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STRUCTURE AND SPREADING HISTORY OF THE CENTRAL CAYMAN TROUGH

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ABSTRACT

Based on newly acquired seismic, magnetic, and sidescan data in the central Cayman Trough, we are able to identify new relationships that bear on the recent development of the region. The presence of a crustal block within the rift valley, the absence of basalt on the top of faulted blocks on the inward-facing rift valley walls, and an offset of the south wall of the trough east of the rift-transform intersection may be explained by a ridge jump and subsequent oblique opening of the rift valley at about one million years ago. The oblique opening results from a right-lateral component of movement between the two walls of the valley.

Orientation of a nodal basin at the southern rift-transform intersection and depth relations west and east of the intersection support the argument in favor of principal transform motion being restricted to the northeast and southwest margins of the trough, as proposed by Holcombe and others (1973). Although there is sidescan-sonar evidence of structural activity along the south margin of the trough east of the rift-transform intersection, it is unlikely that there is any significant transform motion along this segment of the margin.

INTRODUCTION

The Cayman Trough is an easterly oriented strike-slip transform-spreading system (Holcombe and others, 1973) that has formed the northwestern Caribbean plate boundary (Fig. 1) since Eocene time (Molnar and Sykes, 1969; Malfait and Dinkelman, 1972). Almost centered along the trough at about 81°41'W is a north-trending rift valley (Fig. 2A). East of the rift valley, the Oriente Transform Fault extends along the northern wall of the trough where it forms the plate boundary and the boundary between the continental rocks of the Cayman Ridge and the oceanic rocks of the trough (Fig. 2) (Ewing and others, 1960; Eggler and others, 1973; Perfit, 1977). West of the rift valley, the Swan Islands Transform Fault forms the plate boundary located along the south wall of the trough, and, like the Oriente Transform Fault, it generally follows the boundary between oceanic crust of the Cayman Trough and continental rocks, in this case rocks of the Nicaraguan Rise (Fig. 2). An exception is noted where the fault appears to lie south of the Swan Islands microblock (Rosencrantz and Sclater, 1986), which is underlain by continental rocks.

The eastward motion of the Caribbean plate relative to the North American plate has formed a sea-floor spreading system at a jog on the plate boundary that has created new ocean crust that floors the entire trough. The rate at which sea-floor spreading has been taking place is equivalent to the rate at which the two plates are moving past each other. The spreading rate in the Cayman Trough has not been determined unequivocally because of the difficulty in identifying and correlating magnetic anomalies. However, Rosencrantz and others (1988) concluded that the spreading rate in the Cayman Trough has been 1.5 cm/yr for the past 26 Ma based on magnetic lineations, crustal subsidence, and bathymetry and by invoking several ridge jumps. Numerous estimates have also been made based on other lines of evidence such as geologic and geographic relations that give a range of 0.4- to 4.0 cm/yr. The object of this study is to examine the detailed structure of the central Cayman Trough in the light of new simultaneously gathered single-channel seismic, magnetic, and GLORIA (Geologic LOng-Range Inclined Asdic) sidescan-sonar data (Fig. 3). Based on already published data and these new data, we identified relationships that bear on the recent development of the Cayman Trough.

The GLORIA sidescan sonar system (Somers and others, 1978) is a broad-coverage (swath width of about 40 km in water depths greater than 3000 m), low-resolution system (pixel size is about 50- by 150 m in the field data) capable of rapidly surveying very large areas. Processing techniques to correct for geometric and radiometric distortions and to enhance the images were applied to the data followed by digital compilation into a map-coordinated system to create a sidescan-sonar mosaic.

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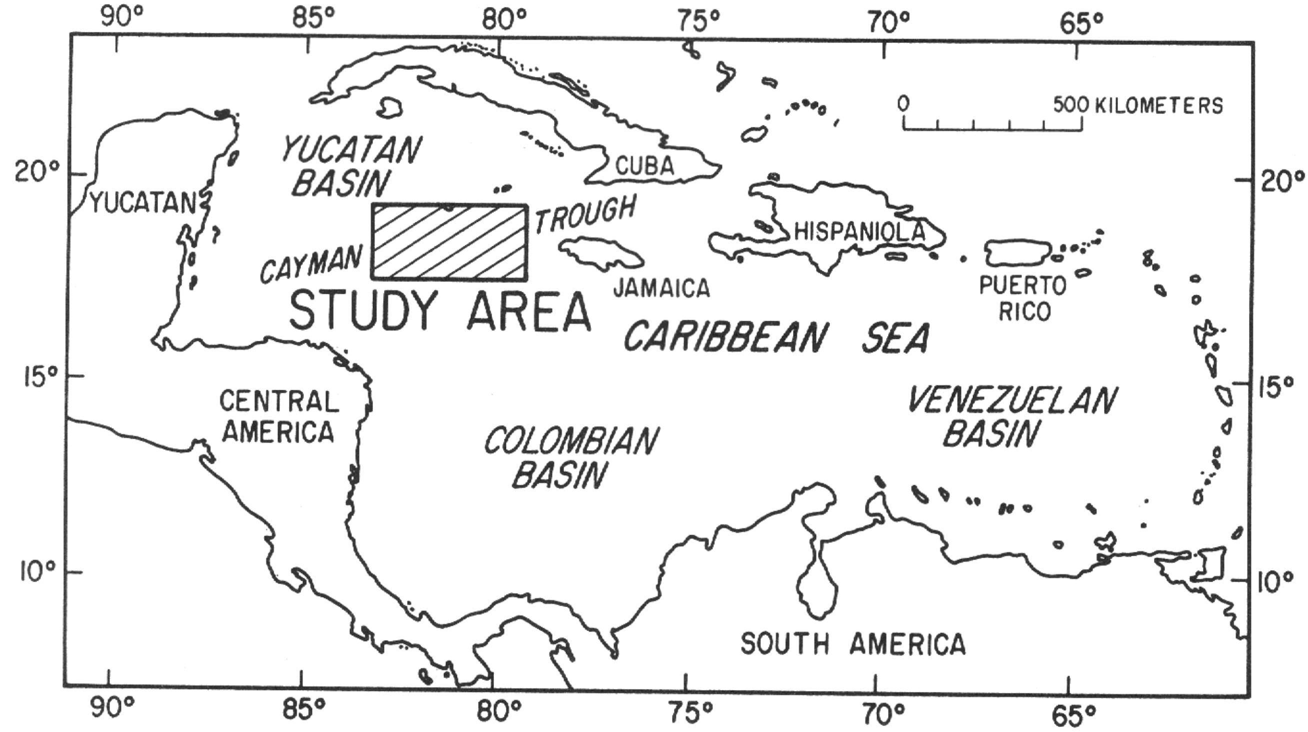

