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## Magnetic studies in the Cayman Trough, Caribbean Sea

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About 2400 line km of magnetic and bathymetric data were collected between the western margin of Jamaica and the eastern margin of Belize covering the Cayman Trough. The echograms show rugged topography between 80° W and 85° W longitude. The mid-Cayman spreading centre is characterized by a rift valley with 4000 m depth. Sea-floor spreading-type linear magnetic anomalies have been observed in the Cayman Trough. A synthetic sea-floor-spreading model is generated across the spreading axis with crustal block thickness of 1 km and a susceptibility of 0.002 cgs units. The anomaly numbers 1 to 8 have been identified on the west and anomalies 1 to 5A on the east of the spreading axis which is located around 81°39' W. The half-spreading rates of 10 mm · yr<sup>-1</sup> (0-2.47 Ma) and 20 mm · yr<sup>-1</sup> (2.47-27.74 Ma) are estimated in the Cayman Trough. The crust west of anomaly 8 appears to form the Continent Ocean Boundary off Belize. It is suggested that the opening of the Cayman Trough was initiated prior to late Oligocene.

On a fait collection d'à peu près 2400 km linéaires de données magnétiques et bathymétriques entre le bord occidentale de la Jamaïque et le bord de l'est de Bèlize le long du Chenal du Caïman. Les échogrammes démontrent une topographie accidentée entre les longitudes de 80° O et de 85° O. Le centre qui s'étend au milieu du Caïman est caractérisé d'un graben d'une profondeur de 4000 m. On a constaté dans le Chenal du Caïman des anomalies magnétiques linéaires de sorte qui s'étend le long du fond de la mer. Un modèle synthétique qui s'étend le long du fond de la mer se produit à travers l'axe étendu dont la croûte est d'une épaisseur en bloc de 1 km et d'une sensibilité de 0,002 unités de cgs. On a identifié les anomalies numéro 1 jusqu'à 8 à l'ouest et les anomalies 1 jusqu'à 5A à l'est de l'axe étalé qui se trouve à 81°39' O. On estime les taux à moitié étalés de 10 mm · an<sup>-1</sup> (0-2.47 Ma) et 20 mm · an<sup>-1</sup> (2.47 à 27.74 Ma) dans le Chenal du Caïman. Il paraît que la croûte située à l'ouest de l'anomalie 8 compose la Frontière Océanique Continentale au large de Bèlize. Il semble que le Chenal du Caïman a commencé à s'élargir avant la fin de l'Ère Oligocène.

Se ha coleccionado unos 2400 km lineares de datos magnéticos y batimétricos entre el borde occidental de Jamaica y el borde del este de Bèlice a lo largo del Tragadero del Caïman. Demuestran las ecogramas una topografía accidentada entre las longitudes de 80° O y 85° O. El centro extendido situado en medio del Caïman se caracteriza por un valle escarpado de una profundidad de 4000 m. En el Tragadero del Caïman se han observado anomalías magnéticas lineares del género que se extiende a lo largo del fondo del mar. Se produce un modelo sintético que se extiende a lo largo del mar a través del eje extendido cuya costra es de un espesor en bloque de 1 km y de una sensibilidad de 0,002 unidades de cgs. Se han identificado las anomalías número 1 hasta 8 en el oeste y las anomalías 1 hasta 5A en el este del eje extendido que se encuentra aproximadamente en 81°39' O. Se estima las tasas medio extendidas de 10 mm · año<sup>-1</sup> (0-2.47 Ma) y de 20 mm · año<sup>-1</sup> (2.47 hasta 27.74 Ma) en el Tragadero del Caïman. Parece que la costra situada en el oeste de la anomalía 8 constituye la Frontera Océánica Continental a distancia de Bèlice. Puede que ser que el Tragadero del Caïman comenzó a extenderse antes del fin de la Época Oligocena.

### Introduction

The pre-Cretaceous history of the Cayman Trough has been extrapolated from the Paleozoic-Mesozoic geology and structures of Central America and Cuba. The Cretaceous to

Holocene evolution of the trough has been attributed to the relative motions between the North American and Caribbean plates (Perfit and Heezen 1978). According to them plate convergence during the Cretaceous caused southerly subduction of oceanic lithosphere beneath the ancestral Cayman Ridge - Nicaraguan plateau, which subsequently led to the formation of a chain of volcanic islands to the south along the North American - Caribbean plate boundary. Early

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Tertiary left-lateral shear and tensional stresses along this plate boundary split the Cayman Ridge from the Nicaraguan plateau giving rise to a small spreading centre in the Cayman Trough (Perfit and Heezen 1978). This mid-Cayman spreading centre plays a major role in regional plate reconstructions (Rosencrantz and Sclater 1986). Several geophysical investigations have been carried out by Bowin (1968), Brune (1968), Molnar and Sykes (1969), Malfait and Dinkleman (1972), Erickson et al. (1972), Holcombe et al. (1973), Perfit (1977), Holcombe and Sharman (1983), and Rosencrantz and Sclater (1986) in the Cayman Trough for the determination of depth, age, and nature of the crust.

