Tectonophysics, 186 (1991) 329–350
Elsevier Science Publishers B.V., Amsterdam

From transtension to transpression along the northern Caribbean plate boundary off Cuba: implications for the Recent motion of the Caribbean plate

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(Received February 12, 1990; accepted May 1, 1990)

ABSTRACT

Calais, E. and Mercier de Lepinay, B., 1991. From transtension to transpression along the northern Caribbean plate boundary off Cuba: implications for the Recent motion of the Caribbean plate. *Tectonophysics,* 186: 329–350.

Marine geophysical surveys using Seabeam, single-channel seismic reflection, gravimetric and magnetic measurements have been conducted along a segment of the northern Caribbean transcurrent plate boundary (SEACARIB II cruise). The data allow a better definition of the geometry and the tectonic regime of this major strike-slip area. They support the following results:

(1) Along the southern Cuban margin, the Oriente fault displays a discontinuous trace, mainly composed of dextral offset, "en echelon" segments. Some pull-apart basins are located between fault segments (Cabo Cruz basin, Chivirico and Baitiquiri basins). In the Windward Passage area, the plate boundary enters into the Tortue Channel and is not connected with the subduction front off northern Hispaniola.

(2) The eastern part of the Oriente Deep and the Santiago Promontory are characterised by active compressional tectonics. They form the Santiago Deformed Belt, described here for the first time. This deformed belt can be divided longitudinally into three main segments, each one characterised by a particular tectonic style. Its development is related to a transpressional mechanism along the left-lateral Oriente strike-slip fault. Our observations suggest that a tectonic and kinematic reorganisation occurred recently in this area, probably in the Late Pliocene, which may be compared with the recent geological events recorded on land in the northern Caribbean domain.

The precise knowledge of both geometry and structures along the Oriente strike-slip fault south of Cuba provides new constraints for the recent kinematic evolution along the northern Caribbean transcurrent plate boundary: it leads us to infer the existence of a convergence component associated with the slip component along the Oriente transform fault.

Introduction

The Caribbean domain and Central America form a small lithospheric plate inserted between North and South America (Caribbean plate) (Molnar and Sykes, 1969) which is moving eastward relative to North America (Fig. 1). During the SEACARIB II oceanographic cruise (R.V. *Jean Charcot,* 16/11/87–23/12/87), we explored in detail a poorly-known segment of the sinistral transcurrent northern boundary of the Caribbean plate, extending from Cuba to Hispaniola and represented there by the Oriente strike-slip fault (73°–77°W). Our approach consists of topographic (Seabeam), structural (seismic reflection) and geophysical (magnetism and gravimetry) investigations along this portion of the plate boundary. It allows a precise analysis of the geometry of the Oriente strike-slip fault and of the deformation pattern along it.

Since two-thirds of the northern Caribbean transcurrent plate boundary are located at sea, the present-day motion along it is up to now been poorly constrained by geological information. This motion has been investigated by several authors using various methods (Jordan, 1975; MacDonald, 1976; Sykes et al., 1982; Stein et al., 1988). Our data, which complement these earlier investiga-