Figure 1. Map of the Caribbean region showing the area of study in the Cayman Trough

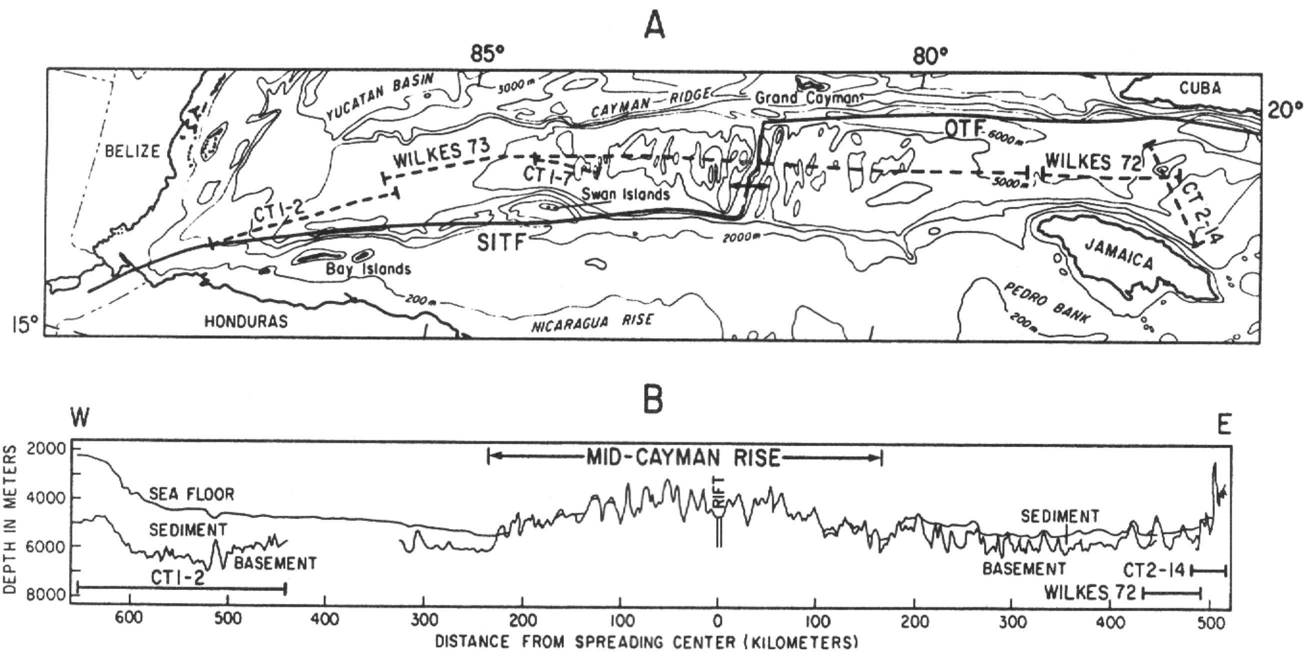

Figure 2. (A) Bathymetric map of the Cayman Trough showing the locations of U.S. Navy Wilkes single channel seismic line and two University of Texas multichannel seismic lines that are combined in part B of this figure. OTF= Oriente Transform Fault; SITF= Swan Islands Transform Fault (Rosencrantz and Sclater, 1986). — (B) Line drawing of the U.S. Navy Wilkes single-channel seismic profile and the University of Texas multichannel seismic data showing the Mid-Cayman Rise and the more subdued, sediment-covered seafloor on each side of the rise. (Rosencrantz and Sclater, 1986).

