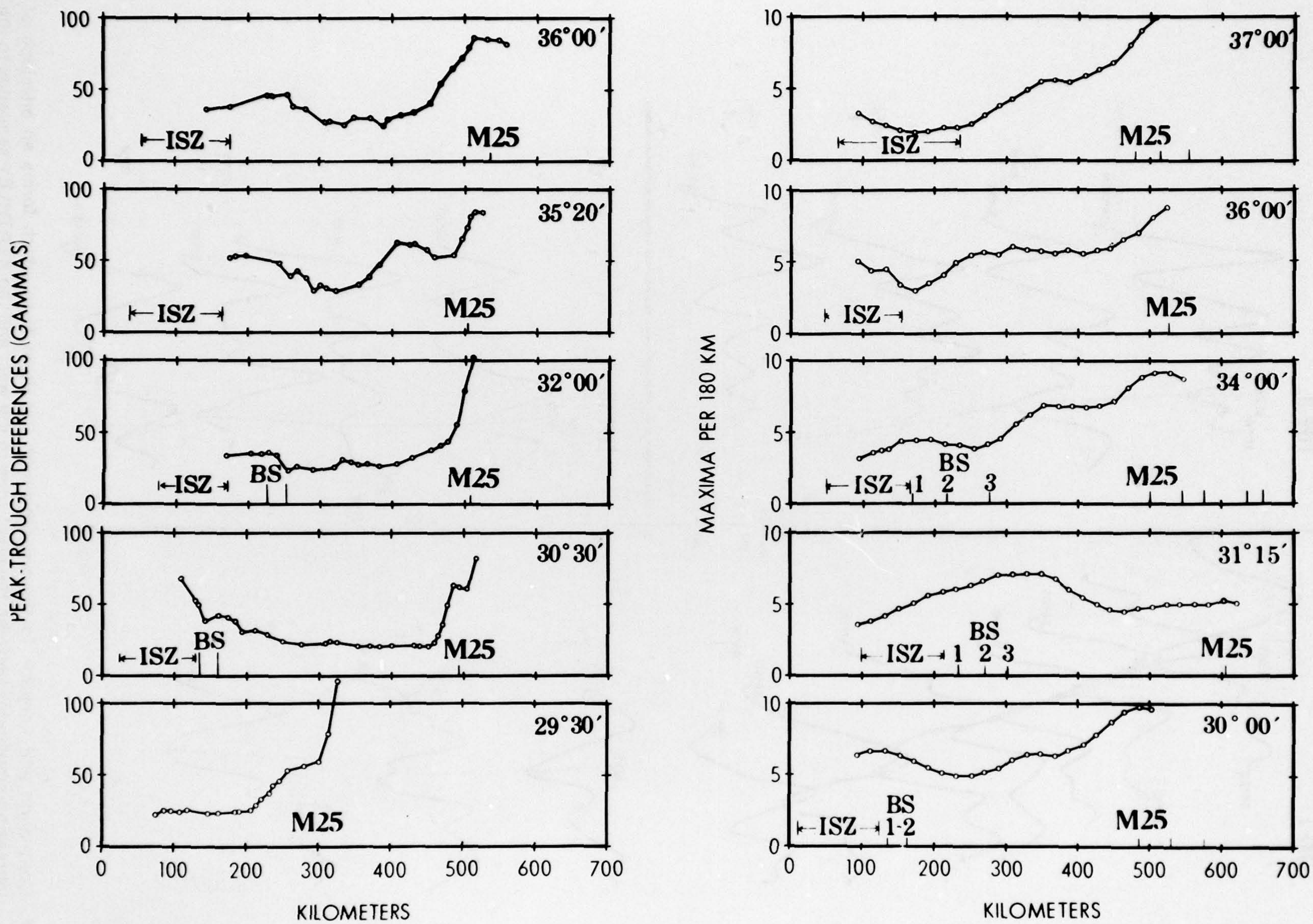

Figure 6. A few selected plots of running averages across the quiet zone; the east coast anomaly is zero, ISZ is the inner smooth zone, BS is the Blake Spur anomaly.

