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INTERPRETATION OF MAGNETIC ANOMALIES OVER THE GRENADA BASIN

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Abstract. The Grenada Basin is a back arc basin located near the eastern border of the Caribbean Plate. The basin is bounded on the west by the north-south trending Aves Ridge (a remnant island arc) and on the east by the active Lesser Antilles island arc. Although this physiography suggests that east-west extension formed the basin, magnetic anomalies over the basin exhibit predominantly east-west trends. If the observed magnetic anomalies over the basin are produced by seafloor spreading, then the orientation of extension is complex. Extension in back arc basins is roughly normal to the trench, although some basins exhibit oblique extension. Present models for the formation of the Grenada Basin vary from north-south extension through northeast-southwest extension to east-west extension. An interpretation of magnetic anomalies over the Grenada Basin supports basin development by nearly east-west extension. Low amplitude magnetic anomaly trends subparallel to the island arc magnetic anomaly trends over the southern part of the basin and the results of forward three-dimensional (3-D) magnetic modeling are consistent with this conclusion. Late Cenozoic tectonic movements may have been responsible for disrupting the magnetic signature over the northern part of the basin. On the basis of our 3-D analysis, we attribute the prominent east-west trending anomalies of the Grenada Basin to fracture zones formed during seafloor spreading at low latitude. This east-west trend is not interpreted as indicating north-south extension of the basin.

INTRODUCTION

The formation and subsequent emplacement of the Caribbean plate into the Atlantic has resulted in a tectonically complex area. Ocean basins in the Caribbean plate include the Columbian, Grenada, Venezuelan, and Yucatan basins. The Columbian and Venezuelan basins are essentially scaled down versions of major ocean basins separated by the aseismic Beata Ridge [Burke et al., 1984; Case et al., 1984; Donnelly, 1975; Ghosh et al., 1984; Pindell et al., 1988; Pindell and Dewey, 1982]. The Grenada and Yucatan basins are back arc basins thought to have formed contemporaneously in early Tertiary time [Bouysse, 1988, Hall and Yeung, 1980; Pindell and Dewey, 1982; Ross and Scotese, 1988]. Refraction data for the Grenada Basin and for many back arc basins of the Western Pacific suggest that their crusts are oceanic [Boynton et al., 1979; Edgar, 1968; Ewing et al., 1957; Hayes et al., 1978; Officer et al., 1957; Officer et al., 1959; Westbrook, 1975]. However, the velocity structures of back arc basins exhibit more variability than "normal" oceanic crust [Ludwig et al., 1971]. Although the crusts of back arc basins may not be identical to that of larger oceanic basins, they do show systematic, layered velocity structures.

The plate boundary between the Caribbean plate and the North and South American plates is a subduction zone that is oriented in a generally north-south direction (Figure 1). Similarly, the trends of the Aves Ridge, Grenada Basin and Lesser Antilles region are oriented north-south. East-west extension is suggested by these trends [Tomblin, 1975]. However, magnetic data indicate that the actual opening of the Grenada Basin may have been more complicated [Bird et al., 1991]. Magnetic anomaly patterns over many of the world's back arc basins are poorly organized indicating changing patterns of seafloor spreading; however, the patterns over other back arc basins are well defined indicating preferred directions of seafloor spreading. A review of back arc basins located along the west Pacific margin demonstrates this relationship [Weissel, 1981]. The orientation of linear anomalies over back arc basins is generally subparallel to their associated subduction zones. Magnetic anomalies over the Grenada Basin, however, exhibit predominantly east-west trends, particularly over the northern part of the basin (Figure 2).

Theories on the development of the Grenada Basin generally agree that it was formed in early Cenozoic time. The direction of extension shown in existing models for the formation of the Grenada Basin varies from north-south [Pindell and Barrett, 1990] to northeast-southwest [Bouysse, 1988] to east-west [Tomblin, 1975]. Apparent contradictions in interpretations of the geophysical and geologic data have contributed to this variation in scenarios for the evolution of the basin. The issue to be addressed here is the relationship between the magnetic anomaly data and the formation of the basin. Interpretations of magnetic data over the basin have been based on qualitative descriptions of the anomalies [Bouysse, 1984, 1988; Speed and Westbrook, 1984; Pindell and Barrett, 1990; Ross and Scotese, 1988]. Here a more rigorous analysis of the magnetic data is attempted.

TECTONIC AND GEOLOGIC SETTING

Tectonics

The plate boundary along the eastern edge of the Caribbean plate is a subduction zone with the Caribbean plate overriding the westward dipping North and South American plates. The relative motion between the plates is 2 cm/yr east-west convergence [DeMets et al., 1985]. The absolute motion of the Caribbean plate in the hot spot reference frame is 1.5 cm/yr to the east for the Caribbean plate [Jarrard, 1986]. Jarrard [1986] has classified this subduction zone, in terms of strain exhibited in the overriding plate, as exhibiting little or no compression or extension. End-members of Jarrard's [1986] strain classification scheme following earlier works are severe folding and thrusting, as seen along Chile, and active back arc spreading, as seen in the Mariana Trough. The north and south plate boundaries of the Caribbean plate are represented by broad regions characterized by strike-slip motion and localized extension and shortening.

Depths of earthquakes range from less than 5 km to greater than 150 km in the region, and earthquake activity is summarized by Speed et al. [1984]. They report that the Benioff zone dips steeply in the south and shallows to the north with the northern and central parts being most active. Using ISC PP and pP delay times, van der Hilst and Engdahl [1991] produced tomographic images of the region. The use of these two independent data sets improved the resolution of the Benioff zone beneath the Caribbean plate [van der Hilst and

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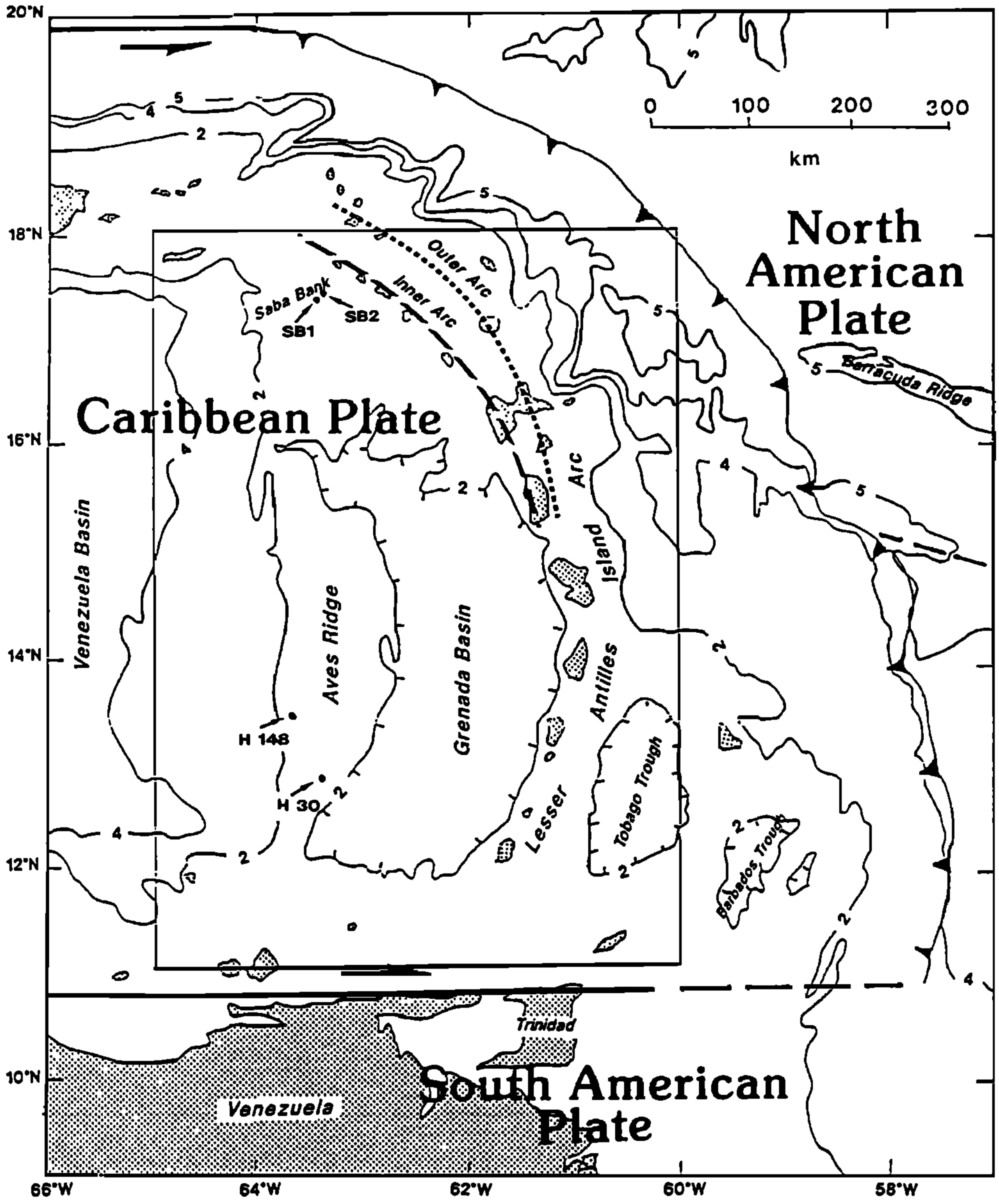