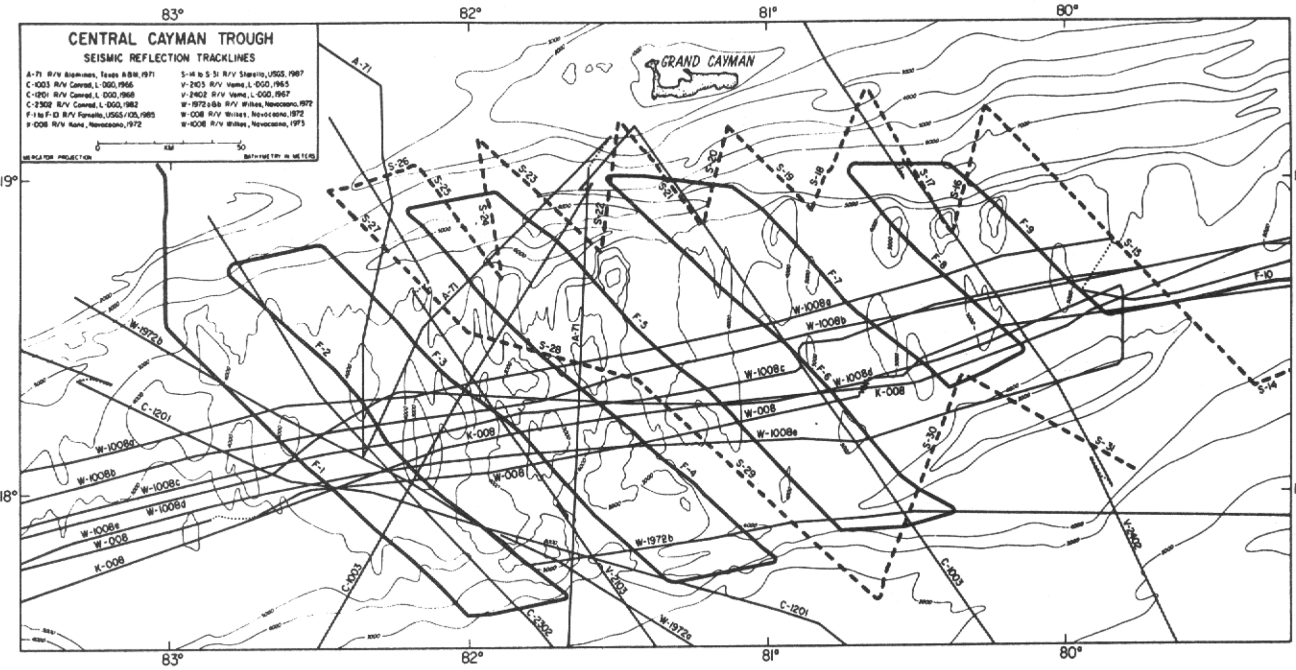

Figure 3. Seismic reflection track lines over the Central Cayman Trough. The Gloria sidescan tracks (R/V Farnella) are the heavy southeast oriented lines. The dashed lines are the R/V Starella lines. Bathymetry is after Jacobs and others (1989).

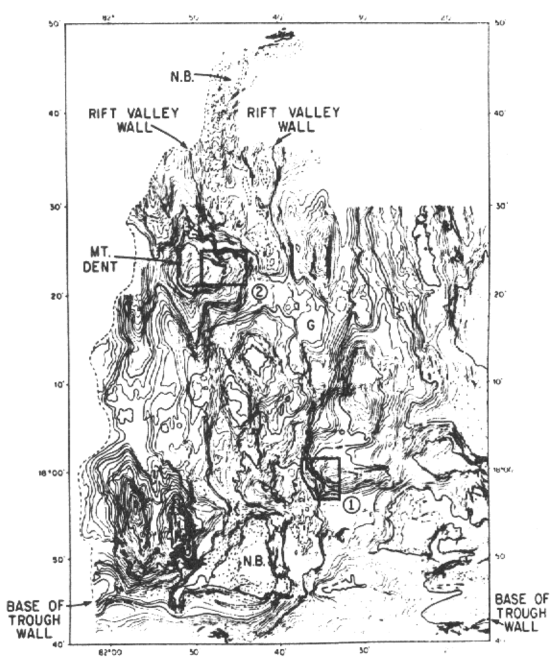

Figure 4. U.S. Navy multibeam bathymetry of the central region of the Mid-Cayman Rise, showing locations of the two ALVIN and one TRIESTE dive areas (CAYTROUGH, 1978). The walls of the rift valley have been stippled for clarification. Contour interval is 50 fm (uncorrected). N.B. = nodal basin; G = gap; W = base of the wall; boxes labelled 1 and 2 are ALVIN dive sites; dashed line is the track of TRIESTE II.

PREVIOUS STUDIES

The central Cayman Trough has been the subject of two important prior studies; the CAYTROUGH (1979) experiment, which utilized the deep-submersible ALVIN, dredging, and multibeam bathymetry in the rift valley area, and a geophysical study on the entire Cayman Trough conducted by Rosencrantz and Sclater (1986) and Rosencrantz and others (1988).

The multibeam bathymetric survey (Fig. 4) (CAYTROUGH, 1979) reveals bathymetric details within the valley that, combined with sampling and photography of the sea floor, delineate areas of very recent volcanic activity, which probably represent the location of the spreading axis. The survey also delineated a nodal basin (Fox and Gallo, 1986) at each of the two rift-transform intersections and revealed that the water depth east of the southern nodal basin is about 2000 m shallower than the depth west of the basin. The walls of the rift valley are also clearly identifiable, their continuity being interrupted only by a mountain, referred to here as Mt. Dent, at about the midpoint along the west wall and a gap on the east wall opposite Mt. Dent (Fig. 4).

Several observation, photographic, and sampling traverses (Fig. 4) were conducted from ALVIN over the western wall of the rift valley (east slope of Mt. Dent) and across the eastern rift valley wall in the southern part of the valley (CAYTROUGH, 1979). These traverses demonstrated that the walls are composed of gabbroic rocks capped by less than 200 m of basalt. Gabbroic oceanic crust is typically capped by about 500 m of basalt (Ballard and Van Andel, 1977). Fault blocks on the rift valley walls are also composed of gabbro, but they are not capped with basalt. The absence of basalt is unusual because fault blocks described on the walls of rift valleys at other locations are capped with about a half a kilometer of basalt, a