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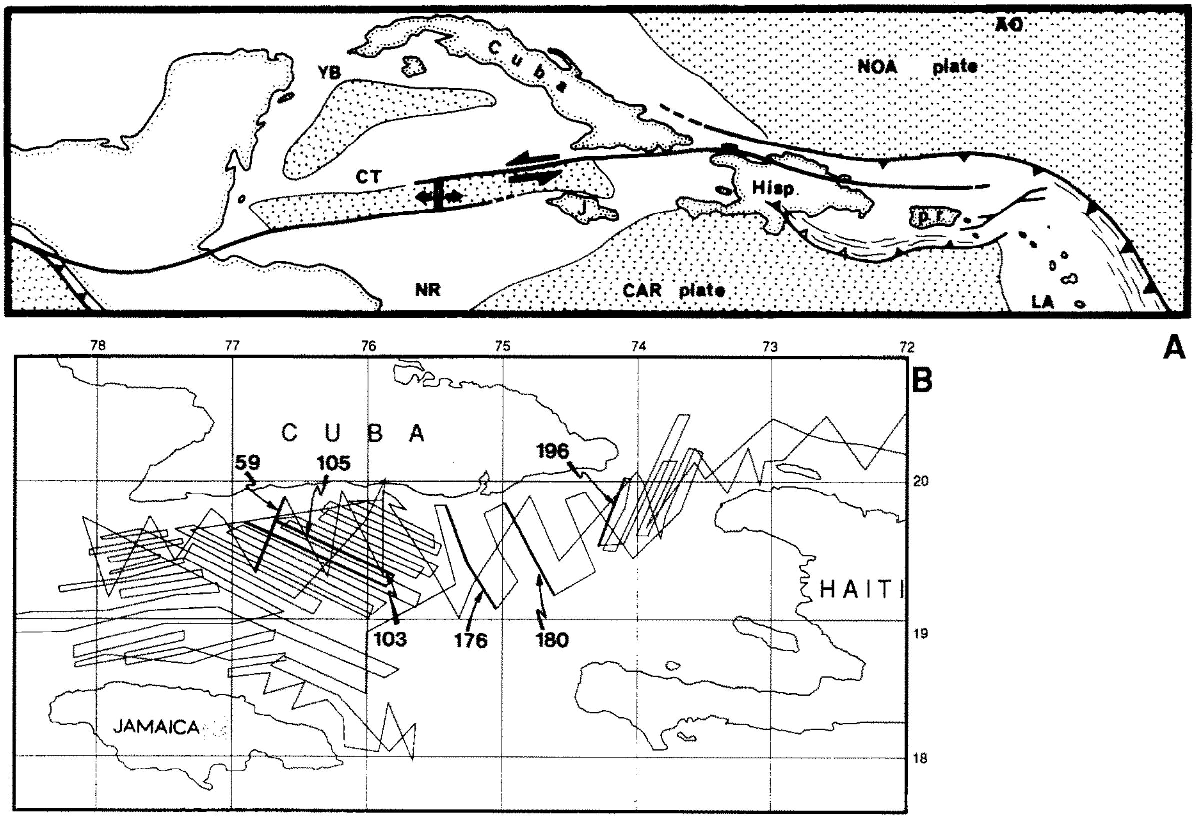


Fig. 1. A. Location of the area studied. B. Location of the ship's track. *AO* = Atlantic Ocean; *CAR* = Caribbean; *CT* = Cayman trough; *Hisp.* = Hispaniola; *J* = Jamaica; *LA* = Lesser Antilles; *NOA* = North American Plate; *NR* = Nicaraguan Rise; *p.r.* = Puerto Rico; *YB* = Yucatan basin; shaded area = oceanic crust.

tions, allow us to determine new constraints for the present-day motion along the northern Caribbean plate boundary. They lead us us to infer the existence of a convergence component associated with the slip component along the Oriente transform fault.

Previous data

Prior to our investigations, the southern Cuban margin was considered as an almost uniform slope coming down from the Sierra Maestra of Cuba (summit Pico Turquino, 2000 m) into a narrow east–west trending depression (6000–6500 m deep), the Oriente Deep (Fig. 2). This basin, first mentioned by Case and Holcombe (1980), is interpreted by Mann and Burke (1984) as an active pull-apart. Their conclusion, however, relies only on bathymetric arguments and on the close association of this basin with the Oriente transcurrent zone. It is therefore questionable and they admit that the existence of the Oriente Deep and its relationships with the strike-slip zone remain unclear. In contrast, Goreau (1983), using some seismic, magnetic and gravimetric profiles located sub-perpendicular to the southern Cuban margin, concluded that this area is structurally complex and mainly undergoing compression. He described folds and north-dipping reverse faults affecting the sediments at the bottom of the slope. Moreover, he noticed a high negative gravimetic anomaly area, parallel to the Oriente Deep axis but slightly shifted to the north, under the deformed sediments. On the basis of these observations he compared this area to an active subduction zone and proposed the existence of a major north-dipping thrust along the southern Cuban margin. However this structural interpretation, based only on 6 profiles, relies mainly on extrapolation.

Thus, despite its interesting location along a major strike-slip fault, the southern Cuban margin