The main objective of the Caribbean Ocean Resources Exploration (CORE) programme, sponsored by the Commonwealth Science Council and CARICOM countries, is acquisition, processing, and interpretation of geophysical data besides imparting on-the-job training to the Caribbean scientists for planning objective-oriented cruise programmes. The Cayman Trough area has been selected for the present study because of its complex evolution since early Cretaceous. About 2400 line km of magnetic and

bathymetric data were collected along predetermined tracks in the Cayman Trough on board the O.R.V. *Sagar Kanya* in 1990 (Fig. 1).

## Underway Geophysical Data

### Position Fixing

A Magnovax Global Positioning System (GPS) was used for obtaining the positions during the survey in conjunction with the Integrated Navigation System on board the O.R.V. *Sagar Kanya*. The GPS had provided the positions for almost 24 h in a day during the survey period. The ship's speed was kept at 8 knots throughout the survey.

### Bathymetry

The vessel is equipped with a shallow-water, narrow-beam sounder (NBS) and a deep-sea pinger (DPS), both echosounders of M/S Honeywell Elac, Federal Republic of Germany, for carrying out bathymetry surveys. The NBS (12 kHz) was used for measuring the depth to the sea bed in the present investigations. During the survey the echosounding data was recorded on a 25.5-cm-wide electrostatic paper

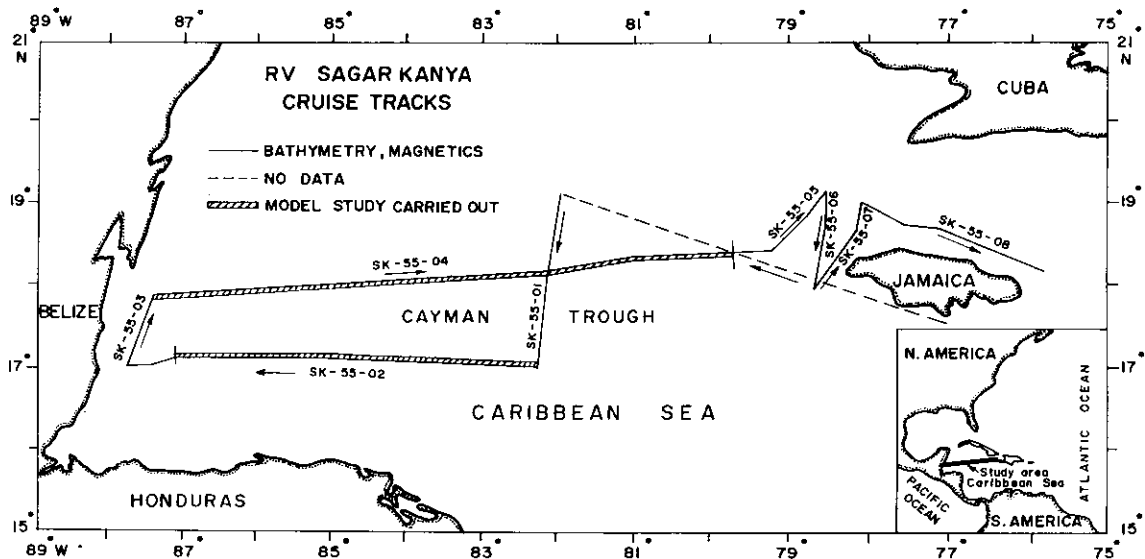


Fig. 1. Cruise tracks in the Cayman Trough.