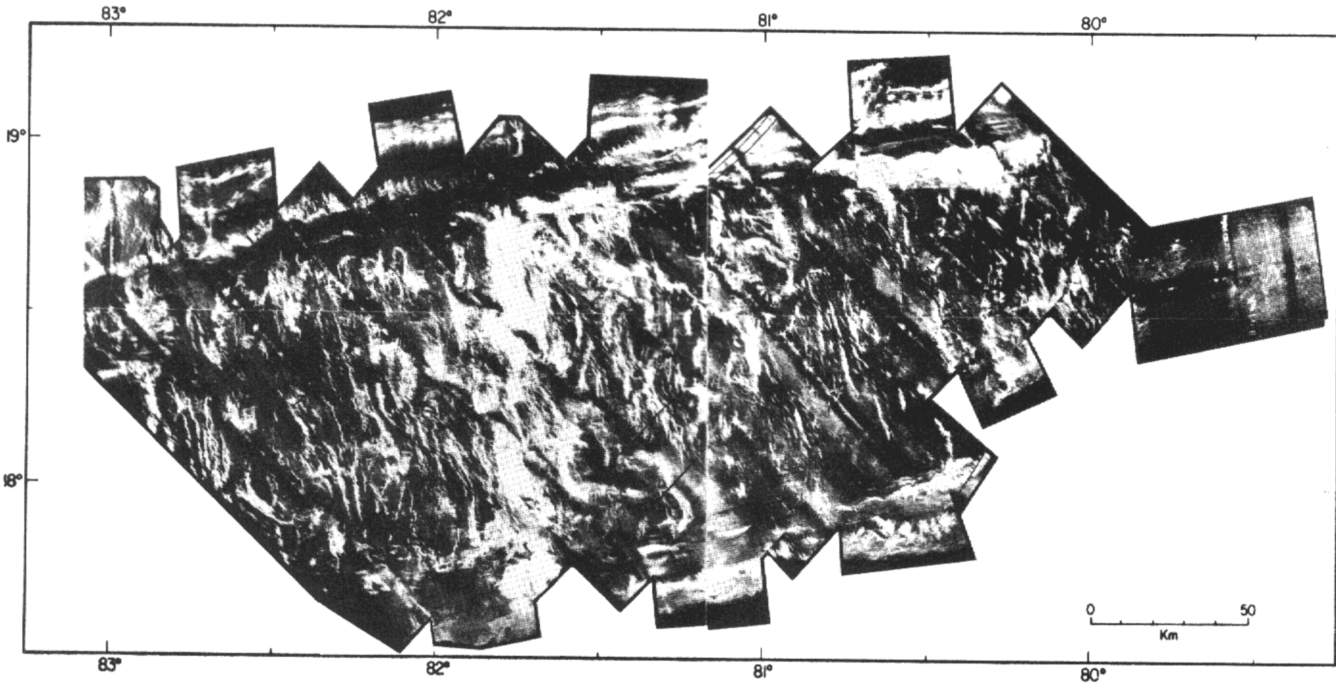

Figure 5(A) Processed GLORIA sidescan mosaic of the central Cayman Trough. White areas are caused by strong-returning acoustic signal, dark areas by weak returns. The north-trending bright zone in the central part of the mosaic is the sediment-free rift valley from which a strong reflection was recorded to the extent that most of the detail is masked. The dark areas are largely covered with sediment. It is virtually impossible to distinguish between pelagic and detrital sediments based solely on these images. Mercator projection.

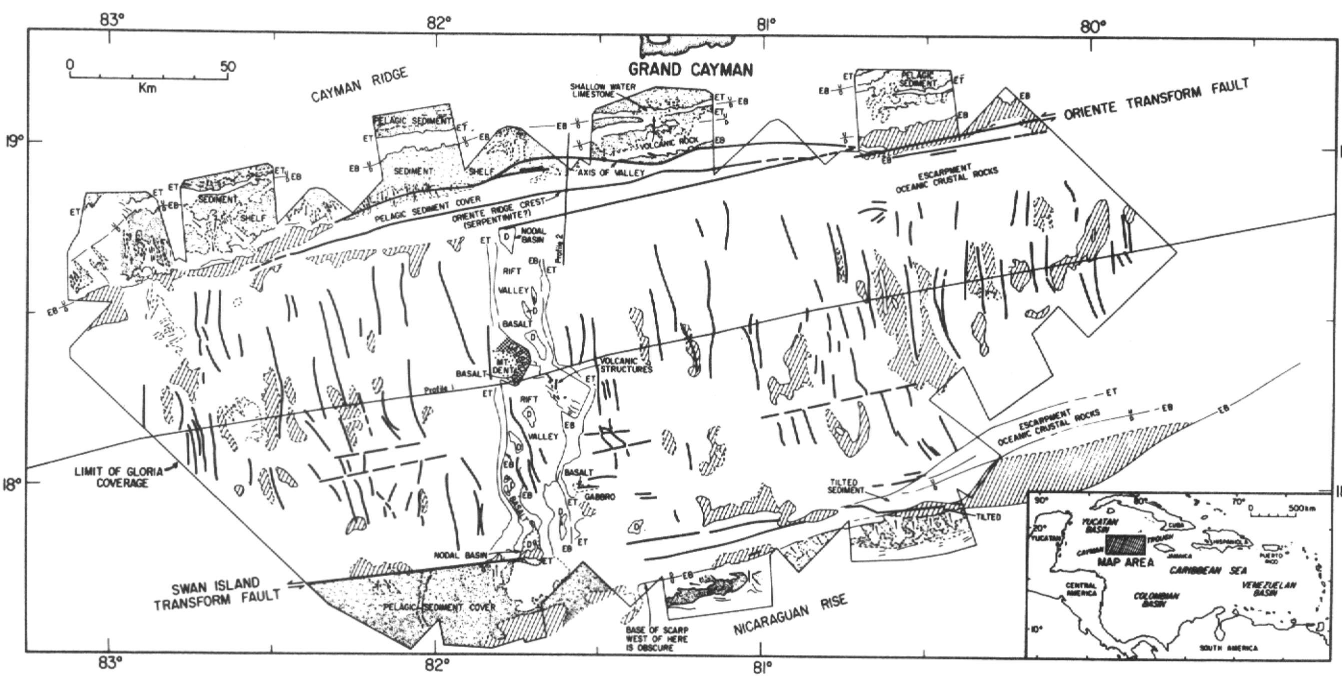

Figure 5(B). Interpretation of the sidescan mosaic. using seismic and bathymetric data. ET = top of escarpment; EB = bottom of escarpment; U = upthrown wall of fault; D = Downthrown wall of fault; stippled areas are sediment covered; areas covered with diagonal lines represent sediment ponds and abyssal plains; heavy lines are lineaments, including faults. Mercator projection.