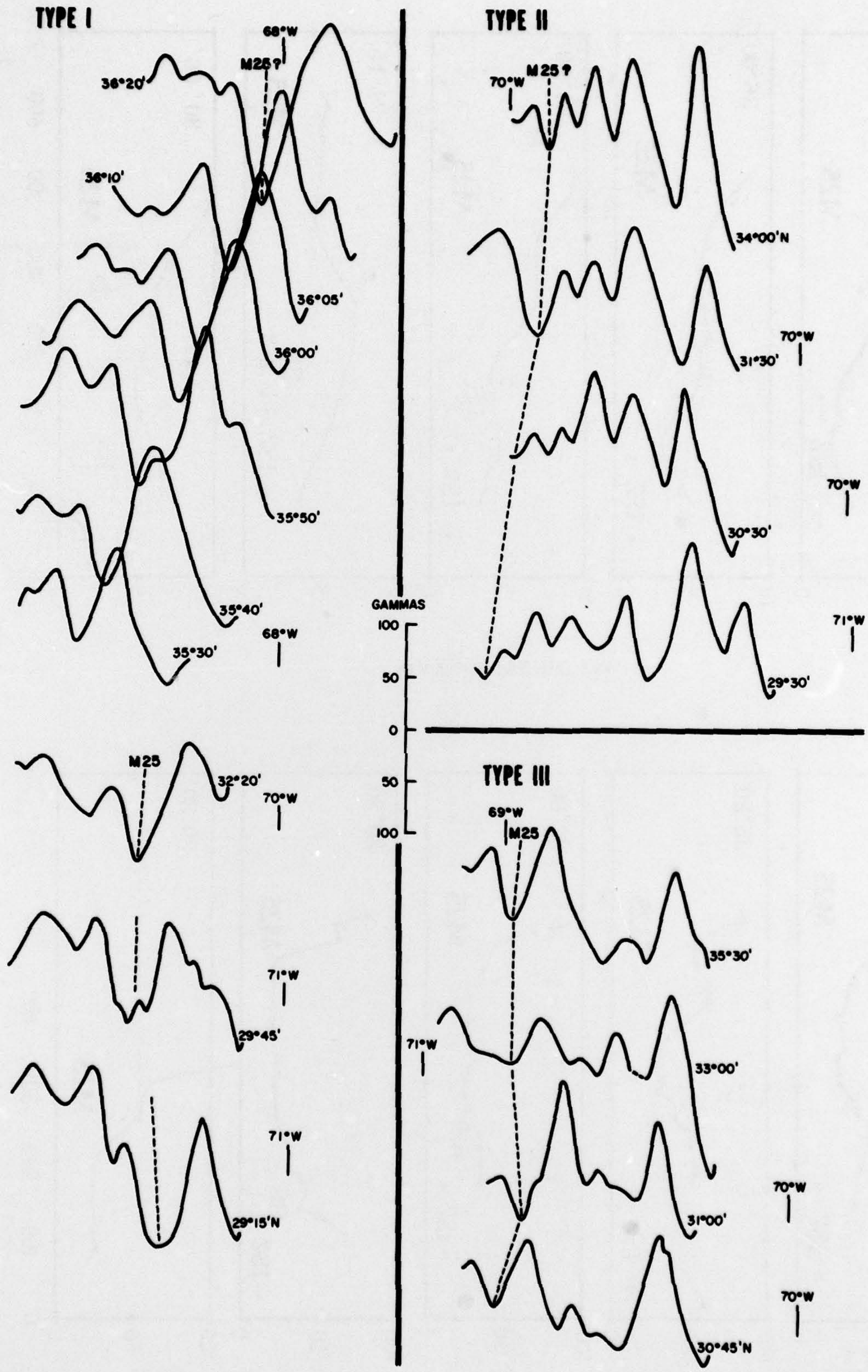

Figure 7. Correlation and lineation in the smooth-rough transition zone which forms an envelope of increasing amplitudes between the quiet zone to the west and the KEATHLEY sequence to the east; "M25" is considered to be the border anomaly of the quiet zone.