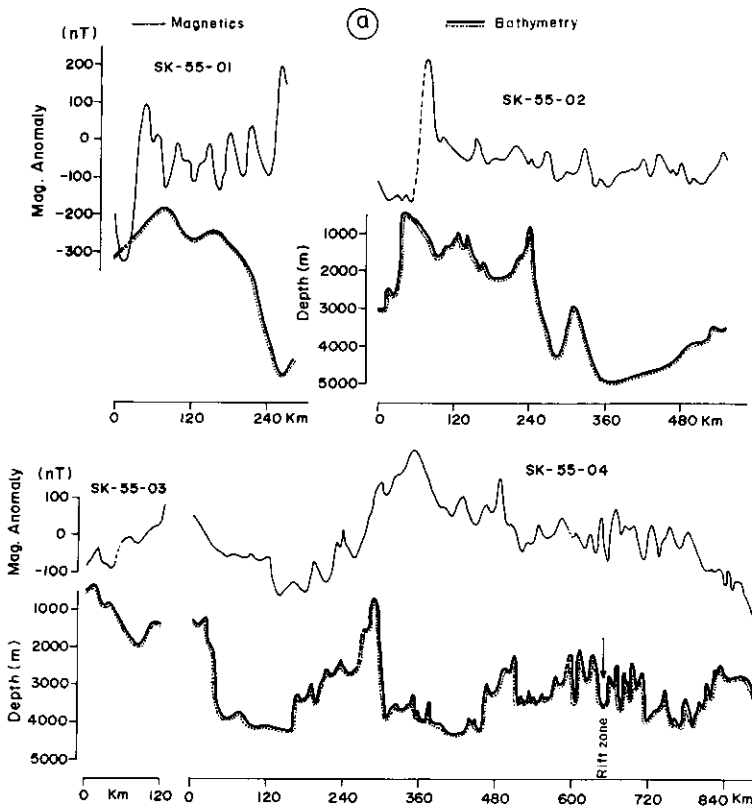


FIG. 2(a). Bathymetry and residual magnetic anomalies along the profiles. Magnetic anomaly (—); sea-floor topography (—).

with optional delays and selected resolution of less than 1 m.

The depth to the sea bed is plotted along the profiles as shown in Fig. 2. In addition to the echosounding data obtained during the cruise, the depths published in the Hydrographic Chart 4402 (International Chart Series, North Atlantic Ocean, Caribbean Sea, produced by the Hydrographic Surveys of the Royal Netherlands, Navy, 1976, and printed in 1987) were also used for constructing the geomorphic map (Fig. 3) of the Cayman Trough and adjacent areas.

### Magnetics

The earth's total magnetic intensity observations were recorded between the western continental

margin of Jamaica and off Belize covering the Cayman Trough, using a Proton Precession Marine Magnetometer (Geometrics, model G 801/3) with  $\pm 1$  nT accuracy. Magnetic data were collected by towing the magnetometer sensor nearly 270 m astern the 108.6-m-long vessel to avoid the effect of the ship's magnetic field. The bathymetry and magnetic data have been recorded digitally along with navigation data on a magnetic tape on an INS computer. Besides, the magnetic data were also recorded in two scales, i.e., 100 nT and 1000 nT continuously in analog form using a strip-chart recorder. This facilitated the quality control of the data recording. The earth's total intensity magnetic field in the study area varied between 41 182 and 43 294 nT. The data was reduced by subtracting the International Geomagnetic Reference Field (IGRF) values computed at each observation point using spherical harmonic coefficients published by the IAGA Division I Working Group 1 (1985).

### Geomorphology

A map depicting various geomorphological features between the latitudes  $17^{\circ}$  N and  $22^{\circ}$  N and longitudes  $75^{\circ}$  W and  $83^{\circ}$  W has been presented for the area (Fig. 3). The inner shelf boundary off Jamaica, Pedro Bank, Rosalind Bank, Explorer Shoal, shelf break, boundary of Cayman Trough, major scarps, depressions, regional terraces, and axis of spreading have been vividly shown. The northern offshore region of Jamaica is characterized by major scarps or faults and steep continental slopes. The Cayman Trough is associated with a group of north-south topographic highs and lows. Seismic reflection and bathymetric studies across the