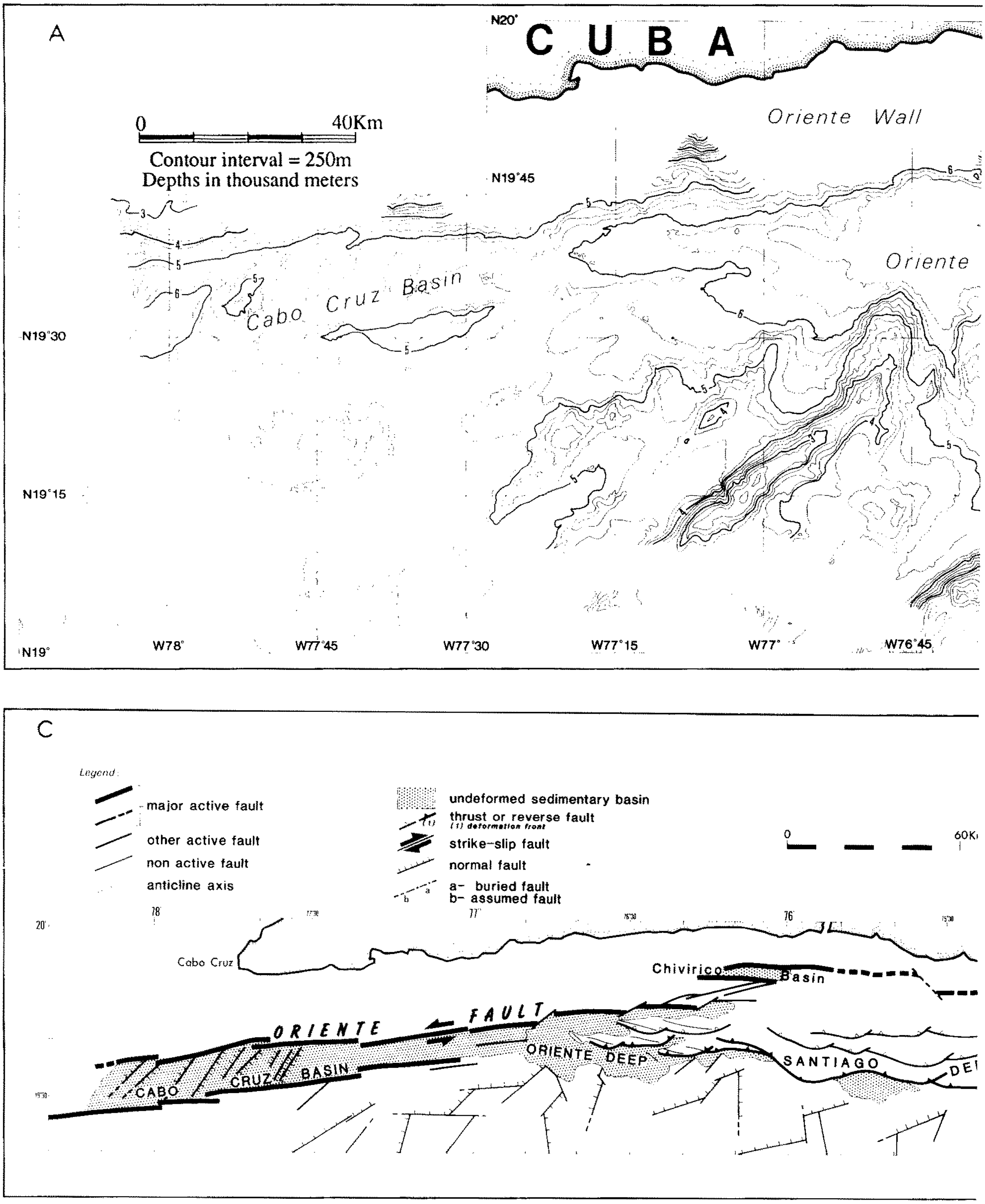
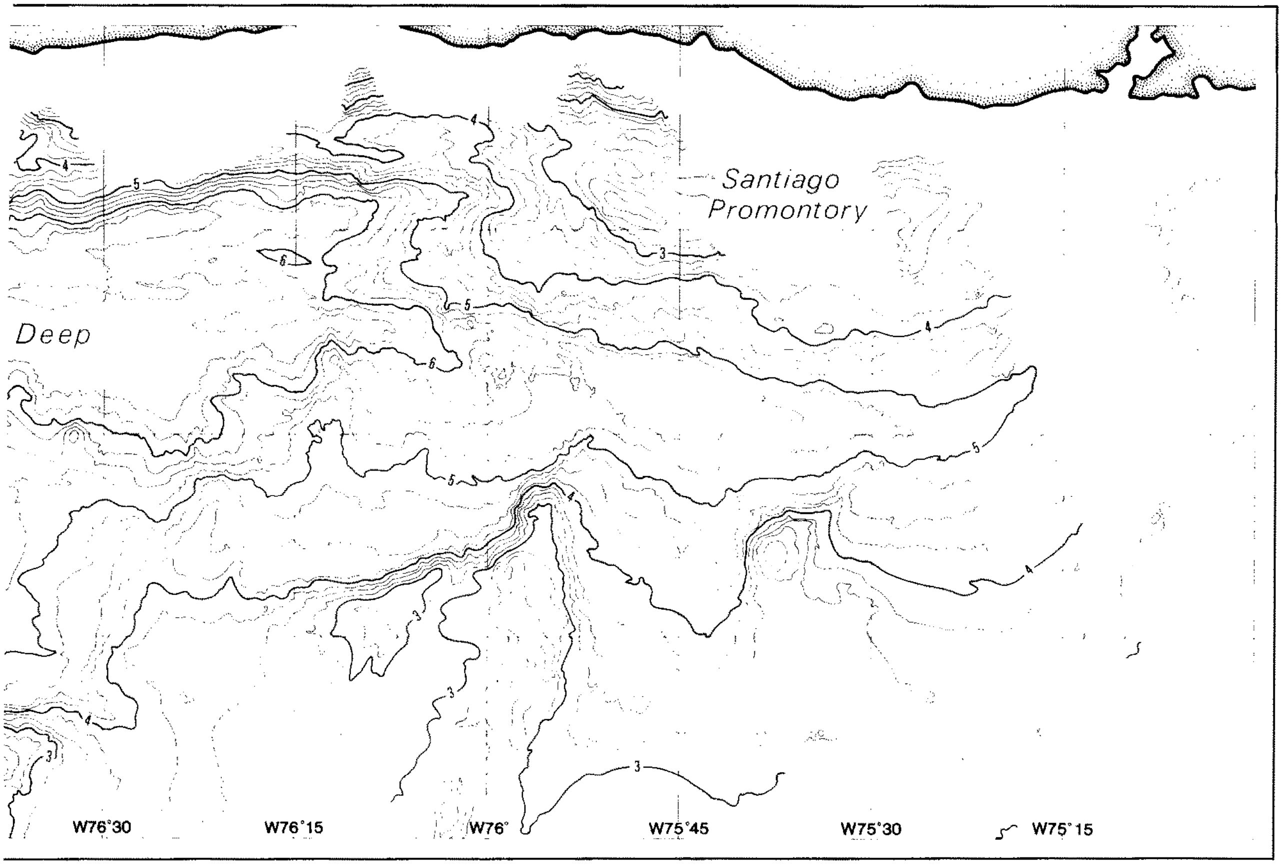