Fig. 1. Physiography of the eastern Caribbean with 2-, 4-, and 5-km isobaths contoured [after Bouysse, 1984]. The outline of the study area, trace of the subduction zone, and strike-slip fault zones which define the North American/Caribbean and South American/Caribbean plate boundaries are displayed. Heavy dashed lines indicate probable locations for plate boundaries. The inner and outer arcs are represented by dashed and dotted lines, respectively. SB1 and SB2 are commercial wells on the Saba Bank, and H148 and H30 are Deep Sea Drilling Project sites.

Engdahl, 1991]. From a detailed study of earthquake data, Wadge and Shepard [1984] have mapped a "kink" in the Benioff zone along the Lesser Antilles near 14.5°N. The strike of the zone north and south of this latitude is NNE and NW. Wadge and Shepard suggest that this kink may represent the boundary where two seperate plates (North and South American) are subducting beneath the Caribbean plate.

From a study of seismic refraction data, Speed and Walker [1991] theorize that high-velocity crust beneath the arc platform of the Grenadines is oceanic and continuous, connecting the Grenada Basin with the Tobago Tough. Through analyses of seismic reflection data in the region, Torrini and Speed [1989] have determined that the accretionary prism of the forearc stepped arcward in Miocene time. They suggest the step could be in response to (1) the formation of a new subduction zone, (2) a velocity change for the subducting slab, or (3) a change in the rate of accretion of sediments.

Geology

The Grenada Basin (Figure 1) is considered to have formed by seafloor spreading in early Cenozoic time [Bouysse, 1988; Boynton et al., 1979; Donnelly, 1975; Pindell and Dewey, 1982; Shurbet, 1976; Uyeda and Kanamori, 1979; Uyeda,

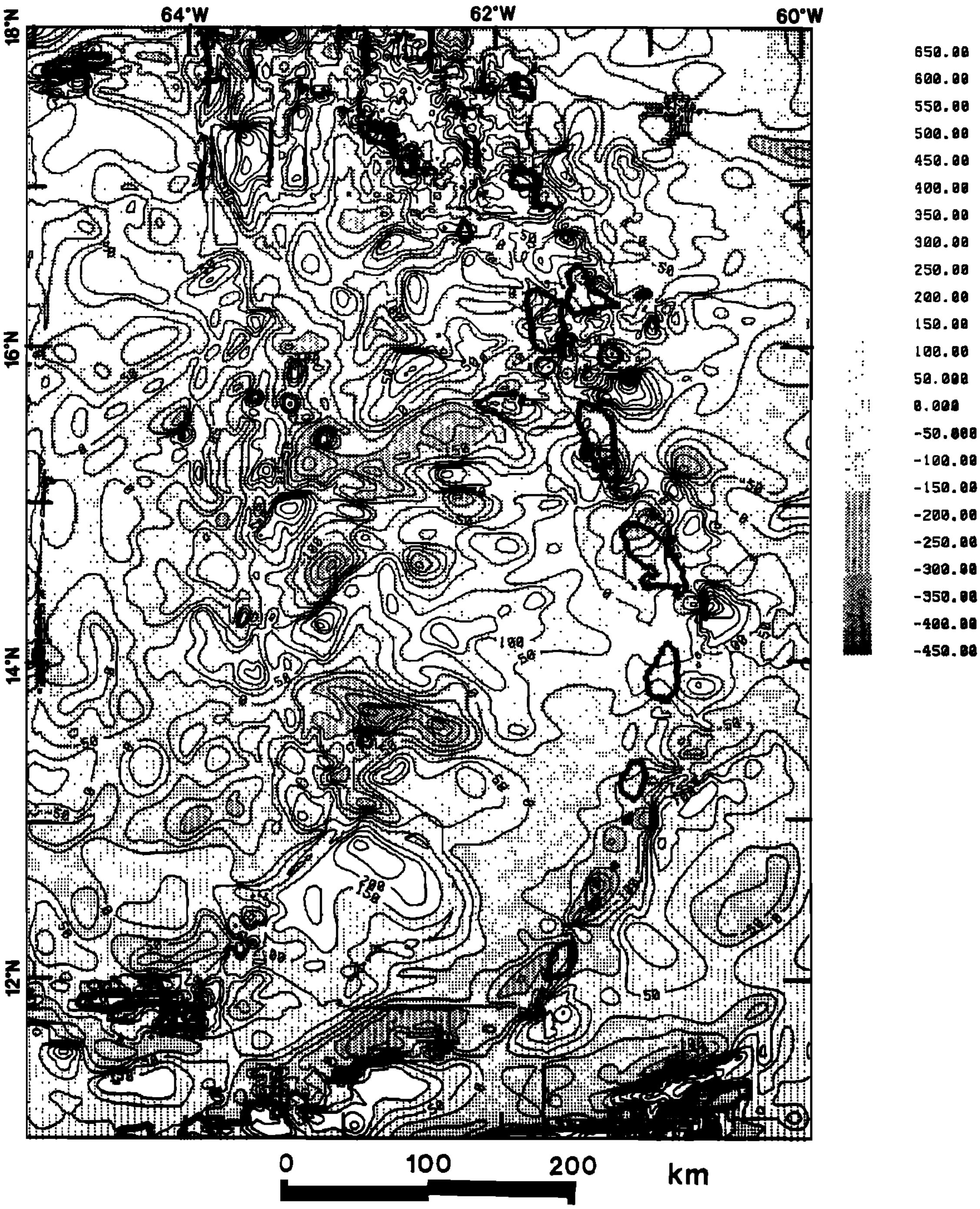

Fig. 2. Total intensity magnetic anomalies over the study area. The contour interval is 50 nT. Gridded data (2 km) were compiled in 1987 by the Geological Society of America Decade of North American Geology Committee on the Magnetic Anomaly Map of North America.

1982; and Westbrook, 1975]. The Basin is bounded to the north by the Saba Bank at the junction of the Greater and Lesser Antilles and to the south by the continental rise of northern Venezuela. The Aves Swell and the Lesser Antilles arc form the western and eastern limits of the basin. The shape is arcuate and has approximate dimensions of 640 km (north-south) by 140 km (east-west) and an average water depth of about 2 to 3 km. Sediment thickness ranges from 2 km in the north to 9 km in the south [Bouysse, 1988].

Morphologically, the ocean floor of the Grenada Basin falls into northern and southern parts. The bathymetry of the northern part has been described by Bouysse [1988, p. 123] as "rugged with a system of spurs and valleys running down from the Lesser Antilles volcanic arc." The southern part of the basin is characterized by a near horizontal, smooth seafloor. The nature of the deep sediments of the Grenada Basin is not known but refraction data indicate that sediments of the Aves Ridge extend and thicken into the Basin [Westbrook, 1975].