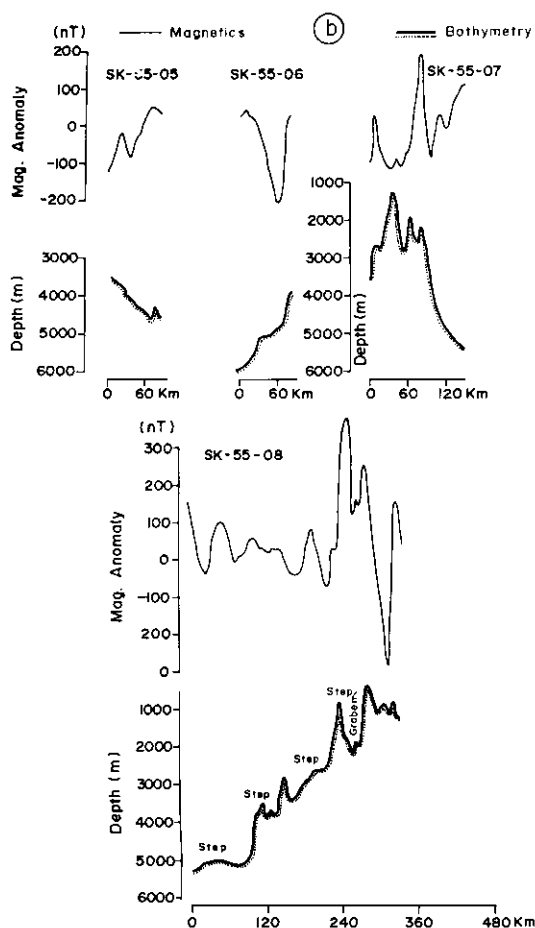


FIG. 2(b). Bathymetry and residual magnetic anomalies along the profiles. Magnetic anomaly (—); sea-floor topography (—).

Cayman Trough by Holcombe et al. (1973) revealed the presence of north-south oriented ridges and valleys on either side of the rift valley that corresponds to a spreading axis.

## Results

### Bathymetry

The depth to the sea bed varies from a minimum of 300 m off Belize (SK-55-03) and Jamaica (SK-55-08) to more than 5900 m north-west of

Jamaica (Fig. 2). However, in the Cayman Trough the depth to the sea bed varies between 300 m (SK-55-01) and about 6000 m (SK-55-02). Very rugged topography prevails on either side of the spreading axial zone (SK-55-04) in the Cayman Trough. The sea bed topography rises from a depth of 5500 m to less than 500 m along SK-55-08 north of Jamaica giving rise to step-like features appearing as horst-and-graben structures.

### Magnetics

The residual magnetic anomalies along profiles SK-55-02 and SK-55-04 resemble typical oceanic anomalies that are generated by a spreading centre (Fig. 2). The amplitudes of the magnetic anomalies, in general, are in the range of 100–150 nT except on the northern and southern boundaries of the Cayman Trough (SK-55-01). The amplitudes of the anomalies are relatively high with larger wavelengths between longitudes 83° W and 85° W on the profile SK-55-04.

### Model Studies

A two-dimensional synthetic sea-floor-spreading magnetic model (Fig. 4) has been generated by assuming a constant crustal layer thickness of 1 km, susceptibility of 0.002 cgs units, and present-day magnetic inclination (47.45°) and declination (0.1° W). The magnetic reversal polarity time scale of Berggren et al. (1985) was used for generating the synthetic anomaly model. The sea-floor topography of the study area along profile SK-55-02 was used for constructing the successive normal and reversal polarity blocks of 1 km thickness. These blocks in turn were used for computing the synthetic magnetic anomaly with the assumed value of susceptibility. Then the observed anomalies along profiles SK-55-02 and SK-55-04 were correlated with the synthetic model (Fig. 4), and magnetic anomalies 1, 2A, 3, 4, 4A, 5, 5A, 5C, 6, 6AA, 6C, 7, and 8 were identified corresponding to the age of the ocean crust of present to late Oligocene. The identification of anomaly 8 is tentative. The identification of anomalies from 5A to 8 on profile SK-55-04 was slightly difficult be-