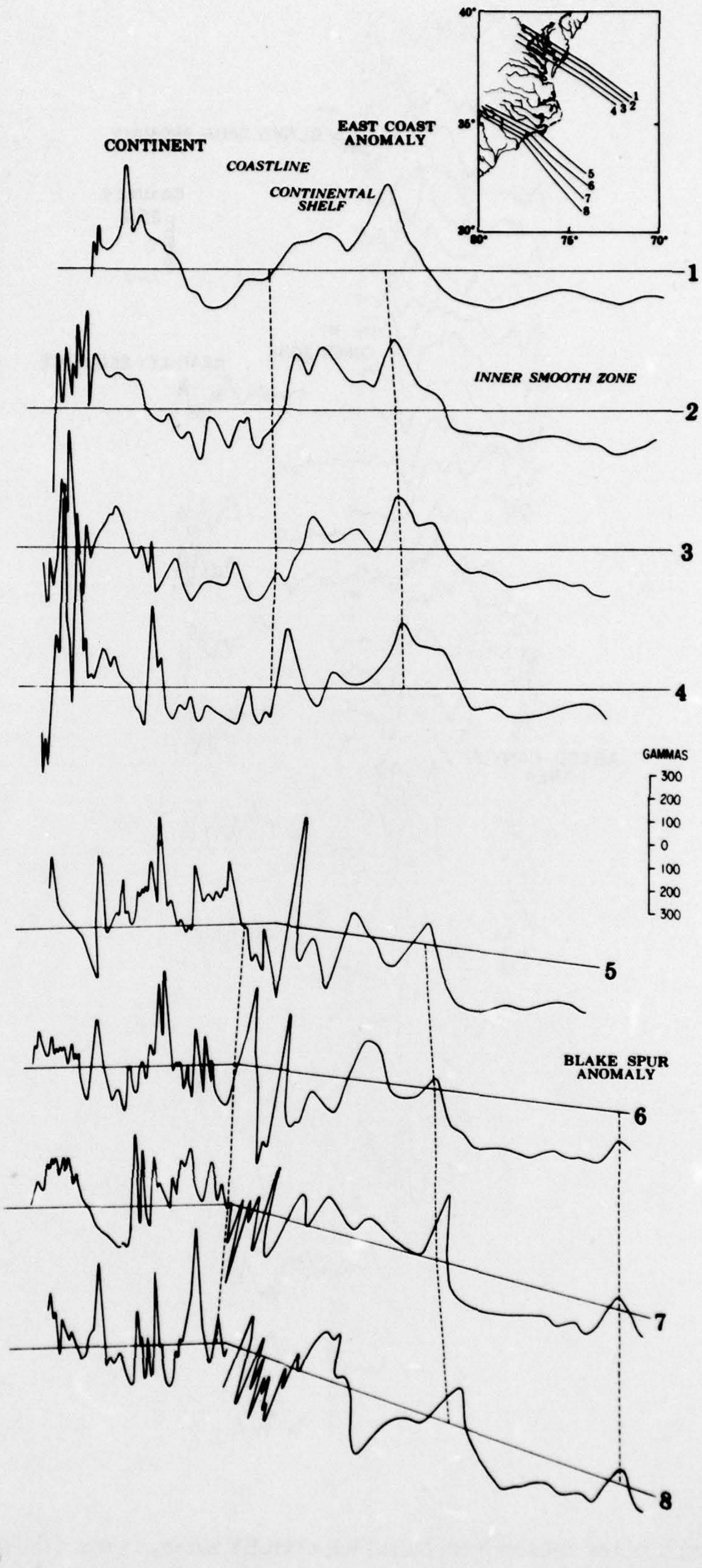

Figure 8. Profiles from the east coast airborne survey, plotted from contour charts on flightlines, with manual removal of the earth's present field.