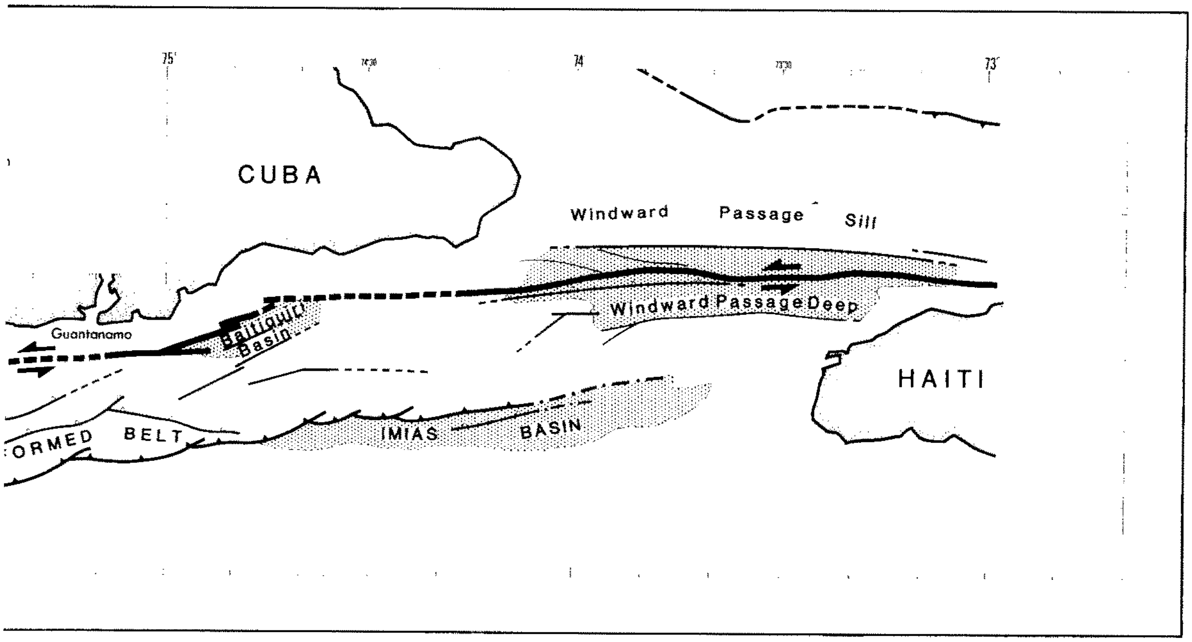