The Aves Swell, an extinct island arc [Bouysse, 1984, 1988], occupies the western side of the basin. Its western edge strikes north-south and dips steeply into the Venezuelan Basin. Its eastern edge is arcuate and descends in steps into the Grenada Basin. Fox and Heezen [1975] report on dredge samples recovered from pedestals and scarps of the Aves Ridge. Dredged volcanic rocks include andesites, basalts, dacites, and volcanic breccias. Farther south along the ridge, Late Cretaceous to Paleocene granodiorites, diabases, and basalts have been dredged [Fox and Heezen, 1975].

Four drilling sites are located in the general area (Figure 1). Two Deep Sea Drilling Project (DSDP) wells were drilled in the southern part of the Aves Swell, and two wells were drilled by Marathon Oil Company on the Saba Bank. DSDP wells 30 and 148 encountered middle to late Miocene volcanic sands [Shipboard Scientific Party, 1970] and possibly Paleocene age volcanics [Shipboard Scientific Party, 1973], respectively. Marathon Oil Company's SB-1 and SB-2 wells in the northern part of the basin encountered early Paleocene to early Oligocene andesite [Warner, 1991].

The Grenada Basin is bordered to the east by the active Lesser Antilles island arc which, like the Aves Swell on the western margin and the Grenada Basin itself, forms a gentle arc concave to the west. The Lesser Antilles splits north of approximately 15°N into an inner and an outer arc (Figure 1). The outer arc is older (35-15 Ma) and inactive, while the inner arc is younger (20 Ma to recent) and presently active [Fox and Heezen, 1975]. A maximum separation of about 50 km perpendicular to the arcs occur at the northern limit of the bifurcated island chain.

The inner and outer arcs of the Lesser Antilles have been named the "Volcanic Caribbees" and the "Limestone Caribbees," respectively [Martin-Kaye, 1969]. Lower Miocene to early Pliocene basalt-andesite-dacite series volcanics are dominant rock types of the northern part of the Volcanic Caribbees (north of 15°N) and pre-Miocene to recent volcanics are dominant in the southern part [Fox and Heezen, 1975]. The Limestone Caribbees are characterized by middle Oligocene to Miocene andesites, dacites, tuffs, and agglomerates intruded by diorite and quartz diorite [Fox and Heezen, 1975].

Late Jurassic age basalts are reported by Fink [1968, 1970] on the island of la Desirade, just east of Guadeloupe. These rocks may represent obducted oceanic crust [Bouysse, 1988; Fox and Heezen, 1975; Mattinson et al., 1980] or evidence for early development of the Mesozoic Arc [Burke, 1988]. Other interpretations include the possibility that these older rocks may be related to the same tectonic event which shifted the center of volcanism westward from the Limestone Caribbees.

PREVIOUS INTERPRETATIONS

Kinematic models for the formation of the Grenada Basin by Bouysse [1988], Pindell and Barrett [1990], and Tomblin [1975] outline the formation of the basin by northeast-southwest extension, north-south extension, and east-west extension, respectively.

East-West Extension

Tomblin [1975] describes two possible scenarios for east-west extension; the first involving an early Tertiary eastward shift of the subduction zone and the second a westward shift of the Aves Ridge. He pointed out that the

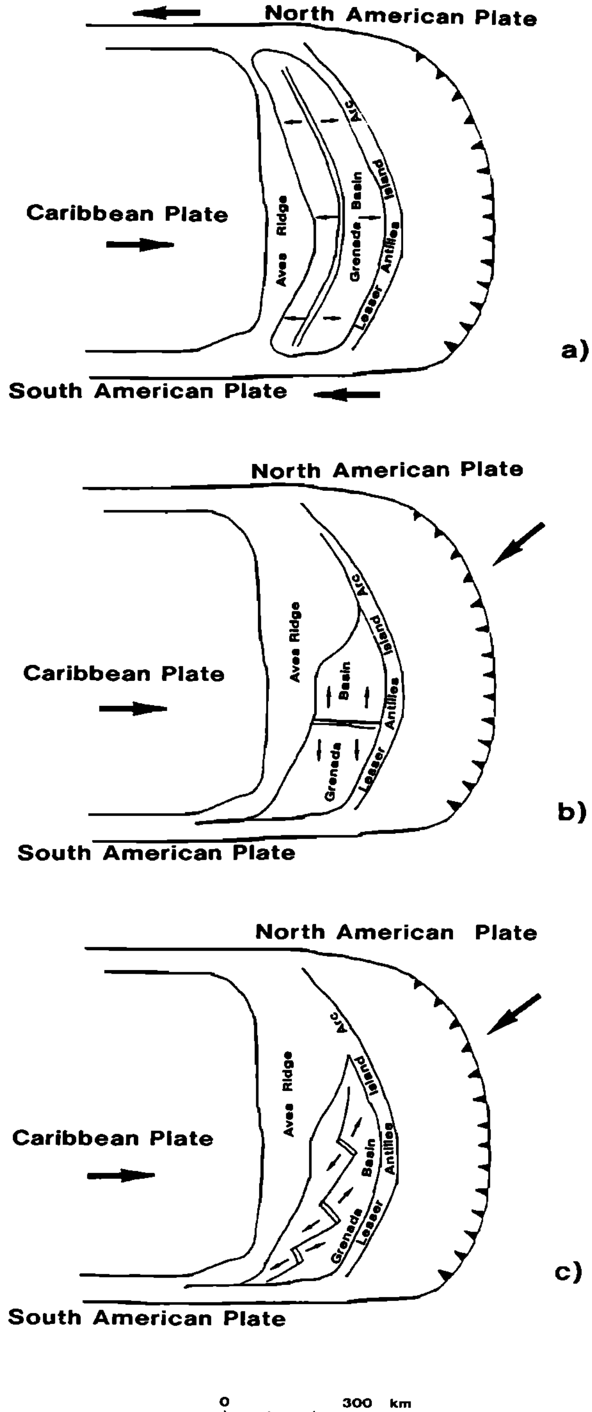

Fig. 3. (a) Possible east-west extension due to an westward shift of the Aves Ridge for the opening of the Grenada Basin as proposed by Tomblin [1975]. Large arrows indicate the relative motions of the North American, Caribbean, and South American plates. Small arrows indicate the directions of exten-sion for the formation of the basin. (b) Possible north-south extension for the opening of the basin as proposed by Pindell and Barrett [1990]. (c) Possible northeast-southwest extension for the opening of the basin as proposed by Bouysse [1988].

westward seperation of the Volcanic Caribbees from the Limestone Caribbees in the Miocene is not related to the eastward shift of the subduction zone, that is; extensional strains which give rise to the formation of the Grenada Basin in early Tertiary no longer exist and compressional strains have dominated in the late Tertiary. In this model, older rocks of la Desirade are either part of an older orogeny and moved eastward with the subduction zone or part of the Atlantic floor obducted onto the eastward moving Caribbean plate.

Tomblin's alternative scenario involving a westward shift of the Aves Ridge requires the formation and subsequent spreading from a north-south oriented median ridge (Figure 3a). He reports that no such ridge has been observed. The more probable scenario is the westward migration of the Aves Swell away from the subduction zone.

North-South Extension

Pindell and Barrett [1990] described a model in which the Leeward Antilles have been coupled to the northern edge of the South American plate (Figure 3b). North-south spreading in the vicinity of the Grenada Basin was a result of oblique convergence with the South American plate. The basin was thus formed by right lateral shear. In this model the Leeward Antilles was part of the Aves Ridge prior to the formation of the basin and represents fragmentation of the arc as the Caribbean plate progressed eastward. Pindell and Barrett [1990] suggest that the general east-west, or perpendicular to the island arc, orientation of magnetic anomalies over the basin support north-south extension. For this model, differences in the nature of the crust of the northern and southern parts of the basin are important. It is suggested that the northern part is block faulted with no development of oceanic crust, whereas the southern part of the basin is probably underlain by oceanic crust [Pindell and Barrett, 1990].