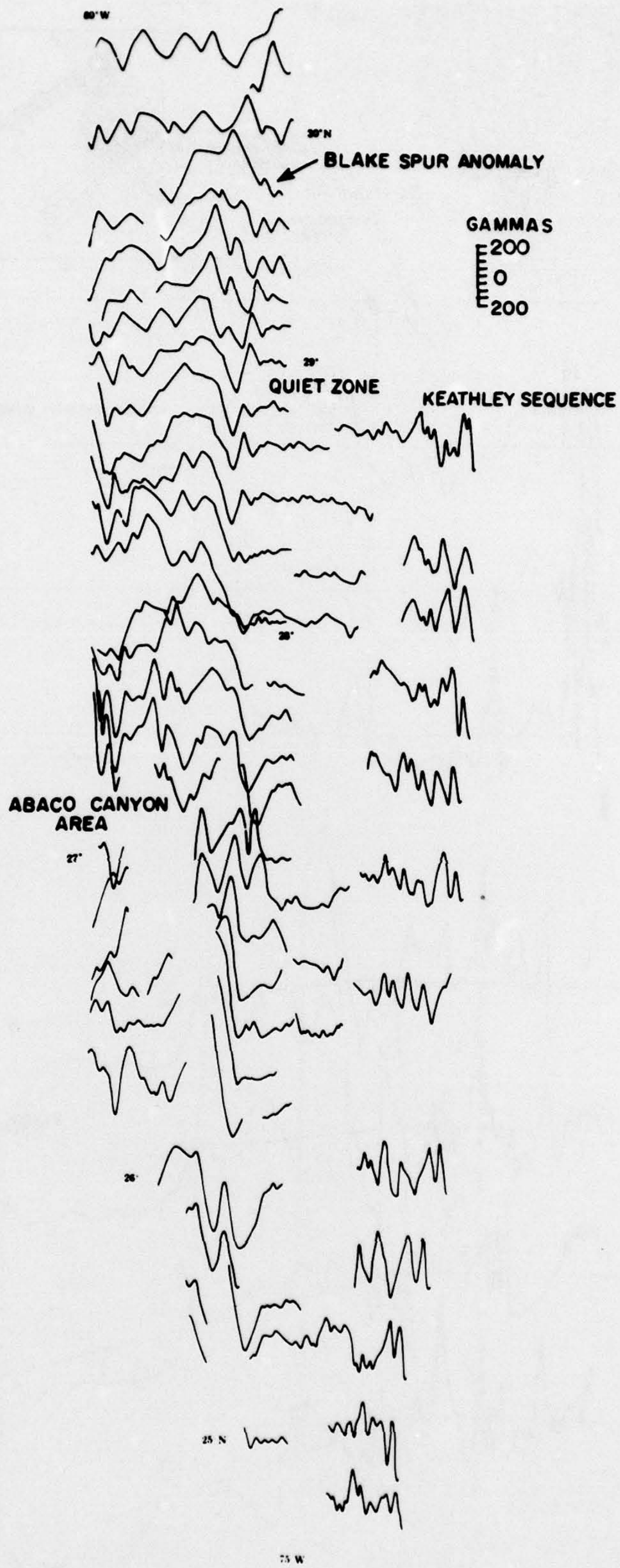

Figure 9. Alternating profiles chosen from USNS KEATHLEY surveys across the Blake Plateau, stacked on longitude lines with exaggerated gamma and north-south distance scales; the inner smooth zone and east coast anomaly branches are not present this far south.