Fig. 2. A. Bathymetric map of the southern Cuban margin. C. Struct





ıral map of the southern Cuban margin and the Windward Passage.

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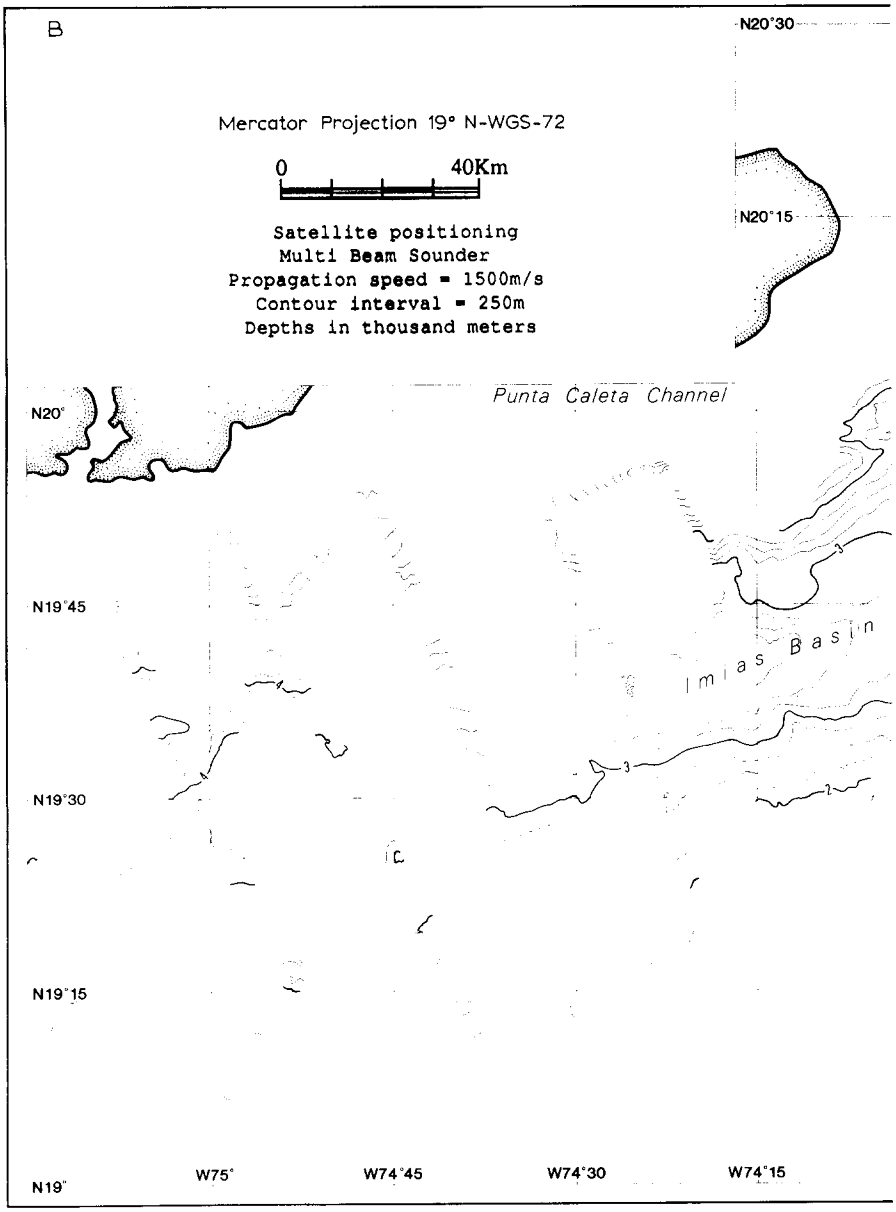
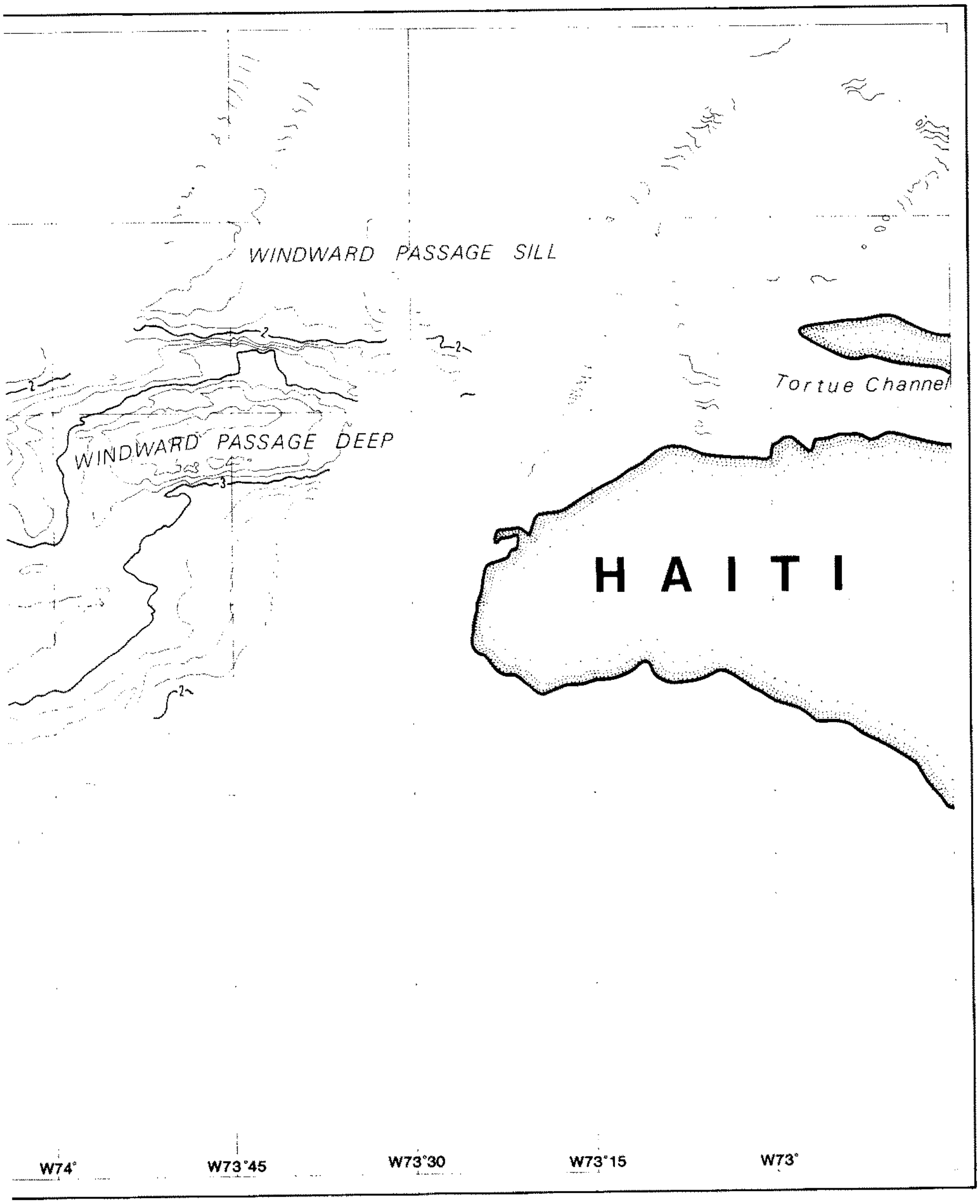