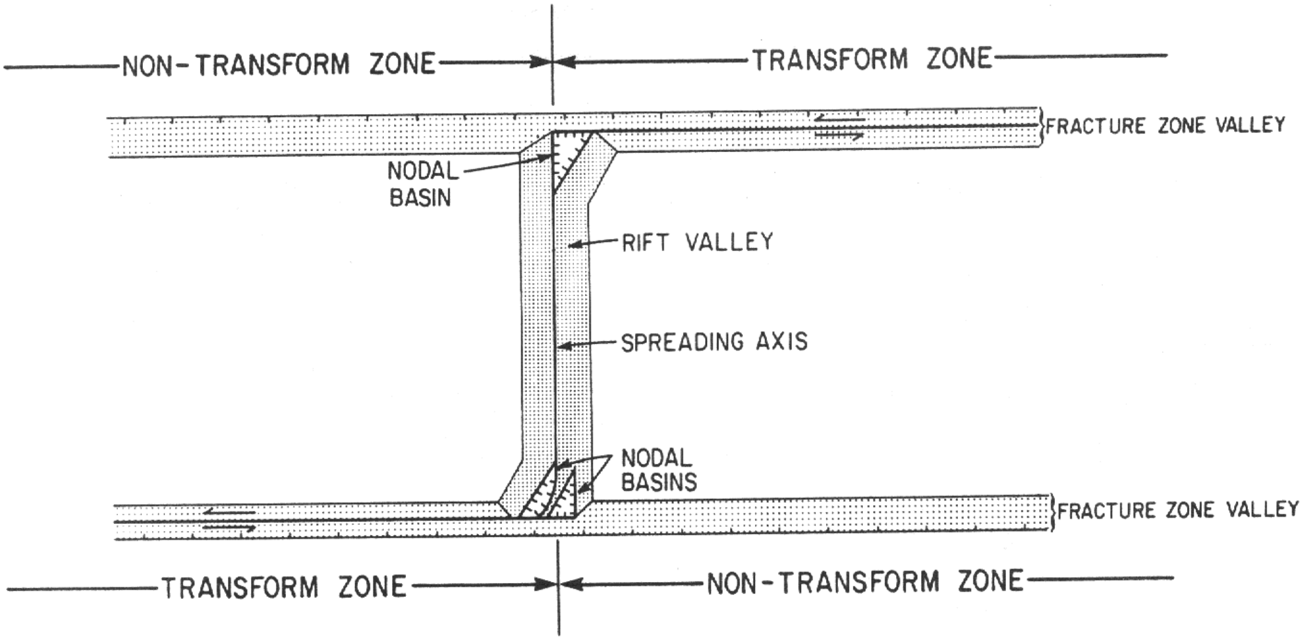

Figure 6. Diagram showing relationship of nodal basins to active transform faults in typical fracture zones. The hypotenuse of the triangular shaped nodal basin faces the active transform limb of the fracture zone valley. Widely spaced hatchures indicate a depression. In some cases, the spreading axis may pass through the nodal basin, splitting the basin as shown on this diagram (after Fox and Gallo, 1986).

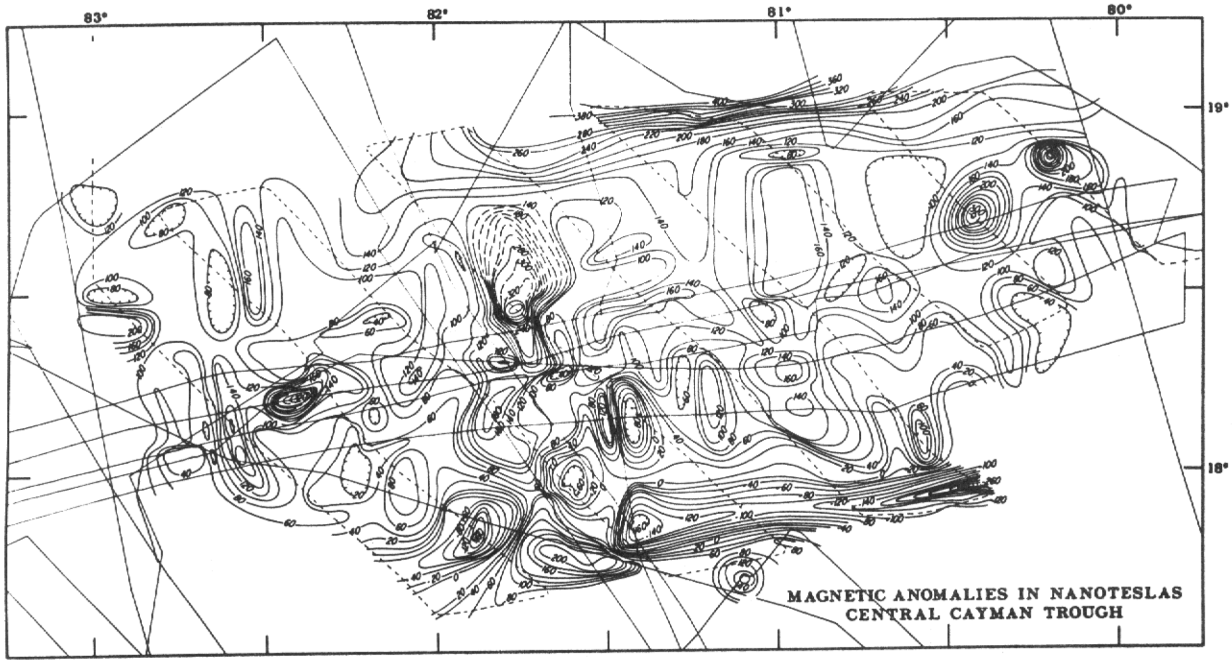

Figure 7. Magnetic anomaly contour map of the survey area in the central Cayman Trough. The area of simple magnetic anomaly pattern in the northern half of the trough is probably an artifact caused by insufficient data. Contour interval is 20 nanoteslas. Mercator projection.

