Bird, D. E., Hall, S. A., Casey, J. F., and Millegan, P. S., 1991, Integrated geophysical interpretation of the Grenada Basin: Society of Exploration Geophysicists, 61st Annual International Meeting and Exposition, p. 172-175.

Integrated Geophysical Interpretation of the Grenada Basin

CH1.5

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SUMMARY

The Grenada Basin formed via back arc extension in Early Tertiary time. The north-south orientation of major physiographic elements along the eastern margin of the Caribbean Plate suggests that simple east-west sea floor spreading resulted in the formation of the Basin. However gridded magnetic anomalies over the Basin exhibit prominent east-west trends, suggesting north-south sea floor spreading. Present models for the formation of the Grenada Basin vary from extension oriented north-south, to extension oriented northeast-southwest, to extension oriented east-west.

An integrated interpretation of magnetics, gravity, seismic (both reflection and refraction), geologic, and well data for the Grenada Basin support near east-west extension for the formation of the Basin. Subtle, magnetic anomaly trends, subparallel to the Lesser Antilles island arc, over the southern portion of the Basin are consistent with this conclusion. Late Tertiary tectonic movements may be responsible for disrupting the magnetic signature north of 15° N.

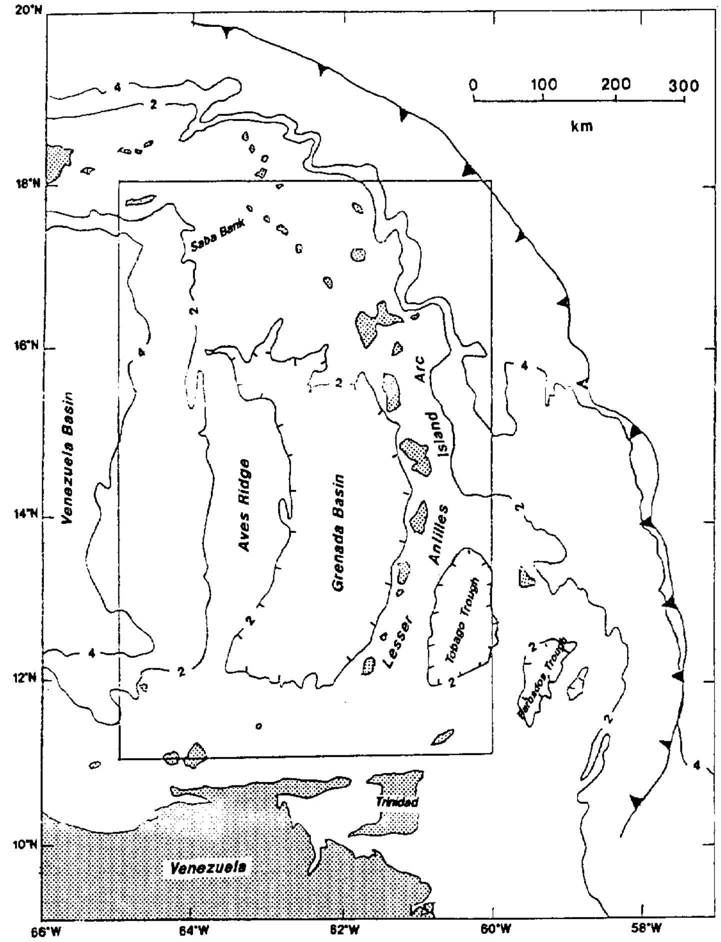

Figure 1

Major physiographic elements of the eastern Caribbean with 2 and 4 km isobaths (after Bouysee, 1984). The trench line of the subduction zone and outline of the study area are also displayed.

INTRODUCTION

The Grenada Basin is bounded on the north by the Saba Bank at the junction of the Greater and Lesser Antilles, and on the south by the continental rise of northern Venezuela (Figure 1). The Aves Swell (or Ridge), a remnant island arc, and the Lesser Antilles arc form the eastern and western limits of the basin, respectively. The shape of the basin is arcuate and has approximate dimensions of 640 km by 140 km with a north-south elongation. Average water depth is 2 to 3 km. Sediment thickness ranges from 2 km in the north to 9 km in the south (Bouysee, 1988). The relative eastward motion of the Caribbean Plate with respect to the North American/South American Plates has produced a subduction zone in which the North American/South American Plates are dipping to the west underneath the eastern edge of the Caribbean Plate. Late Tertiary tectonic movements in the region have caused the Lesser Antilles island arc, north of approximately 15° N, to bifurcate.

East-west extension appears to be supported, in part, by seismic refraction, gravity, and heat flow data. Other geophysical information, such as seismic reflection, isostatic and magnetics (Figure 2) data, indicate that the mechanism of extension may be more complicated. Although alternative models seem to be constrained by the data, the orientation of extension resulting in the formation of the basin is still conjectural. This comprehensive study reveals geophysical evidence which supports east-west extension (Tomblin, 1975).