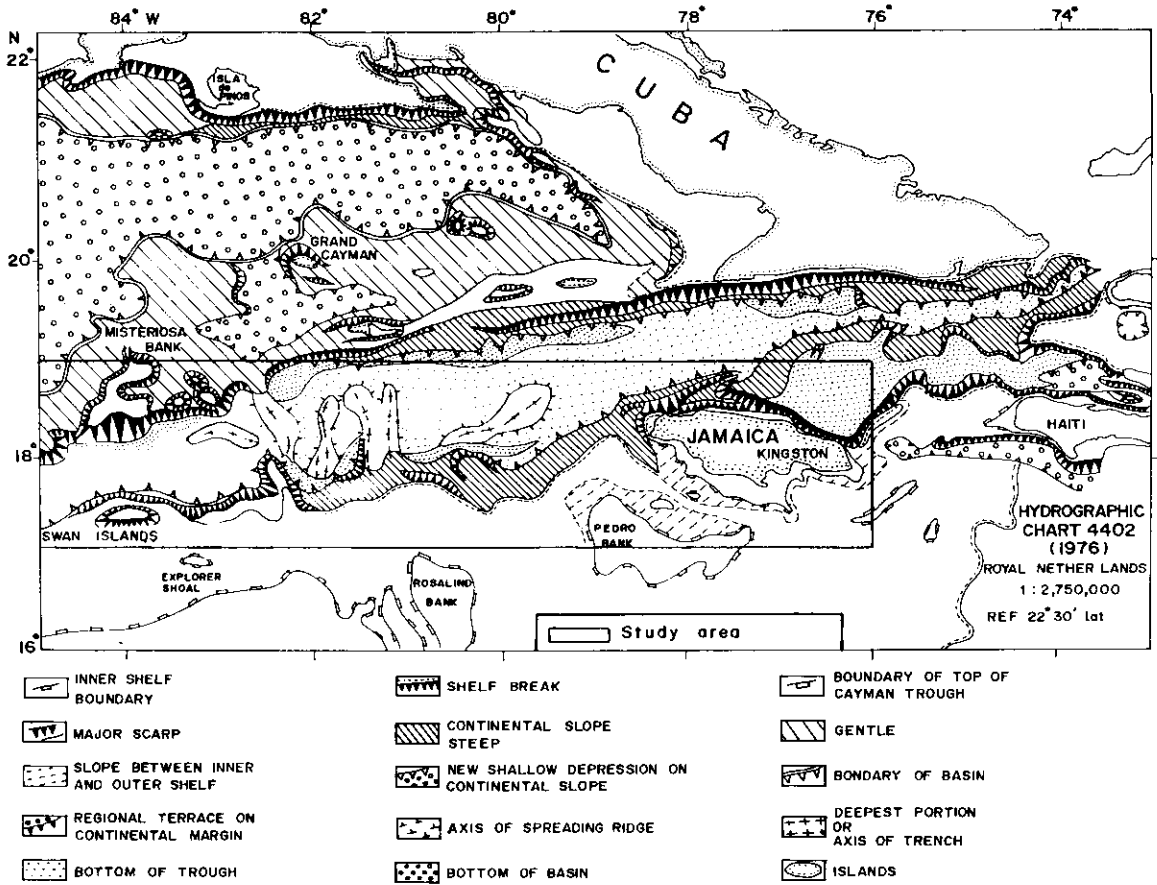


FIG. 3. Geomorphic units associated with the Cayman Trough and adjacent areas.

cause the anomaly signatures seem to be influenced by the Motagua-Polochi fault zone. However, these anomalies are reflected more clearly on profile SK-55-02, which helped in consolidating our identifications. The model also suggests that the estimated half-spreading rate of  $10 \text{ mm} \cdot \text{yr}^{-1}$  for the younger crust is limiting to anomaly 2A (2.47 Ma) whereas the anomalies 2A to 8 (2.47–27.74 Ma) are evolved with a half-spreading rate of  $20 \text{ mm} \cdot \text{yr}^{-1}$ .

### Discussion

The depth in the rift valley of the spreading centre varies from 2000 to 4000 m (Fig. 2). It

is flanked by rugged topography on either side up to a distance of about 140 km suggesting that the ocean floor is relatively young. Beyond this distance on the western flank, the sea bed is comparatively smooth probably inferring that the ocean floor of this region was generated at a higher rate of spreading. Several NE-SW trending faults north of Jamaica shown by Rosencrantz and Sclater (1986) are observed in the present study in the form of step-like rises and grabens. Land (1979) interpreted a series of horst-and-graben-like features in the eastern margin of the Cayman Trough, north of Jamaica, that are capped with clastic deposits of Eocene age which are down-faulted. The observed step-like rises (SK-55-08) seem to be the manifesta-