Northeast-Southwest Extension

Bouysse [1988] describes a possible mechanism for extension, quite like Pindell and Barrett's, in which coupling of the southern part of the Lesser Antilles with the South American Plate also precedes opening of the basin (Figure 3c); however, the mechanism of back arc spreading in this model is similar to a mechanism described by Poehls [1978]. He suggested, as did Burke [1988] and Pindell and Barrett [1990], that the Netherland-Antilles, the Lesser Antilles, and the Greater Antilles formed a continuous Mesozoic arc prior to the injection of the Caribbean plate between the American plates. Bouysse [1988] further suggests that subsequent seafloor spreading was oriented northeast-southwest at the onset of the Cenozoic in a segmented manner such as described by Tamaki [1985] for the Sea of Japan Basin. Initial spreading was in the southernmost part of the basin and gradually progressed northward over time.

Bouysse's model provides for contemporaneous formation of the Yucatan and Grenada basins. This development occurred when the Caribbean plate, traveling northeast with respect to the North American Plate, was wedged between the North American and South American plates in late Cretaceous/early Tertiary time. Subsequent to this double collision, the Caribbean plate rotated clockwise and began traveling in an east-west direction.

DATA BASE

The data base for this study includes both profile and gridded magnetic anomalies. The gridded total intensity magnetic anomalies (2 km) were compiled in 1987 by the Geological Society of America Decade of North American Geology (DNAG) Committee on the Magnetic Anomaly Map of North America. Figure 4 shows the coverage of shipboard magnetics profile data for the study area. For the most part, the profile magnetic data set was leveled and contoured, then digitized to create the DNAG gridded data sets used for this study.

Magnetic anomalies over the Grenada Basin (Figure 2) exhibit amplitudes of several hundred nanoteslas with wavelengths ranging from 10 to over 50 km. Anomalies over the southern part of the basin display longer wavelengths and smaller amplitudes than those over the northern part. Similarly, shapes and trends of anomalies change from north to south. The shape of the anomalies over the northern part of the basin is typically oblong with an east-west trend and degrades to patchy and disorganized to the south. Magnetic anomalies over the Aves Swell are similar to those of the northern part of the basin except that they are oriented north-south. The magnetic anomalies over the Lesser Antilles range in amplitude from 150 to 600 nanoteslas and display wavelengths ranging from 5 to 40 km.

ANALYSES

Analyses of the data included a qualitative interpretation of the DNAG anomaly field, correlation of anomaly highs and lows from two-dimensional (2-D) anomaly profiles (i.e., trend analysis), and forward three-dimensional (3-D) modeling. A large percentage of anomalies over the Grenada Basin have aspects ratios less than 5:1, hence 3-D modeling is most appropriate.

Several low-amplitude (approximately 30 nT) magnetic anomaly trends from magnetic profile data, oriented subparallel to the Lesser Antilles arc, are defined over the southern part of the basin (Figure 5). Anomaly trends are oriented both parallel and perpendicular to the island arc over the northern part of the basin. Anomaly trends over the Aves Ridge are oriented north-south. Figure 6 displays selected magnetic anomaly profiles over the southern part of the basin with some of the major anomaly trends indicated. Note that several trends, although discontinuous, are oriented generally north-south, or concentric to the island arc and the trench line of the subduction zone.

Speed et al. [1984] mapped an acoustic basement surface in time utilizing extensive multiple and single-channel seismic reflection data sets. Although acoustic basement and magnetic basement may not coincide in regions of continental crusts, these surfaces should coincide for oceanic crust. In order to construct a 3-D magnetic model for the Grenada Basin, the acoustic basement surface time contours were digitized and converted to depth. The velocity function utilized to convert the time horizon to depth was determined from the Lamont-Doherty Geological Observatory cruise RC1904, line 15 velocity analyses and refraction line 29 [Officer et al., 1957]. Time-depth curves were calculated at even increments across the basin from line 15. These curves were combined, and a best fit curve was interpreted. At the intersection of reflection line 15 and refraction profile 29 the lower part of the best fit curve was forced to tie with the refraction data. This velocity function was then used to calculated depths for the entire basin. For the first-order tectonic problem studied here; that is, the orientation of extension and opening of the Grenada Basin, the resultant basement surface in depth should be sufficiently accurate. Subtracting the forward calculated field from the observed field removes the effect of basement relief and results in a residual anomaly field produced only by changes in magnetization, including geomagnetic polarity reversals.

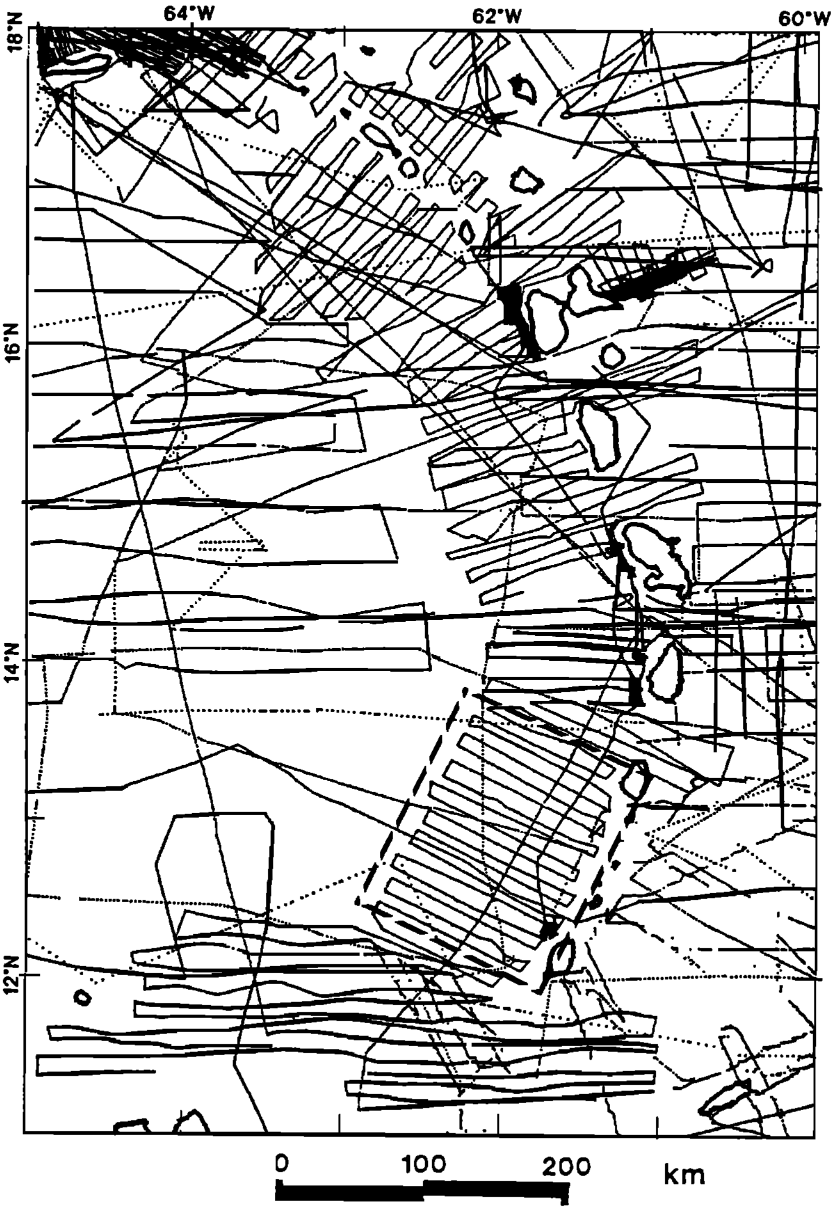

Fig. 4. Shipboard magnetics data coverage for the study area. Anomaly profiles for west-northwest oriented shiptracks outlined by the dashed box are displayed in Figure 6.