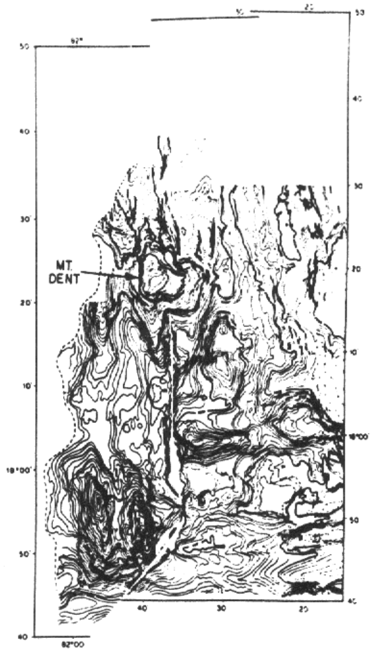

Figure 8. Multibeam bathymetric reconstruction of pre-rift jump (rift valley removed). Contour interval is 50 fm (uncorrected).

result that would be anticipated from the uplift of blocks from a basalt-covered rift valley floor.

NEW DATA AND OBSERVATIONS

GLORIA mosaic

The dominant lineament evident in the GLORIA mosaic (Fig. 5A) is a northerly trend that represents morphology resulting from the sea-floor spreading process between the east-northeast-trending walls of the Cayman Trough. The bright, northerly oriented band at 81°41'W is caused by strong reflections from the bare-rock surface of the rift valley. The trend of the lineaments east and west of the rift valley are parallel or subparallel to the rift valley, suggesting that there has been little change in the orientation of the spreading system within the survey area (20-26 Ma, Rosencrantz and others, 1988). The number and size of the sediment ponds trapped in valleys between ridges increases with increasing distance (increasing age) from the rift valley. Excluding the Oriente and Swan Islands Transform Faults, indications of strike-slip faulting in the Cayman Trough are few, and where evident, displacement does not appear to exceed 10 km (Fig. 5A and 5B).

The outline of the rift valley is well displayed, but details are obscured by the strength of the reflections from the young, bare-rock surface. A northerly trending line of volcanic structures, which probably formed along the spreading axis, is evident in the rift valley east of Mt. Dent. It is not known whether they are active. Lineaments of some of the larger features show a north-northwest trend in the rift valley south of Mt. Dent (Fig. 5A and 5b) that is consistent with the trend indicated by the multibeam bathymetry (Fig. 4). A crossing of one of these lineaments, a ridge south of Mt. Dent (Fig. 4), by the deep submersible TRIESTE II (CAYTROUGH, 1979) indicates that this volcanic ridge is no longer active, based on the evidence of a thin cover of pelagic sediment.. Volcanically active or most-recently active, areas south of Mt. Dent lie in the western part of the rift valley at the base of the west rift valley wall and probably represent the active spreading axis in the rift valley (Stroup,1981).

Particularly bright patches at the north and south ends of the rift valley (Fig. 5A) are strong reflections from depressions in the sea floor, or nodal basins. The existence of these basins is confirmed by the multibeam bathymetry (Fig. 4). Nodal basins are characteristic of rift-transform intersections (for a summary see Fox and Gallo, 1986) and their typical shape emulates a right triangle (Fig. 6).

Easterly trending ridges composed of oceanic rocks have been mapped and dredged (Perfit, 1977) along the north and south margins of the trough at about 80°25'W. The northern ridge is capped by north-elongated pinnacles, whereas the southern ridge does not appear to be capped with pinnacles (Fig. 3 and 5B). The southern ridge was referred to as the "east microblock" by Rosencrantz (1986). Although a direct correlation cannot be made, it is possible that the southern ridge is an extension of easterly oriented structures that parallel the southern margin at about 81°W (Figs. 4, 5A, and 5B), but there is no apparent topographic connection.

Topographic and structural features east and west of the southern nodal basin are quite different. The sidescan-sonar and multibeam data show a band of easterly trending ridges and valleys that parallel the southern margin of the Cayman Trough east of the southern nodal basin (Figs. 4 and 5a). These contrast with the northerly oriented features adjacent to the southern margin of the Cayman Trough west of the southern nodal basin. The south wall of the Cayman Trough appears to be offset to the south by about 5 km on the east side of the rift-transform intersection (Figs. 4, 5A, and 5B).

Magnetic anomaly map

The magnetic anomaly map (Dillon and others, 19xx) shows a strong positive anomaly of 320 nanoteslas located on the west side of the rift valley at the intersection with the northern slope of Mt. Dent and extending southward across the peak (Fig. 7). Mt Dent was demonstrated to be a gabbroic crustal block by ALVIN sampling (CAYTROUGH, 1979). There are no magnetic data across the rift valley north of Mt. Dent, and those tracks that cross the rift valley south of Mt. Dent show virtually no significant anomaly with a magnitude typical of a central anomaly in an active ocean-opening rift valley.

CONCLUSIONS

Ridge jump and oblique openingThree anomalous features of the rift valley, the presence of a crustal block within the valley (Mt. Dent), the absence of basalt on the top surface of the step-faulted gabbroic blocks on the inward wall of the valley, and the offset of the south wall of the Cayman Trough across the southern rift-transform intersection may be explained by a ridge jump and subsequent oblique opening. The displacement of the spreading center from its prejump position is probably relatively small, based on the gross bathymetric

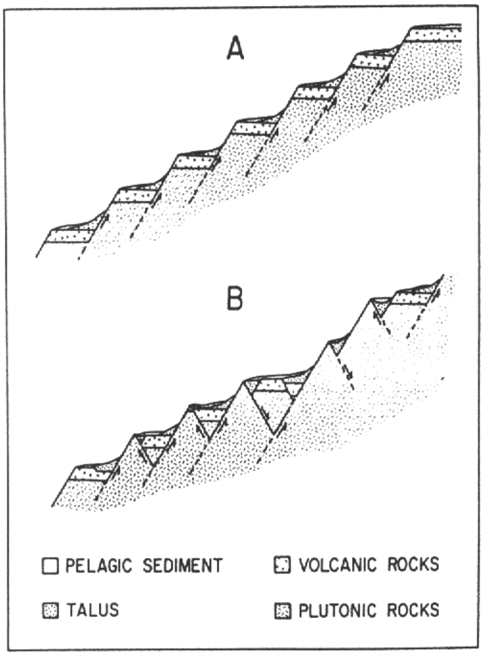

Figure 9. Diagram showing the White and Stroup (1979) model for explaining the absence of basalt on the crests of step-faulted blocks of gabbro on the walls of the rift valley. Blocks of gabbroic, basalt-capped crust are initially uplifted from the rift valley floor (A) according to the model of the mid-oceanic ridge system. Basalt on the crest of each of the fault blocks is downfaulted into grabens, then covered by talus (B). The result is the apparent absence of of basalt from the crest of the fault blocks.