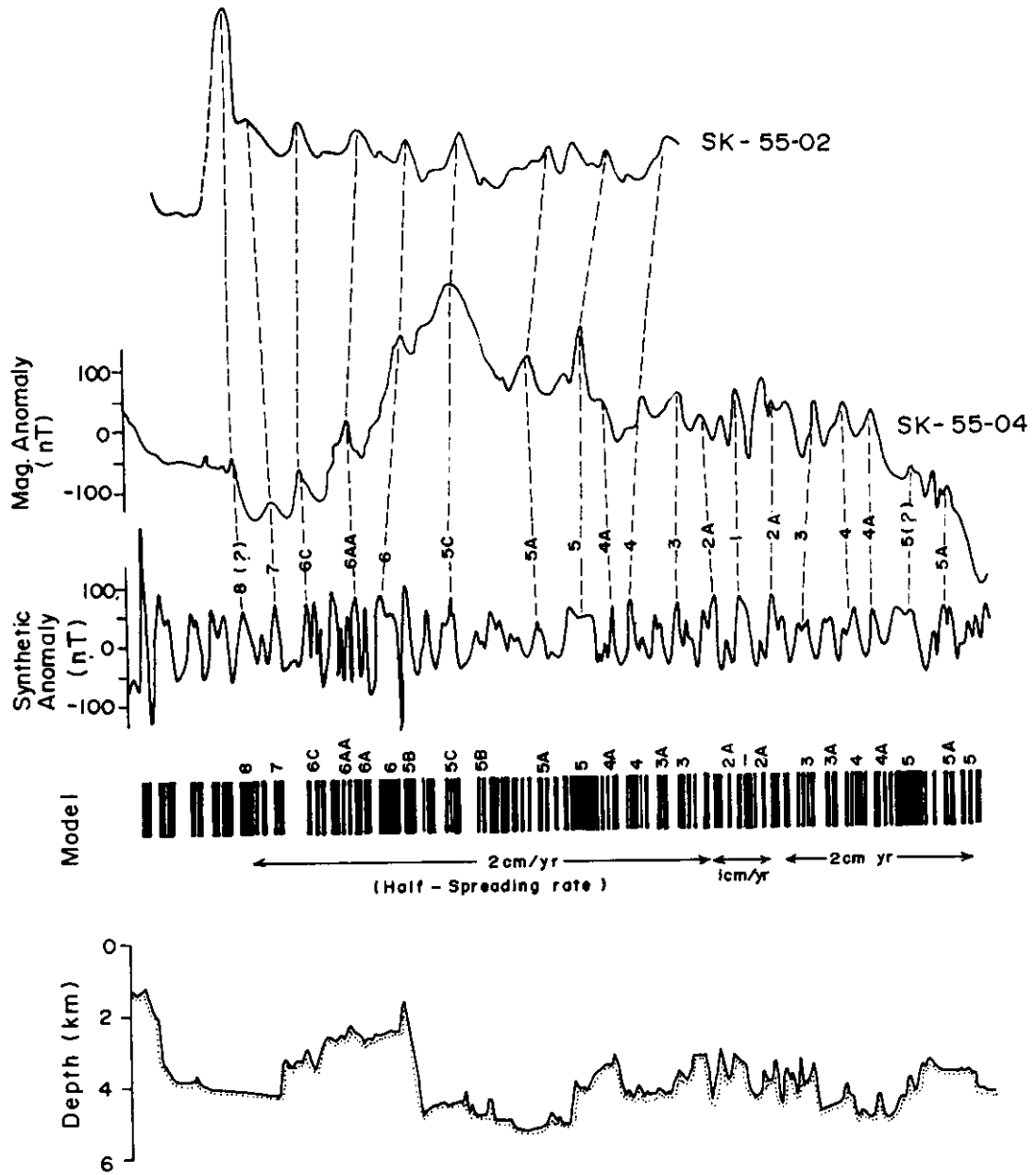


FIG. 4. The synthetic sea-floor-spreading anomaly model generated corresponding to normal and reversal time scale (Berggren et al. 1985) along profile SK-55-04. The magnetic anomalies on profiles SK-55-02 and SK-55-04 are correlated with the synthetic model.

tion of the NE–SW trending faults as reported by Land (1979). These faults are seen associated with high-amplitude magnetic anomalies (SK-55-08).

The residual magnetic anomalies along SK-55-02 and SK-55-04 in the Cayman Trough resemble typical sea-floor-spreading magnetic anomalies and are associated with rugged topographic expressions. The axis of the rift valley lies around  $81^{\circ}39'$  W longitude on SK-55-04. The amplitudes of the anomalies are relatively low. The north–south profile SK-55-01 right across the Cayman Trough runs parallel to the spreading axis and is characterized by large amplitude magnetic anomalies at the northern and southern ends (Fig. 2). The observed large amplitudes of magnetic anomalies are perhaps due to the Cayman Ridge in the north and the Nicaraguan rise in the south, which are the topographic boundaries of the Cayman Trough. According to Perfit and Heezen (1978), the Cayman Ridge and Nicaraguan Rise are a single unit that extended east of the present Honduras coast prior to the Cretaceous period, and the Motagua–Polochi left-lateral strike-slip fault was the locus of submarine volcanism and eugeosynclinal sedimentation throughout the Cretaceous period. Further, it is stated that the upliftment of the Nicaraguan plateau in the middle Miocene caused renewed faulting and minor volcanism. The high-amplitude broad wavelength magnetic anomalies observed along a portion of profile SK-55-04 ( $83^{\circ}$  W –  $84^{\circ}30'$  W) seem to originate from the Motagua–Polochi fault zone.