INTERPRETATION

Anomalies north of 14°N are better defined than those to the south (Figure 2) because of the southward deepening of the basement. For any magnetized body there exists a straightforward relationship between the wavelength of its magnetic anomaly and the distance from the body. Therefore, as the basement depth increases, anomalies over the basin become longer in wavelength and smaller in amplitude and begin to interfere with one another. Suprabasement effects, or structural relief of the basement surface, as well as intrasedimentary sources typically produce relatively small amplitude anomalies (tens of nanoteslas). However, if the structural relief is large enough (kilometers), anomalies can range in the hundreds of nanoteslas. Anomalies produced within the basement, or intrabasement, usually exhibit larger amplitudes (hundreds of nanoteslas). Therefore in general, short-wavelength, small-amplitude anomalies are interpreted to be produced by shallower intrasedimentary or shallow suprabasement sources, and long-wavelength, high-amplitude anomalies are interpreted to be produced by deeper intrabasement features such as lithologic boundaries or boundaries related to geomagnetic polarity reversals. However, these general rules may have important exceptions in areas characterized by low geomagnetic inclinations (less than 30°).

The north-northeast to north-south orientation of anomaly trends over the basin south of 14°N are interpreted to be produced by seafloor spreading and indicate a near east-west direction of extension and opening of the Grenada Basin. Although these anomalies exhibit amplitudes of about 40 nT,

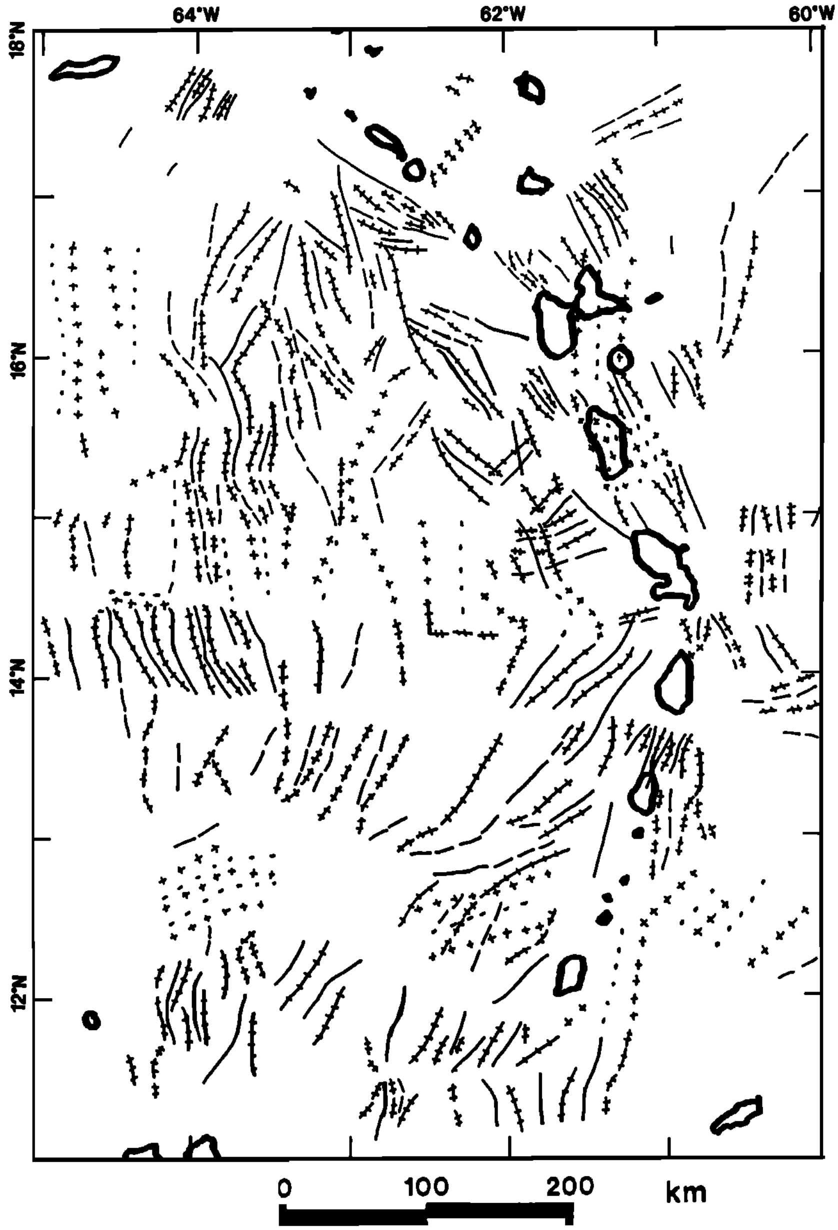

Fig. 5. Magnetic anomaly trends over the study area from profile data. Anomaly highs are indicated by plus signs with continuous plus signs, pairs of plus signs, and single plus signs corresponding to good, fair, and poor correlations, respectively. Anomaly lows are indicated by solid, dashed, and dotted lines which correspond to good, fair, and poor correlations, respectively.

confidence in these trends is high. This confidence is supported by two aspects of the region and the magnetic field. First, the trends were correlated using data from a single cruise (U. S. Navy WI932010) with 18 lines spaced approximately 8 km apart. Second, the acoustic basement surface in this part of the basin is relatively smooth, suggesting intrabasement sources are responsible for the anomaly trends observed in profiles. Trends over the northern part of the basin may possibly have been developed as a result of the tectonic event responsible for the bifurcation of the northern Lesser Antilles. That is, the original magnetic signature is thought have been disrupted by faulting, and possible strike slip motion. Speed and Westbrook [1984] suggest that the morphology of the northern part of the basin is apparently controlled by a NW-SE horst and graben system and possible right lateral strike-slip motion.

The magnetic field calculated for a constant susceptibility, 3-D model (a single basement half- space) produces strong, subparallel to the arc anomalies over the southern part of the basin (Figure 7a). The magnetic signature over the northern part of the model is relatively quiet, with only a few high-amplitude (greater than 100 nT) anomalies. The residual field (Figure 7b) displays anomalies oriented north-south to northeast-southwest in the southern part of the basin but mostly