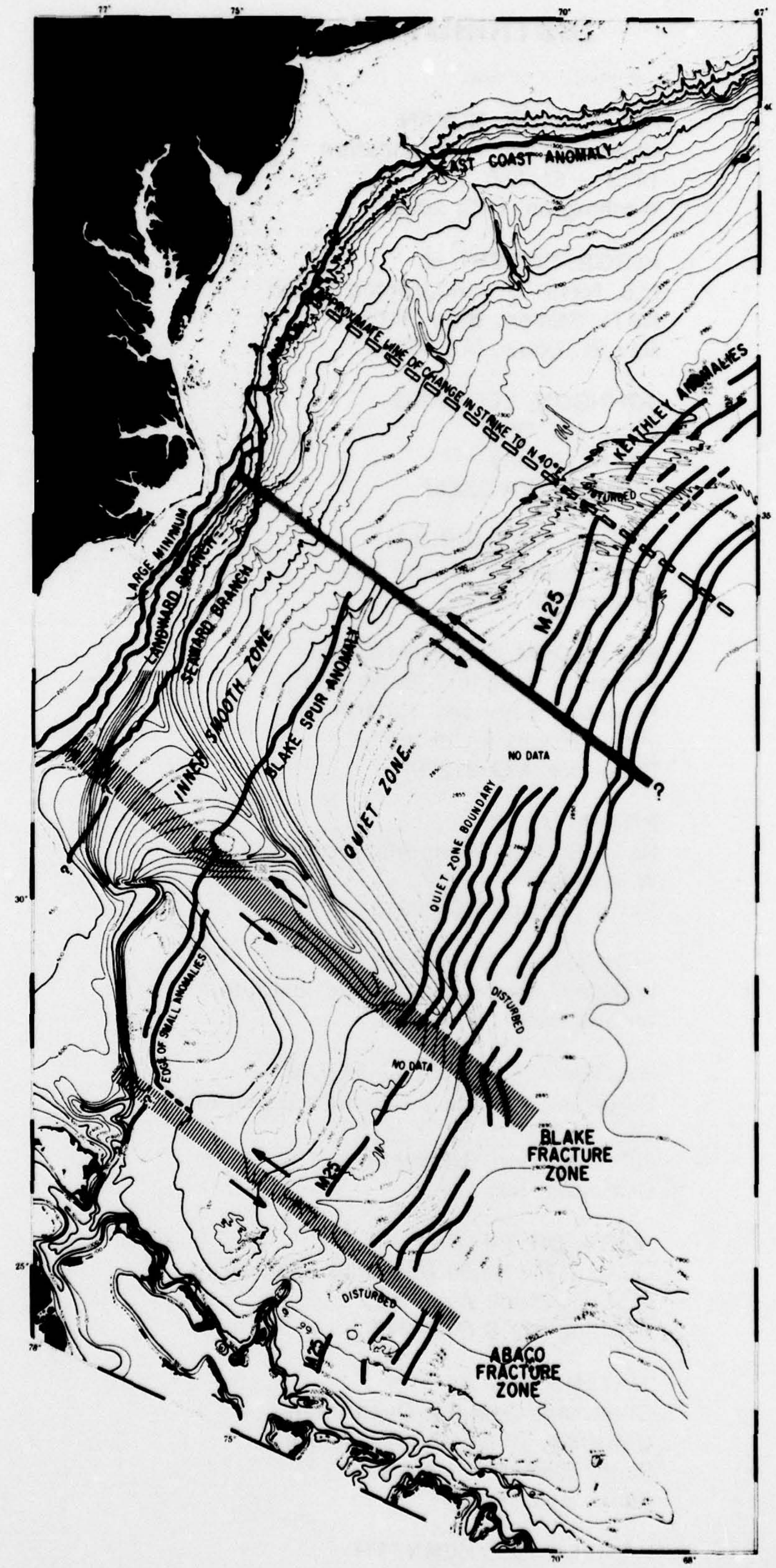

Figure 10. Lineations of prominent anomalies superimposed on bathymetric contours; the zones cut across major topographic features, but the presence of possible fractures and dislocations in the basement rock beneath the sediments is indicated by offsets in lineations.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The magnetic pattern in the western North Atlantic near the east coast of North America is dominated by a linear region of low magnetic intensities. This magnetic "quiet zone" possesses characteristics of sea-floor spreading: linearity, continuity, and bilateral symmetry with the quiet zone found in the eastern Atlantic. Its small internal anomalies can be shown to have a spatial origin. Some appear linear, but discontinuous, and a degree of correlation can be found over large, intervening distances.

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20. (Continued)

A portion of the quiet zone shows possible division into an inner and outer smooth zone. The inner smooth zone, near the shelf edge, has no counterpart in the eastern Atlantic, and, when considered as a proto-Atlantic, could account for the comparatively greater width of the total western quiet zone. Pre-rift fits of the African and North American continents usually show the African continental margin superimposed on both the inner smooth zone and the unique anomalies of the Blake Plateau which lies to the south. An oceanic origin for the inner smooth zone then implies the same origin for a major part of the Plateau.

The magnetic zones show little relationship with present current-shaped sea-floor topography, but offsets in the lineations of prominent anomalies attest to displacements in the rock floor beneath the deep sediments.

The detail of this survey, which shows north-south differences in the magnetic quiet zone, possible fracture locations, and areas of amplitude diversity on the Blake Plateau, provides a good base for many studies, including the characteristics of the underlying rocks and the pre-rift fit of the continents, and comparative studies with the magnetic pattern of the quiet zone in the eastern Atlantic near the African margin.