The Cayman Trough, 120–180 km wide, is seismically active (Sykes and Ewing 1965). Molnar and Sykes (1969) were of the opinion that the trough is still developing and the present-day configuration attained its shape in the Miocene period. The part of the Cayman Trough between  $79^{\circ}$  W and  $87^{\circ}30'$  W is associated with the sea-floor-spreading magnetic anomalies SK-55-02 and SK-55-04 (Fig. 2) with relatively low amplitudes (100–150 nT). A similar order of anomalies were earlier reported by Holcombe et al. (1973) and MacDonald and Holcombe (1978).

In this report, study of the sea-floor-spreading magnetic model suggests that the spreading history of the Cayman Trough initiated in the late Oligocene with half-spreading rates of 10 to 20 mm  $\cdot$  yr<sup>-1</sup>. These spreading rates concur with the rates reported by MacDonald and Holcombe (1978) and Rosencrantz and Sclater (1986). The spreading scenario presented by MacDonald and Holcombe (1978) is limited to the identification of anomaly 4' ( $\approx$  8 Ma), which was subsequently interpreted by Rosencrantz and Sclater (1986) as anomaly 5C (16–17 Ma). The present authors have identified still older anomalies up to 8 (27.74 Ma) on the western side of the mid-Cayman spreading axis while only up to anomaly 5A on the eastern side. The spatial distribution of these anomalies are shown in Fig. 5 for a better understanding. Inadequate data east of anomaly 5A in the western offshore region of Jamaica restricted further identification.

The gravity and magnetic model studies of Dillon and Vedder (1973) have shown the transition of continental crust to oceanic at a distance of about 120–150 km from the coast of Belize. The tentative identification of older anomaly 8 from the present study, which lies around 130–150 km from the Belize coast ( $\approx$   $87^{\circ}$  W), appears to coincide with this crustal transition as shown by Dillon and Vedder (1973). The authors are therefore of the view that the crust west of anomaly 8 (27.74 Ma, late Oligocene) forms the Continent Ocean Boundary off Belize in the western region of the Cayman Trough. Additional geophysical data off Belize perhaps substantiate this view more convincingly.

High-amplitude magnetic anomalies are observed along SK-55-05, SK-55-06, and SK-55-07. These high amplitude anomalies have been attributed in this study to Tertiary faults that traversed the Jamaican island and extend into the western offshore region of Jamaica. Further, the observed large amplitude magnetic anomalies on profile SK-55-09 north of Jamaica appear to be generated by a series of step-like features controlled by horst and grabens.

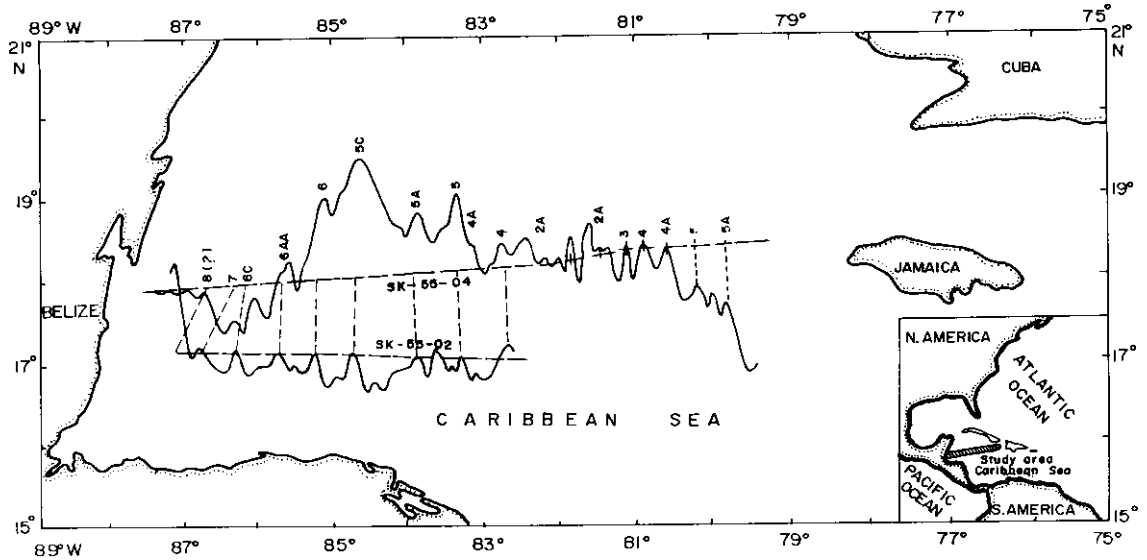


FIG. 5. The spatial distribution of magnetic anomaly isochrones in the Cayman Trough.