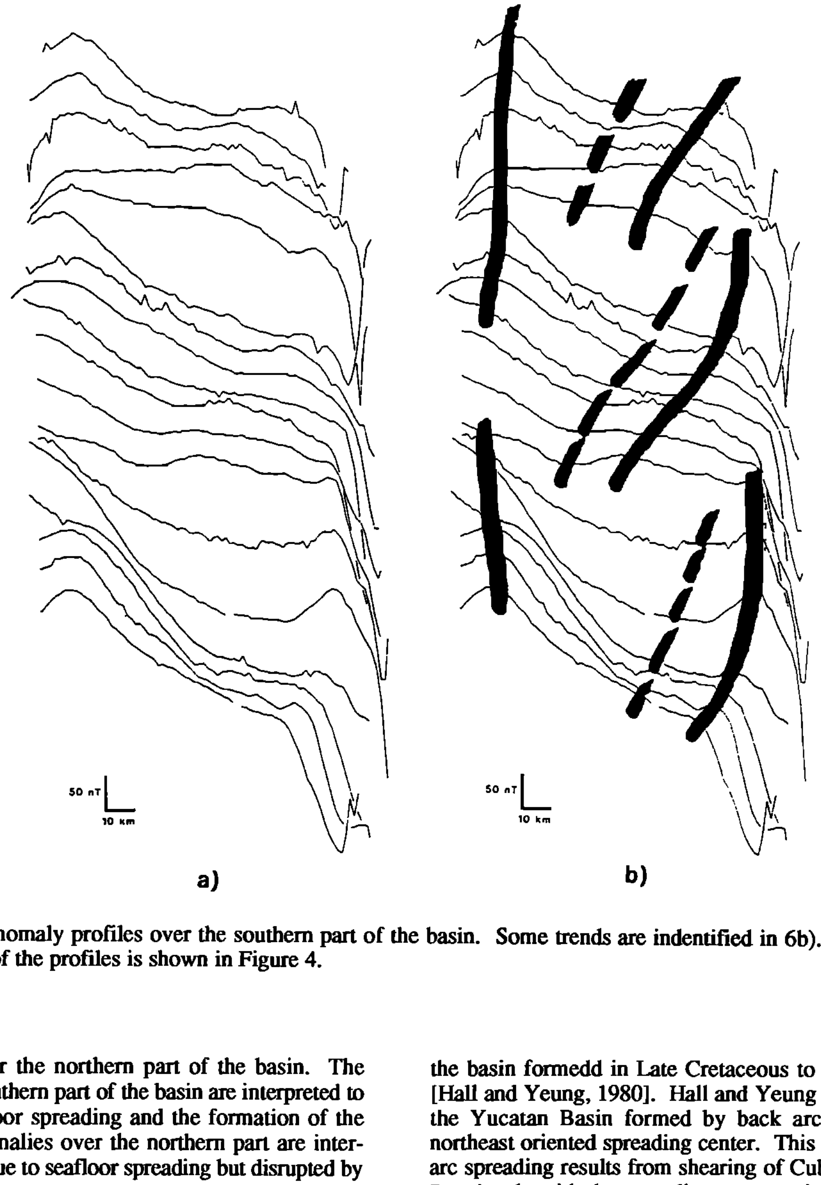

Fig. 6. Anomaly profiles over the southern part of the basin. Some trends are indentified in 6b). The location of the profiles is shown in Figure 4.

irregular patterns over the northern part of the basin. The anomalies over the southern part of the basin are interpreted to be produced by seafloor spreading and the formation of the Grenada Basin. Anomalies over the northern part are interpreted to be possibly due to seafloor spreading but disrupted by recent tectonic movements.

DISCUSSION

In his discussion regarding the magnetic anomalies over the Grenada Basin, Bouysse [1988] points out that the great depth to the oceanic basement combined with a possible location near the geomagnetic equator of the eastern Caribbean may blur the original anomaly pattern. These observations are the primary reason for the confusion regarding the magnetic field over the Grenada Basin. The 3-D residual magnetics remove the effect of structural relief on the deep basement, leaving anomalies produced by lithologic variations and boundaries resulting from geomagnetic polarity reversals. A drawback of our analysis is the lack of susceptibility information, but the choice of susceptibility used in modeling appears to affect only anomaly amplitudes, and not the anomaly patterns themselves. Forward 3-D magnetics, calculated with a constant suscepti-bility of 13,000 micro cgs units produces anomaly patterns similar to those obtained with 8000 micro cgs units.

Magnetic anomaly data over the Yucatan Basin suggest that the basin formedd in Late Cretaceous to early Tertiary time [Hall and Yeung, 1980]. Hall and Yeung further suggest that the Yucatan Basin formed by back arc extension form a northeast oriented spreading center. This orientation ob back arc spreading results from shearing of Cuba past the Yucatan Penninsula with the spreading center oriented approximately normal to the trend of the shear zone. East-west spreading in the Grenada Basin with shearing past South America may represent a similar mechanism.

To illustrate the dependence of magnetic anomaly data on the geomagnetic inclination and strike of the source body, four profiles have been calculated utilizing two geomagnetic inclinations and two strike directions for the 2-D model (Figure 8). Most plate reconstructions place the leading edge of the Caribbean plate at approximately 12° latitude at the time the basin formed [Duncan and Hargraves, 1984; Ghosh et al., 1984; Pindell et al., 1988; and Ross and Scotese, 1988]. A paleomagnetic inclination is calculated, to simulate a remanent inclination and hopefully resolve anomalies produced by this remanent field utilizing the relationship [Sharma, 1976]:

$$\tan(\text{inclination}) = 2 \tan(\text{latitude})$$

This formula yields a value of about 23°. A paleodeclination of 0° is also used. Two profiles were oriented south-north across an east-west trending body, and the other two were oriented west-east over a north-south trending body.

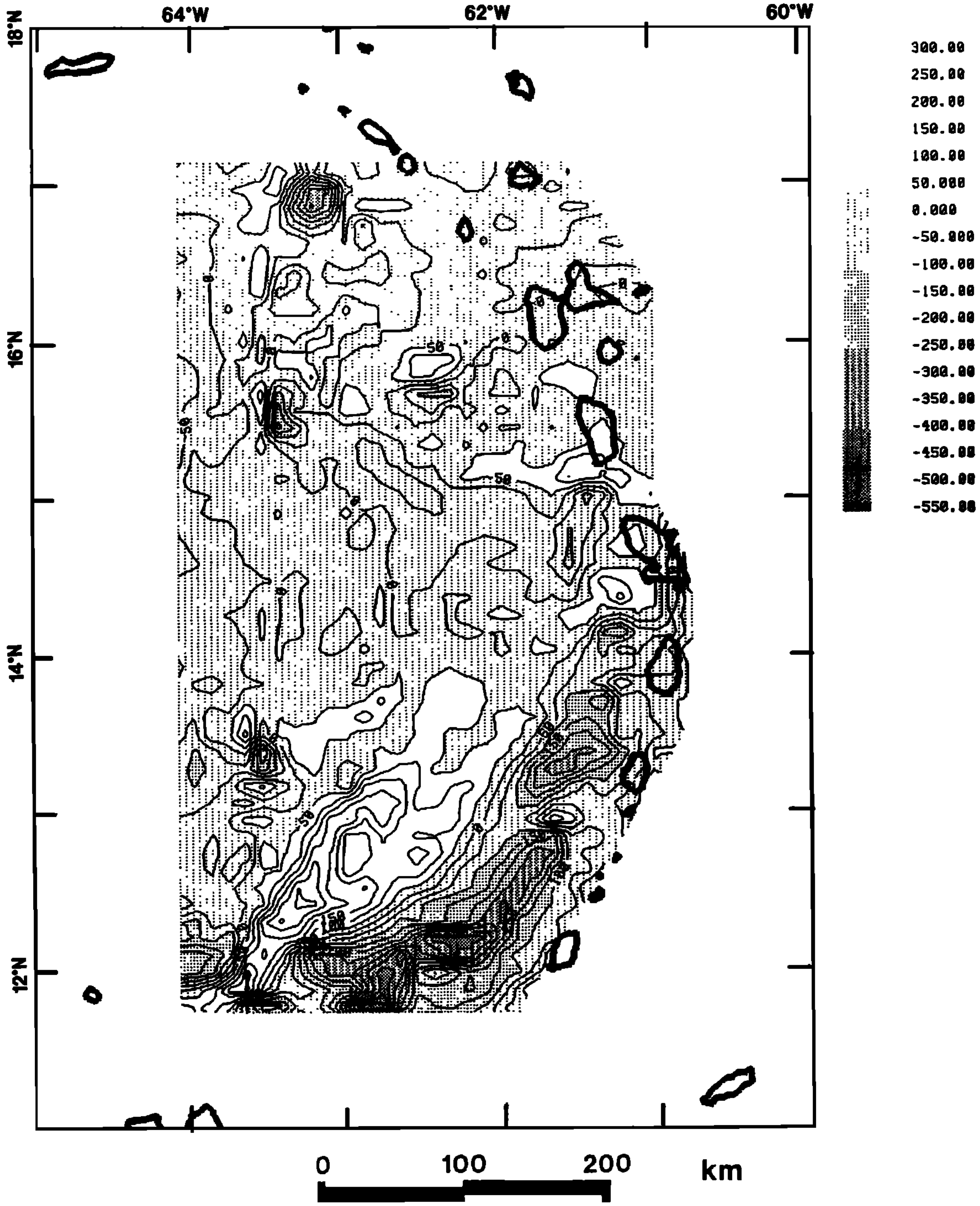

Fig. 7. (a) Magnetic anomalies over the study area calculated from a three-dimensional model with layers of uniform magnetic susceptibility. The contour interval is 50 nT.