PREVIOUS INTERPRETATIONS

Although theories on the development of the Grenada Basin generally agree it was formed during the Paleocene, the proposed directions of spreading vary by up to 90 degrees. Tomblin (1975) has described two possible scenarios for east-west extension. The first scenario involves an early Tertiary eastward shift of the subduction zone, and the second scenario involves an early Tertiary westward shift of the Aves Swell. Basin formation due to a westward shift of the Aves Swell requires the formation and subsequent spreading from a north-south oriented median ridge. While Tomblin (1975) reports that no such ridge has been observed, this scenario seems the most reasonable of Tomblin's models since it is mechanically difficult to "break" a lithospheric plate as required by an eastward shift of the subducting slab.

Intuitively, east-west extension appears most likely. Magnetic anomaly lineations over many back arc basins also support this idea (i.e., the South Sandwich, Lau, Havre, North Fiji, Banda Sea, Parece-Vela, Shikoku, and Sea of Japan Basins).

Pindell and Barrett (1990) describe a process whereby the Leeward Antilles have been coupled to the northern edge of the South American Plate. In this model north-south spreading in the vicinity of the Grenada Basin is produced by the continued eastward progression of the Caribbean Plate. The basin is thus formed via right lateral shear. If the magnetic anomalies over the basin are produced by sea floor spreading, then this model appears to "fit" the gridded magnetics data.

Pindell and Barrett's complex model may appear unlikely, however magnetic anomaly lineations over the Andaman Sea Basin are oriented at high angles to the trench line of the Andaman Subduction Zone. Magnetic anomaly lineations over the Celebes and Sulu Sea Basins are also oriented at high angles to the subducting Philippine Plate, but tectonic relationships in this region are much more intricate. These anomalies suggest that back arc extension is near parallel to the subduction zones.

Similar to Pindell and Barrett's model, Bouysee (1988) describes a possible mechanism for extension in which coupling of the lower part of the Lesser Antilles with the South American Plate also precedes opening of the basin. He suggests 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. Bouysee further theorizes that a system of segmented spreading ridges, with extension oriented northeast-southwest, resulted in the formation of the basin. Initial spreading was in the southernmost portion of the basin and gradually continued northward over time.

Back arc spreading from a system of segmented ridges is observed in the Sea of Japan. This system of spreading centers has resulted in anomaly patterns which are poorly defined, but are oriented subparallel to the island arc. The existence of magnetic anomaly lineations at high angles to the trench lines noted above (i.e., the Andaman, Celebes, and Sulu Sea Basins) can support Bouysee's model as well.

INTERPRETATION

Refraction data for the Grenada Basin and many back arc basins of the West Pacific indicate that their crusts are oceanic in nature. However the velocity structure exhibits more variability than "normal" oceanic crust. Oceanic crustal Layers 2 and 3 for back arc basins may range from 4.5 to 5.6 and 6.1 to 6.9 km/s respectively; while velocities of normal oceanic crust average 5 and 6.4 to 7.1 km/s (Ludwig et al., 1971). Also, the crusts of back arc basins may include a layer below Layer 3 displaying velocities ranging from 7.4 to 7.7 km/s; slightly slower than crust/mantle velocities described by Ludwig et al. (1971) of 7.8 to 8.5 km/s. This layer may represent an anomously high velocity lower crustal layer or a transition from lower crust to mantle velocities. Although the crusts of backarc basins may not be identical to normal oceanic crust, they do exhibit systemic, layered velocity structures similar to crusts of major ocean basins.

Forward 2-D and 3-D models, incorporating gravity and seismic data (both reflection and refraction), support