Fig. 2B. Bathymetric map of the V



indward Passage.

has remained up to now a poorly-known segment of the Northern Caribbean plate boundary. More detailed investigations were required in order to provide a clear picture of its structural framework.

Seabeam imaging of the southern Cuban margin

The first step in our understanding of the southern Cuban margin framework was undertaken during the SEACARIB II cruise by establishing a precise topographic map of this area. The bathymetric map of this domain obtained with the multibeam echo sounder SEABEAM is given (Fig. 2), together with a block diagram of it processed at the IFREMER centre of Brest, France (Fig. 3).

The study area is for the most part at depths ranging from 4000 to 6500 m. It is characterised by significant differences in bathymetry caused by very steep submarine scarps. The following seven morphologic domains can be distinguished (Fig. 2):

(a) *The Oriente Wall* is a very steep scarp, coming down from the Cuban coast and stretching from 76°10′W to 78°W. The difference in bathymetry ranges from 6000 to 6500 m and corresponds to an average slope of 35% (20°). This slope is irregular: it displays some inflexions, sometimes marked by important flats. Its apparent trend is E–W but this is a composite made up from the juxtapositioning of segments trending N60°E and N100°E.

(b) *The Cabo Cruz basin* is a narrow E–W trending depression (8–15 km wide by 80 km long), with a rectangular shape, extending from the bottom of the Oriente Wall, between 77°W and 78°W. This basin is formed from three subbasins, separated by two N45°–50°E trending ridges.

(c) *The Oriente Deep* is a narrow E–W trending depression, extending from 76°10′W to 77°W. It is bordered to the north by the Oriente Wall, to the east by the Santiago Promontory and to the south by a slightly north-dipping slope. To the west it is morphologically continuous with the Cabo Cruz basin. The bottom of the Oriente Deep is flat and located at around 6500 m. It is, however, interrupted around 76°40′W by an E–W trending band of highs, separating the Oriente Deep into two narrow branches. These highs constitute a succession of gentle hills, ranging from 300 to 600 m above the bottom of the Oriente Deep. Their southern flank is often steeper than the northern. These hills display an elliptical shape with an average width of 3 km and length of 10 km. Their axes trend N110°E on average and are therefore oblique to the general east–west direction of this hilly area.