An amplitude decrease from south-north to west-east calculations using 43° inclination is about 57% (from about 300 to 130 nanoteslas). A more dramatic, and important to this study, decrease is observed from south-north to west-east calculations using 23° inclination. The decrease in amplitude is about 86%, or over a sevenfold decrease (from about 290 to 40 nanoteslas).

Anomalies correlated from the observed profile magnetic data over the southern part of the basin exhibit amplitudes near 40 nanoteslas and there does not appear to be structural relief on the acoustic basement surface which would produce these anomalies. Furthermore, the 40 nanoteslas amplitude for a north-south oriented body indicates that magnetization of the body is caused primarily from the remanent field (or 23°

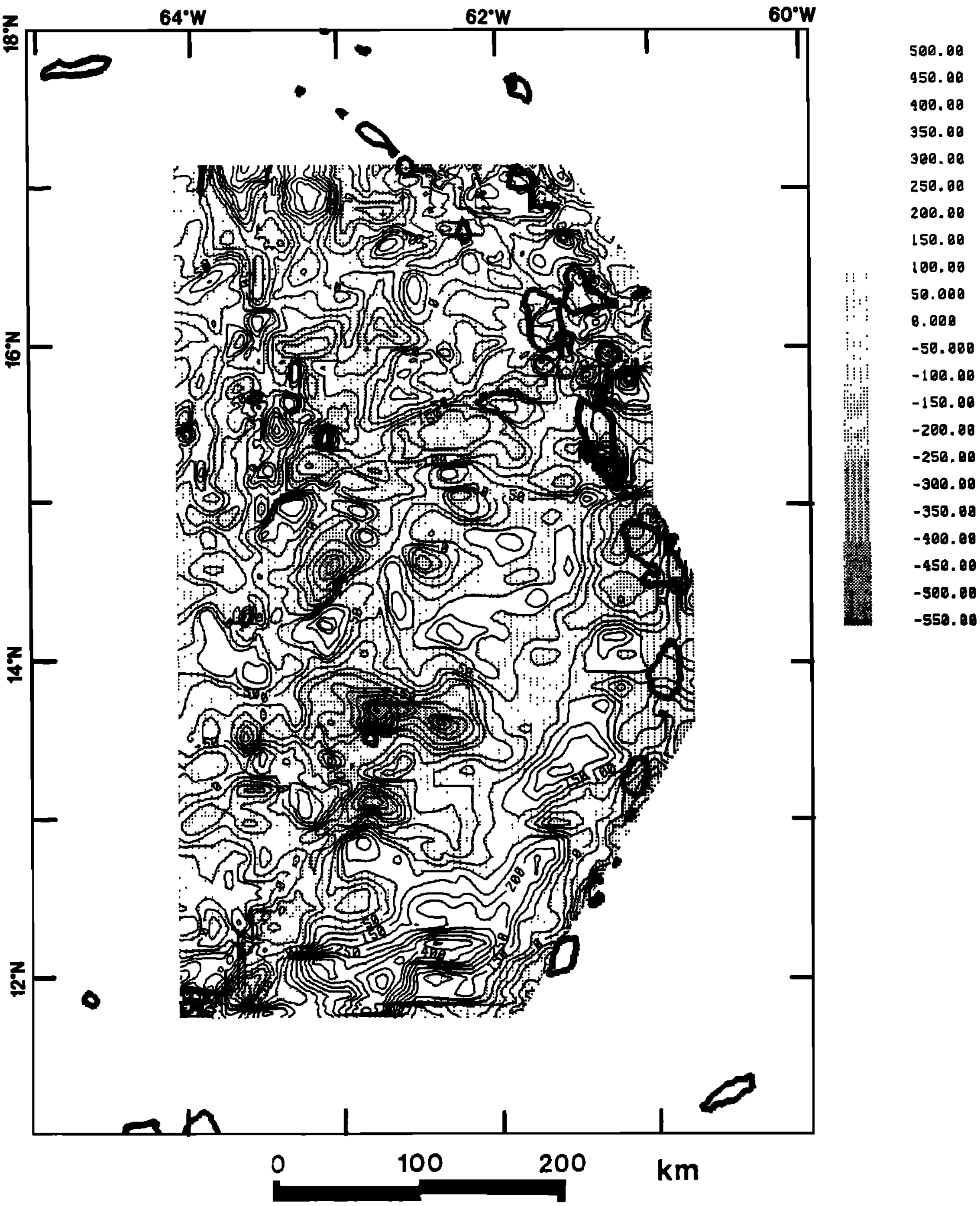

Fig. 7. (b) Total magnetic intensity (Figure 1) minus calculated magnetic anomalies over the study area. The contour interval is 50 nT.

inclination). This is because any effect of the inducing field would only increase the amplitude, since the west-east profile at 43° inclination produces a larger amplitude anomaly (i.e., 130 nanoteslas). The effect of magnetization contrasts caused by geomagnetic polarity reversals also increases the amplitude of anomalies.

At low geomagnetic inclinations, east-west trending features such as transform faults which have been injected with magnetized material or the ends of offset spreading ridge segments, would produce anomalies of hundreds of nanoteslas. However, a north-south trending ridge segment would produce anomalies of only tens of nanoteslas. At the magnetic equator a north-south ridge segment would produce no anomaly.

A 3-D, variable susceptibility surface is generated (Figure 9a) on the basis of results from the interpretation of the total intensity magnetic anomalies and the magnetics profile trend

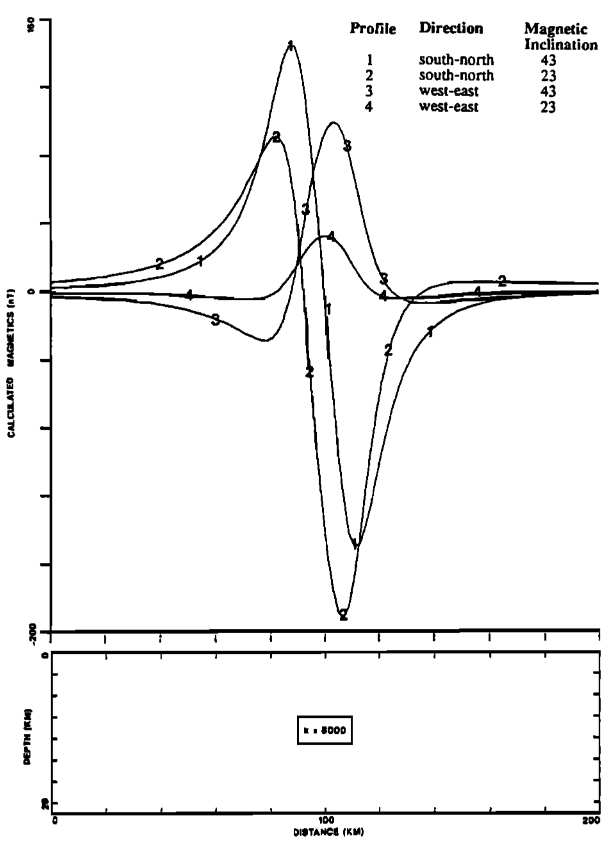

Fig. 8. Magnetic anomalies calculated for two inclinations (23° and 43°) and two profile directions (south-north and west-east). In each calculation, the same two-dimensional causative body was used: 5 km thick, at 12 km depth, and 8000 micro cgs units susceptibility magnetization.

analysis. The variable susceptibility surface is then incorporated in a 5-km-thick basement layer, and the magnetic field is calculated (Figure 9b). Susceptibilities of +8000, -8000, and 2000 micro cgs units are assumed for normally magnetized oceanic crust, reversely magne-tized oceanic crust, and arc material, respectively. The purpose of this exercise is to test the hypothesis that near north-south spreading centers may produce small-amplitude anomalies relative to east-west oriented transform fault zones. The magnetization vector assigned to the model coincides with a paleoinclination and paleodeclination of 23° and 0°, respectively. The calculated field utilizes present-day inclination and declination of 43° and -11°. Inspection of Figure 9b reveals that east-west features produce anomalies with amplitudes 2 to 4 times as large as the north-south trending ridge segments. If the geomagnetic inclination was less than 23° when the Grenada Basin formed, then the ratio of anomaly amplitudes produced by east-west versus north-south features would be greater.