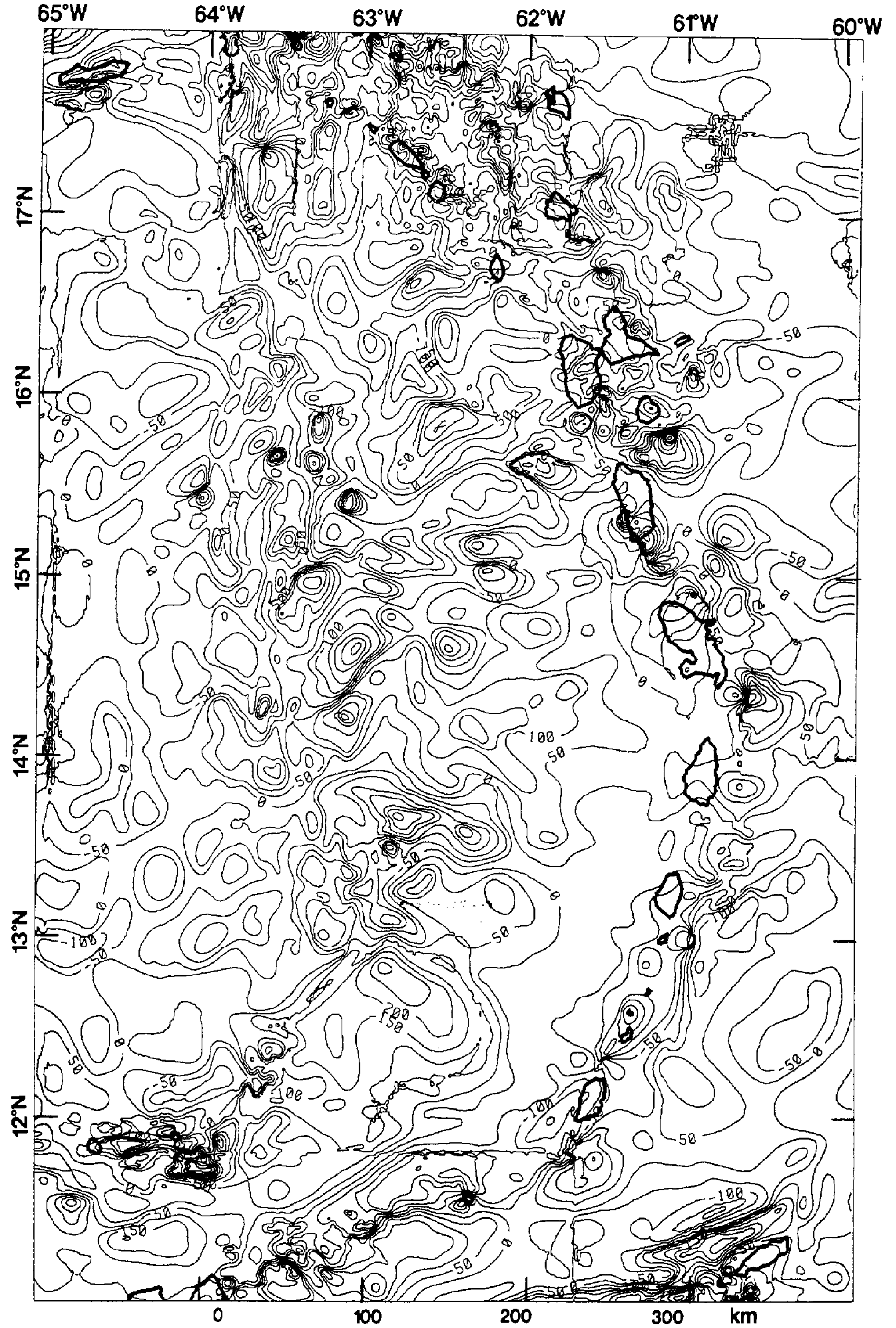

Figure 2

Total magnetic field anomalies of the study area. Gridded data (2 km) were compiled in 1987 by the Geological Society of America Decade of North American Geology Committee on the Magnetic Map of North America.

the concept of thin oceanic basinal crust bounded on the east and west by island arc material. Seismic reflection data reveal different reflection patterns in the northern and southern portions of the basin. Sediments in the north have been recently disturbed by basement movements, while reflectors in the southern portion of the basin are generally smooth and undisturbed.

A trend analysis of magnetic anomaly profiles indicate subtle, near parallel to the arc anomalies over the southern portion of the basin. These anomalies are characterized by approximately 40 nT amplitudes. Anomaly patterns over the northern portion of the basin appear to be oriented perpendicular as well as parallel to the Lesser Antilles Arc. However, similar anomalies can be correlated when the profiles are offset relative to one another.

Subtraction of calculated magnetic anomalies (constant susceptibility, single basement layer, 3-D model) from the total magnetic intensity anomalies produces subparallel to the arc anomalies over the southern portion of the basin. Inspection of the residual field reveals anomalies oriented north-south to northeast-southwest in the southern portion of the basin. Residual magnetics over the northern portion form irregular patterns.

It is suggested here that the marked difference between the northern and southern portions of the basin is genetically linked to the Late Tertiary tectonic movements responsible for bifurcation of the Lesser Antilles. Hence, the development of the Grenada Basin is interpreted to be affected by two tectonic events. First, Early Tertiary near east-west extension, possibly from a system of segmented ridges similar to those observed in the Sea of Japan, lead to the formation of the basin. Second, Late Tertiary compression resulted in a westward shift of the center of volcanism north of 15°N. This second event also disrupted the crust of the northern portion of the basin as well as the magnetic signature.

The relatively small size of the Basin, when compared to most ocean basins, results in a limited number of magnetic anomalies produced by sea floor spreading (given average spreading rates of 1 to 7 cm/a). As a result of this, a definitive correlation with the geomagnetic time reversal scale is impossible. Thus, it should be noted that the results of this interpretation, with regard to magnetics, cannot absolutely confirm the age or orientation of any sea floor spreading.

CONCLUSION

An integrated interpretation of geophysical and geologic data for the Grenada Basin suggests that the Basin formed via east-west extension in Early Tertiary time. Late Tertiary compressional tectonic movements disrupted the northern portion of the Basin including its magnetic field. These conclusions are consistent with the east-west mechanism for the formation of the Basin proposed by Tomblin (1975).

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