The ocean floor between anomaly 5A and the western shelf of Jamaica is least studied. Additional geophysical data would provide the missing link between Central America and the Lesser and Greater Antilles, and a new model for the evolution of a northern boundary of the Caribbean plate.

### Conclusions

The depth in general varied from less than 300 m off Belize in the west and off Jamaica in the east to around 6000 m in the study area. The Cayman Trough associated with a spreading centre around  $81^{\circ}39' W$  longitude is characterized by a rift valley of 4000 m depth. On either side of the rift valley, the sea floor is characterized by rugged topography.

Sea-floor-spreading magnetic anomalies are noticed in the Cayman Trough between  $79^{\circ}40' W$  and  $87^{\circ}30' W$  longitudes. The amplitudes of the anomalies are 100–150 nT except over the region  $83^{\circ} W$  to  $85^{\circ} W$  on profile SK-55-04. These high amplitude anomalies are due to the Motagua–Polochi fault zone.

A synthetic sea-floor-spreading model has been generated across the spreading centre in the Cayman Trough. Magnetic anomalies 1, 2A, 3, 4, 4A, 5, 5A, 5C, 6, 6AA, 6C, and 7 are identified confidently while only up to anomalies 5A have been identified towards the east. Identification of anomaly 8 (27.74 Ma) off Belize is tentative. This seems to be the oldest anomaly in the Cayman Trough. The Continent Ocean Boundary off Belize coincides with the crust west of anomaly 8 (27.74 Ma). This led the authors to believe that the opening of the Cayman Trough might have taken place prior to late Oligocene.

It is expected to have a similar sequence of anomalies beyond 5A towards Jamaica. Inadequate magnetic data in this area constrained the authors in identification of these anomalies.

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- Berggren, W. A., D. V. Kent, J. J. Flynn, and J. A. V. Couvering. 1985. Cenozoic geochronology. *Geol. Soc. Am. Bull.* **96**: 1407-1418.
- Bowin, C. O. 1968. Geophysical study of the Cayman Trough. *J. Geophys. Res.* **73**: 5159-5173.
- Brune, J. N. 1968. Seismic moment, seismicity and the rate of slip along major fault zones. *J. Geophys. Res.* **73**: 777-784.
- Dillon, W. P., and J. G. Vedder. 1973. Structure and development of the continental margin of British Honduras. *Geol. Soc. Am. Bull.* **84**: 2713-2732.
- Erickson, E. J., G. E. Helsley, and G. Simmons. 1972. Heat flow and continuous seismic profiles in the Cayman Trough and Yucatan Basin. *Geol. Soc. Am. Bull.* **83**: 1241-1260.
- Holcombe, T. L., and G. F. Sharman. 1983. Post-Miocene Cayman Trough evolution: a speculative model. *Geology* **11**: 714-717.
- Holcombe, T. L., P. R. Vogt, J. E. Mathews, and R. R. Murchinson. 1973. Evidence of seafloor spreading in the Cayman Trough. *Earth. Plan. Sci. Lett.* **20**: 357-371.
- IAGA Division I Working Group 1. 1985. International geomagnetic reference field revision. *J. Geomagn. Geoelectr.* **37**: 1157-1163.
- Land, L. S. 1979. The fate of reef derived sediment on the north Jamaican island slope. *Mar. Geol.* **29**: 55-71.
- MacDonald, K. C., and T. L. Holcombe. 1978. Inversion of magnetic anomalies and seafloor spreading in the Cayman Trough. *Earth. Plan. Sci. Lett.* **40**: 407-414.
- Malfait, B. T., and H. G. Dinkleman. 1972. Circum-Caribbean tectonic and igneous activity and the evolution of the Caribbean plate. *Geol. Soc. Am. Bull.* **83**: 251-272.
- Molnar, P., and L. R. Sykes. 1969. Tectonics of the Caribbean and middle America regions from focal mechanisms and seismicity. *Geol. Soc. Am. Bull.* **80**: 1639-1664.
- Perfit, M. R. 1977. Petrology and geology of mafic rocks from the Cayman Trench: Evidence for spreading. *Geology* **5**: 105-110.
- Perfit, M. R., and B. C. Heezen. 1978. The geology and evolution of the Cayman Trench. *Geol. Soc. Am. Bull.* **89**: 1115-1174.
- Rosencrantz, E., and J. G. Sclater. 1986. Depth and age in the Cayman Trough. *Earth. Plan. Sci. Lett.* **79**: 133-144.
- Sykes, L. R., and M. Ewing. 1965. The seismicity of the Caribbean region. *J. Geophys. Res.* **70**: 5065-5070.