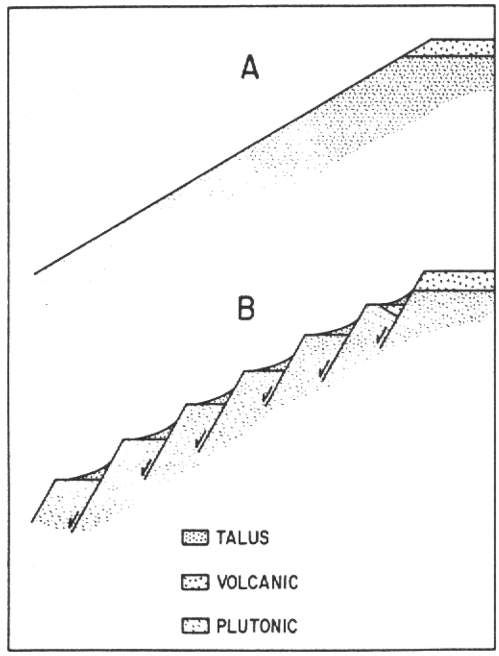

Figure 10. Diagram showing the model presented in this paper for the absence of basalt on the crests of step-faulted blocks of gabbro on the walls of the rift valley. Following the ridge jump (A), a tensional regime resulted in the downfaulting of gabbroic blocks from the escarpment of the rift valley wall (B). The result is a series of fault blocks composed of gabbroic rock.

symmetry of the Mid-Cayman Rise (Fig. 2), so the difference in age between the rocks of the walls and those of the rift valley floor should not be great.

On the assumption that the rift valley is the site of all of the most recently generated crust, the area can be restored to its prejump configuration (Fig. 8) by removing the rift valley area from the bathymetric map (Fig. 4). In so doing, it is apparent that, if the direction of closing is orthogonal to the valley walls, the closure cannot be completed because of the presence of Mt. Dent, assuming that Mt. Dent is older than the rift valley crust. However, if the direction of closure is about 117°, Mt. Dent fits snugly into the gap in the east wall of the valley and the closure can be completed as shown in Figure 8. It could be argued that Mt. Dent was uplifted after the initial formation of the rift valley, but if this were the case, then the gap in the east wall of the rift valley would remain unexplained. We also note that the distance between the east slope of Mt. Dent and the eastern end of the gap is the average width of the rift valley.

White and Stroup (1979) offered a rather contrived explanation for the absence of basalt on the top of the step-faulted gabbroic blocks on the inward-facing walls of the rift valley in which they called upon grabens at the crest of each gabbroic block into which the basalt was dropped and then covered with talus (Fig. 9). These authors assumed that the blocks were uplifted from the basalt-covered valley floor. However, the absence of basalt on the top of the blocks may also be explained by assuming that the blocks of gabbro dropped down from the face of the rifted escarpment (Fig. 10). Down-dropped blocks would result from the rifting apart (tension) of existing crust following the relocation of the spreading center.

By closing the rift valley obliquely so that Mt. Dent fits into the gap in the east wall, the south wall of the Cayman Trough east of the rift-transform intersection aligns with the wall west of the intersection (Fig. 11).

The combined evidence from these three observations strongly support the concept of a ridge jump into older crust and a subsequent oblique opening. Accepting Rosencrantz's spreading rate of 1.5 cm/y for the past 26 My and 15 km as an average width of the rift valley, the jump occurred about one million years ago. It is not clear from where the spreading center jumped, but the bathymetric symmetry about the rift valley (Fig. 2) would suggest that the previous location of the rift valley is not far from its present location.

Plate boundary

Burke and others (1980) proposed that the boundary between the North American and Caribbean plates is a zone about 200 km wide and that, in addition to the principal transform motion along the north wall of the trough, about 40