(d) *The Santiago Promontory* interrupts the Oriente Wall around 76°W. At this longitude the east–west trending isobaths of the Oriente Wall change rather abruptly to trend N–S. To the east they bend first in a N115°E direction and then progressively change to a general trend of N75°E. The Santiago Promontory is therefore convex to the south, as is the corresponding Cuban coast. The slope of the margin (10%, 6°) is lower than on the Oriente Wall and is moreover very irregular, cut into by transverse inflections, flats and some depressions. These slope breaks often show a curvilinear trace, convex to the south.

(e) *The Imias basin* is a narrow depression (8 km wide on average, 130 km long and around 4000 m deep) streching between 73°40′W and 74°50′W in a general east–west direction. This basin is bordered to the north by the Santiago Promontory scarp and to the south by a north-dipping slope coming down from the Gonave Ridge. To the east it disappears off the northwest peninsula of Haiti.

(f) *The Chivirico and the Baitiquiri basins* are two small depressions, perched upon the Oriente Wall. The rectangular Chivirico basin is located between 76°W and 76°15′W. It is bordered to the north and south by two significant escarpments. The Baitiquiri basin has only been mapped in its westernmost part, where it is bounded by a N70°E trending scarp.

(g) *the Windward Passage* is a large strait separating the eastern extremity of Cuba from the northwestern peninsula of Haiti. It essentially corresponds to a submarine plateau, the Windward Passage Sill (Goreau, 1983), located at a depth of around 1500 m. This plateau is bordered to the north by the Hispaniola basin and to the south by the Windward Passage Deep (Goreau, 1983), a