On the basis of our 3-D analysis, we attribute the prominent east-west trending anomalies of the Grenada Basin to fracture zones formed during seafloor spreading at low latitude. This east-west trend is not interpreted as indicating north-south extension of the basin.

CONCLUSION

Interpretation of magnetic anomalies at low geomagnetic inclinations depends on the strike of the geologic features and the anomaly patterns they produce. The magnetic anomaly patterns over the Grenada Basin and our interpretation of them demonstrates this dependence. The Grenada Basin is interpreted to have formed by near east-west, or subparallel to the island arc, extension in the early Tertiary. This conclusion is supported by forward 3-D magnetics modeling and subtle magnetic anomaly trends over the southern part of the basin. These low-amplitude (about 40 nanoteslas) anomalies are produced by a roughly north-south oriented spreading center(s) near the geomagnetic equator. The chaotic, patchy anomalies over the northern part of the basin are thought to have formed by seafloor spreading also, but later were disrupted by the late Tertiary event responsible for the bifurcation of the Lesser Antilles.

Although the magnetic data over some areas of the Grenada Basin are sparse, the authors feel that the present data base is sufficient for the purpose of this study. Additional data which may help define the orientation of extension in the basin include the acquisition of seismic refraction and/or seismic reflection data. Existing refraction data for the northern part of the basin consists of a single, relatively short, unreversed profile [Speed et al., 1984]. Additional data here may help define the crustal architecture of this part of the basin. The correlation of similar features on the western flank of the

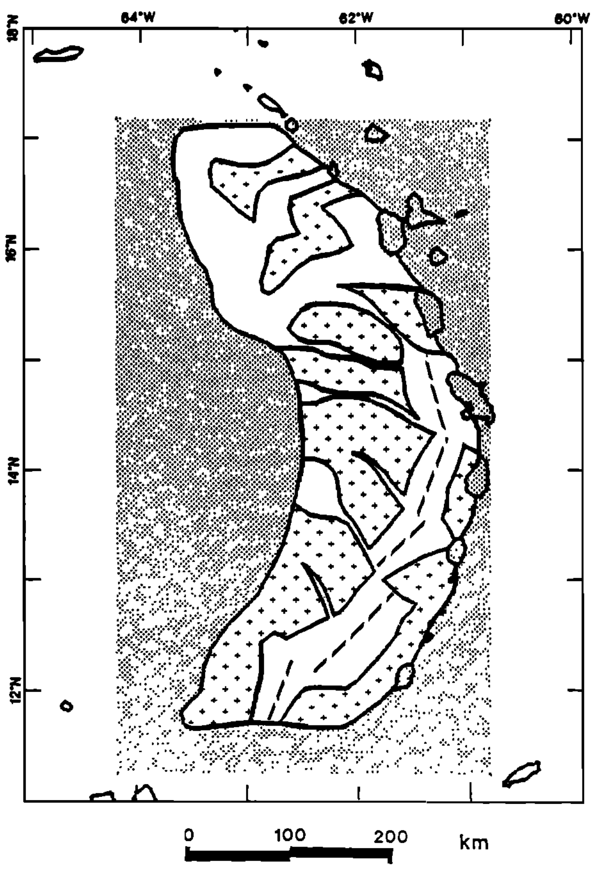

Fig. 9. (a) Variable susceptibility surface which incorporated in a 5-km-thick basement layer to generate a variable susceptibility model. The dashed lines indicate possible spreading centers. The identification of normal polarized oceanic (+8000 micro cgs units), reversed polarized (-8000 micro cgs units), and arc crust (+2000 micro cgs units) are shown by plus, white, and dotted patterns, respectively.

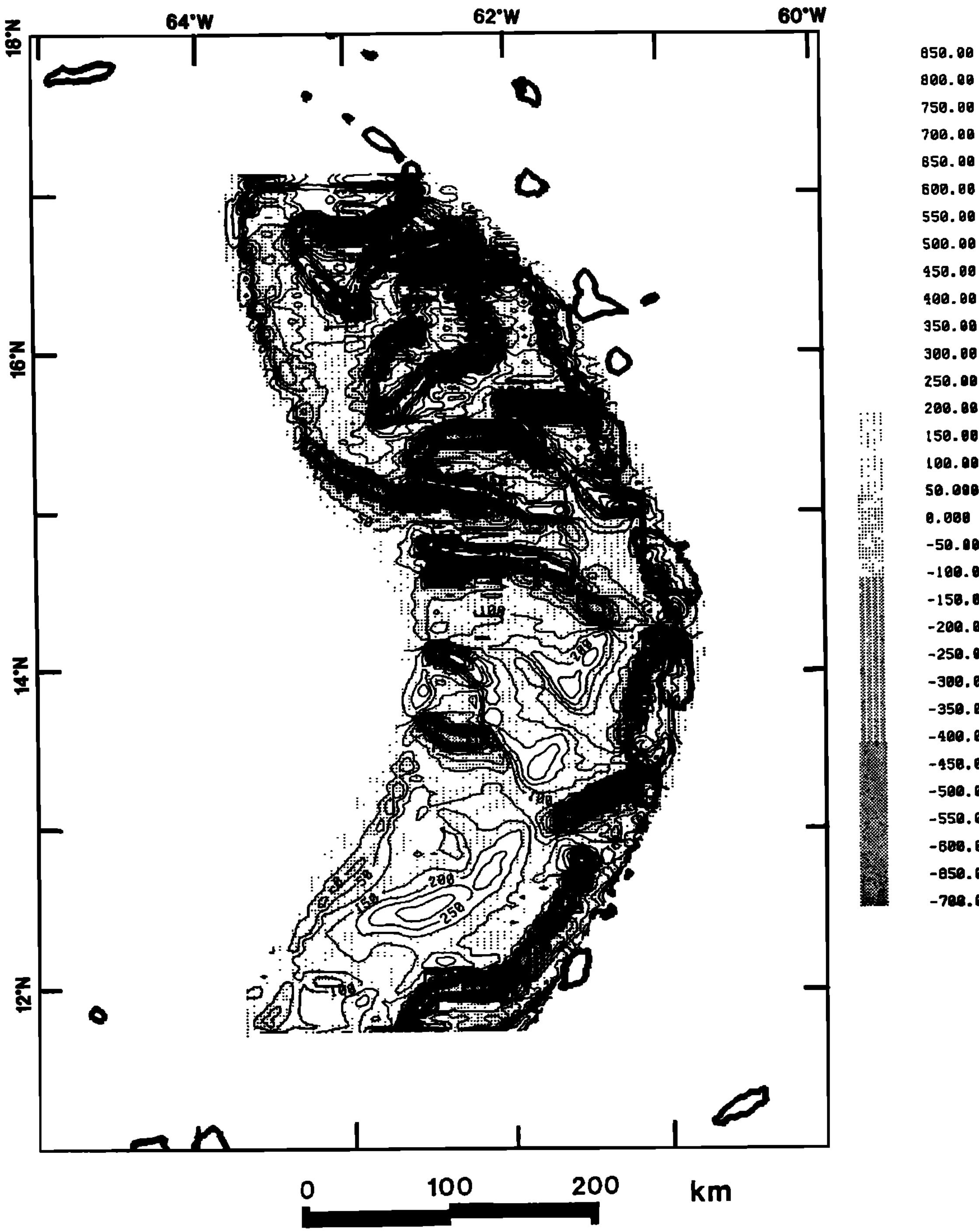

Fig. 9. (b) Calculated magnetic anomalies from the variable susceptibility model. The contour interval is 50 nT.

Lesser Antilles with the eastern flank of the Aves Ridge, by either seismic reflection or geologic means, may lead to further evidence regarding the orientation of extension and subsequent development of the basin.

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