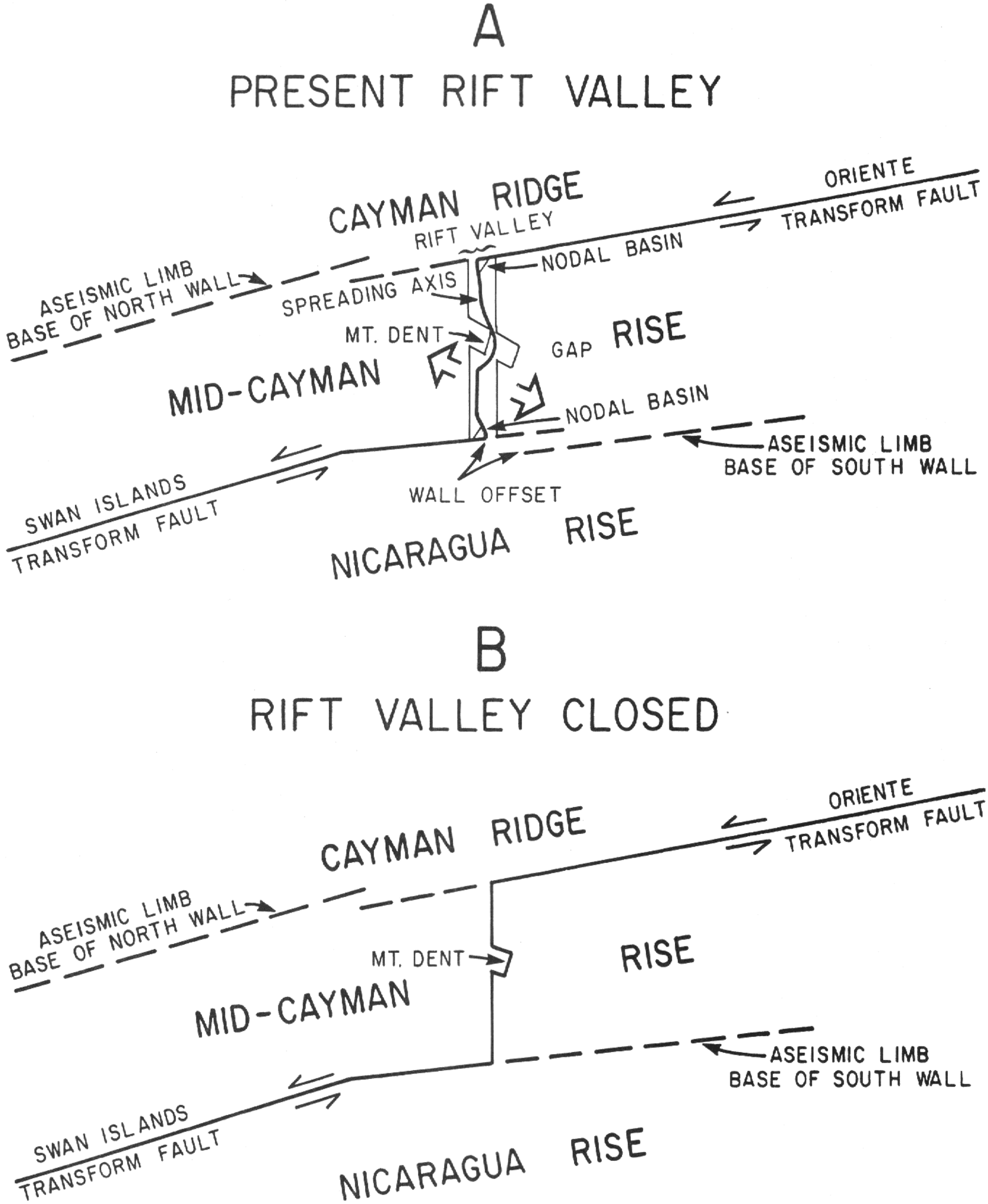

Figure 11. Diagram showing the present structural relationships in the rift valley (A) and when it was closed, at about 1 Ma (B).

km of transform motion has occurred in the Cayman Trough along the south margin east of the rift valley. This view was supported by Sykes and others (1982) who proposed that there is a significant component of left-lateral motion along the southeastern margin of the trough. However, two lines of evidence from bathymetric and sidescan data suggest that no significant component of motion occurs along the southeastern margin.

The orientation of nodal basins provides the first line of evidence. Nodal basins, discussed earlier, form at the intersection of spreading axes and transform faults, are shaped like right triangles with the hypotenuse of these triangular shaped basins facing toward the limb of the fracture zone valley on which there is active transform motion (Fig. 6). In the Cayman Trough (Fig. 4, 5A, and 5B), the hypotenuse of the nodal basin at the north end of the rift valley faces northeast towards the Oriente Transform Fault; at the southern terminus the hypotenuse faces southwest toward the Swan Islands Transform Fault. Hence, the orientation of the nodal basins indicates that the principal transform displacement zones are the Oriente Transform Fault and the Swan Islands Transform Fault and that there is no, or no significant, transform motion along the southern margin of the trough east of the rift valley as suggested by Burke and others (1980) and Sykes and others (1982).

The second line of evidence comes from the water depth associated with principal transform displacement zones. Transform fault zones are generally associated with greater water depths than adjacent areas (for summary see Fox and Gallo, 1986), probably because active fracture zones are underlain by shallow dense mantle rocks (Cochran, 1973; Robb and Kane, 1975). Meyerhoff (1966), Bowen (1966), Erickson (1972), and Holcombe and others (1973) noted that the deepest part of the Cayman Trough lies along the two bounding transform faults mentioned above and that the floor of the trough east of the rift valley slopes northward and west of the rift valley it slopes southward. The water depth along the southern margin east of the rift-transform intersection is about 1000 m shallower than that west of it and over 2000 m shallower than the northern boundary occupied by the Oriente Transform Fault, further supporting the statement that there is, or has been, little or no movement along the southeastern margin.

In the typical mid-oceanic ridge situation, ridge axis-parallel topographic features terminate at right angles against the aseismic limb of a transform fault (for summary see Fox and Gallo, 1986). This is not the case in the southern Cayman Trough where structures east of the rift valley are oriented orthogonal to the rift valley and extend eastward from the rift valley for tens of kilometers. Consequently, the structure of the rift-transform intersection along the southern margin of the Cayman Trough is different from that reported on the mid-oceanic ridge and may have resulted from some minor transcurrent movement along the southern aseismic limb of the fracture zone. In addition, there is evidence of topographic lineament in the abyssal plain along this aseismic limb that could be interpreted as resulting from transform motion. However, in view of the geometry of the nodal basin and water depth evidence cited above, it is unlikely that transform motion (displacement) has been, or is, significant.

SUMMARY

Evidence from sidescan sonar, seismic profiles, and bathymetry suggest that the present rift valley was created as a result of a ridge-axis jump about one million years ago. By fitting morphological features across the rift valley, we conclude that spreading has been oblique to the northerly trend of the valley. The depth pattern of symmetry of the Mid-Cayman Rise suggests that the spreading axis did not jump far from its previous position.

The primary motion along this segment of the northern Caribbean plate boundary is confined to the Oriente Transform Fault and the Swan Islands Transform Fault. Although the sidescan images show evidence of strike-slip movement along the southern aseismic limb east of the rift valley, the motion is probably not significant.

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