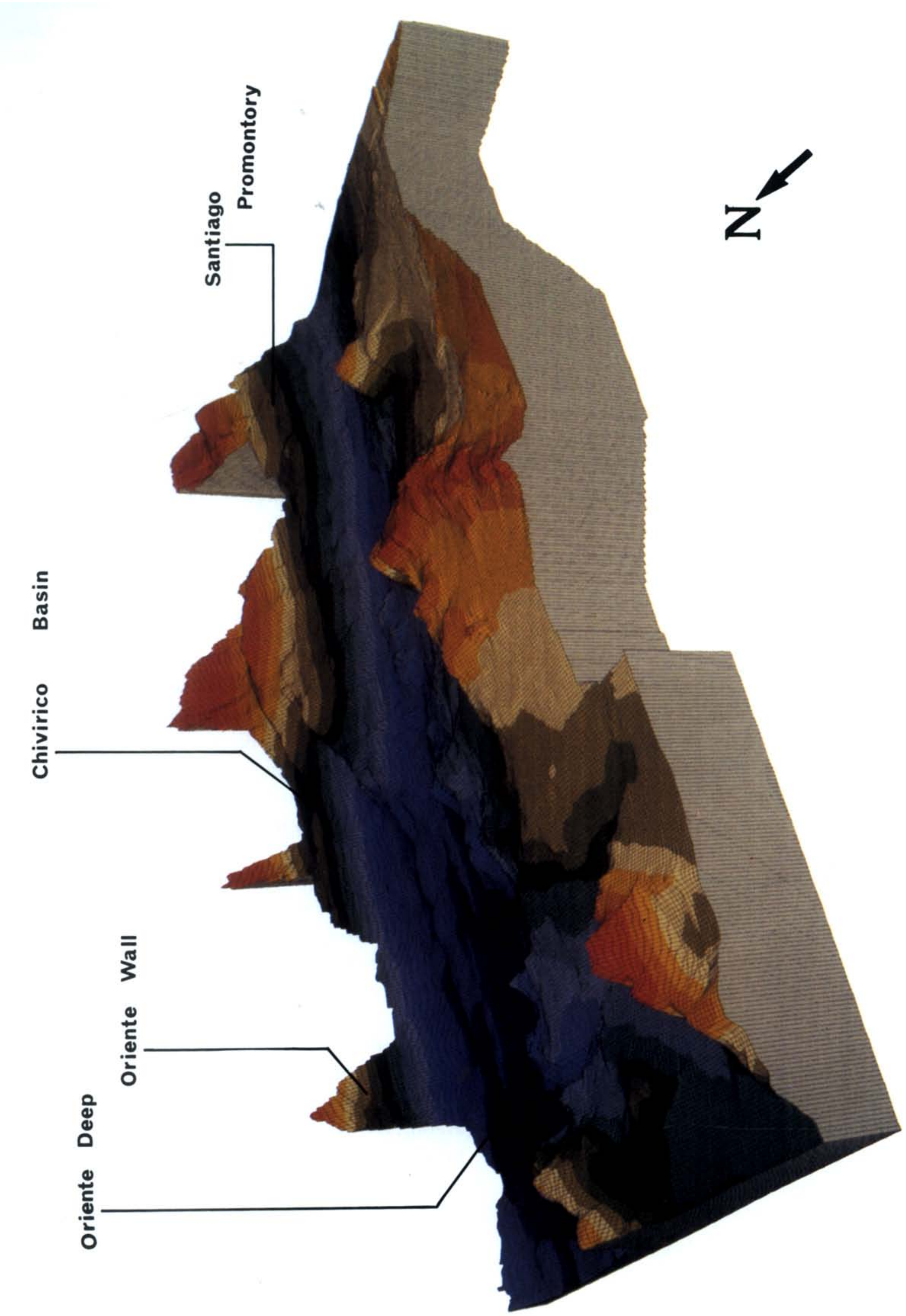


Fig. 3. Three-dimensional representation of the southern Cuban margin bathymetry.

rectangular, E–W trending depression located at a depth of around 3500 m.

To sum up, the bathymetric map of the southern Cuban margin clearly shows an east–west regional morphologic trend. However, a detailed analysis of its bathymetric features reveals other important morphologic directions, notably N45°E to N60°E and N115°E to N100°E interfering with the main N80°E to N90°E trend.

The trace of the Oriente fault and its associated structures

The trace of the Oriente fault

The southern Cuban margin

The Oriente fault has never previously been explored and interpreted in detail in the study area. The steep slope of the southern Cuban margin is generally identified as its morphologic expression. However, as previously stated, this slope displays many irregularities which seem to indicate that it is not related to a single continuous fault, but probably to one or more "en échelon" segments.

In the western part of the study area, the trace of the Oriente fault is the Oriente Wall, bounding the Cabo Cruz basin and the Oriente Deep to the north (Fig. 2). It displays a quite rectilinear N80°E trending trace to 76°40′W. Further to the east the fault is more discontinuous and seems to be formed by the succession of N60°E and N100°E trending segments with a dextrally offset en échelon arrangement. However its general direction remains N80°E. This scarp can be followed to the east as far as 76°10′W where it suddenly disappears, even on seismic reflection profiles. The Oriente Fault must, therefore, undergo a major displacement here and its continuation to the east has to be tracked to the north or to the south of the eastern end of this scarp. Just to the north of this end lies the Chivirico basin (Figs. 2 and 3), which is limited to the north by a E–W trending scarp. This scarp can be followed continuously to around 75°50′W, but further east its identification becomes less certain because of less detailed Seabeam covergage. However two other rectilinear E–W trending scarps, between 75°50′W–75°35′W, and 75°35′W–75°W, can be partly identified. To the east of 75°W this fault scarp disappears and we have to begin the search again for an "en échelon" fault segment. In this area the end of the previous scarp is marked by the Baitiquiri basin, bounded to the west by a N70°E trending fault: this probably represents another significant segment of the Oriente fault. Unfortunately the lack of bathymetric data to the east of 74°50′W does not allow us to follow this fault further east. We do however see a 250 m deep elliptic high around 74°20′W–19°55′N, separated from the Cuban coast by a narrow and deep channel, the Punta Caleta channel (Calais et al., 1989) (Fig. 2). Since it leads straight on from the main faults of the Windward Passage (Fig. 2), this channel could represent the eastward continuation of the Oriente Fault.

Although the data collected during the SEACARIB II cruise are still insufficient to confidently determine the geometry of the plate boundary over its entire length in the study area, the southern Cuban margin seems to be made from the juxtapositioning of numerous discontinuous fault scarps, determining four major lineaments: (1) an almost continuous N80°E trending one from 78°W to 76°10′W; (2) a N90°E trending one from 76°10′W to 75°30′W; (3) a N90°E trending one from 75°30′W to 74°50′W, shifted to the south with respect to the former one; (4) a probably N90°E trending one from approximatively 74°50′W to 74°W, connected to the previous one by a N70°E trending segment. Around 76°10′W and 74°50′W these lineaments are connected by two important offset areas, each one marked by a small perched basin (Chivirico and Baitiquiri basins). As they are located on dextrally offset segments of a left-lateral strike-slip fault, these basins are probably related to transtension.

The Windward Passage

In the Windward Passage area, the fault pattern displays an E–W general trend. The faults do not cut obliquely through the Windward Passage Sill to join the Hispaniola basin, but continue into the Tortue Channel. Therefore, we clearly have the structural evidence that there is no continuity, in the Windward Passage area, between the Oriente

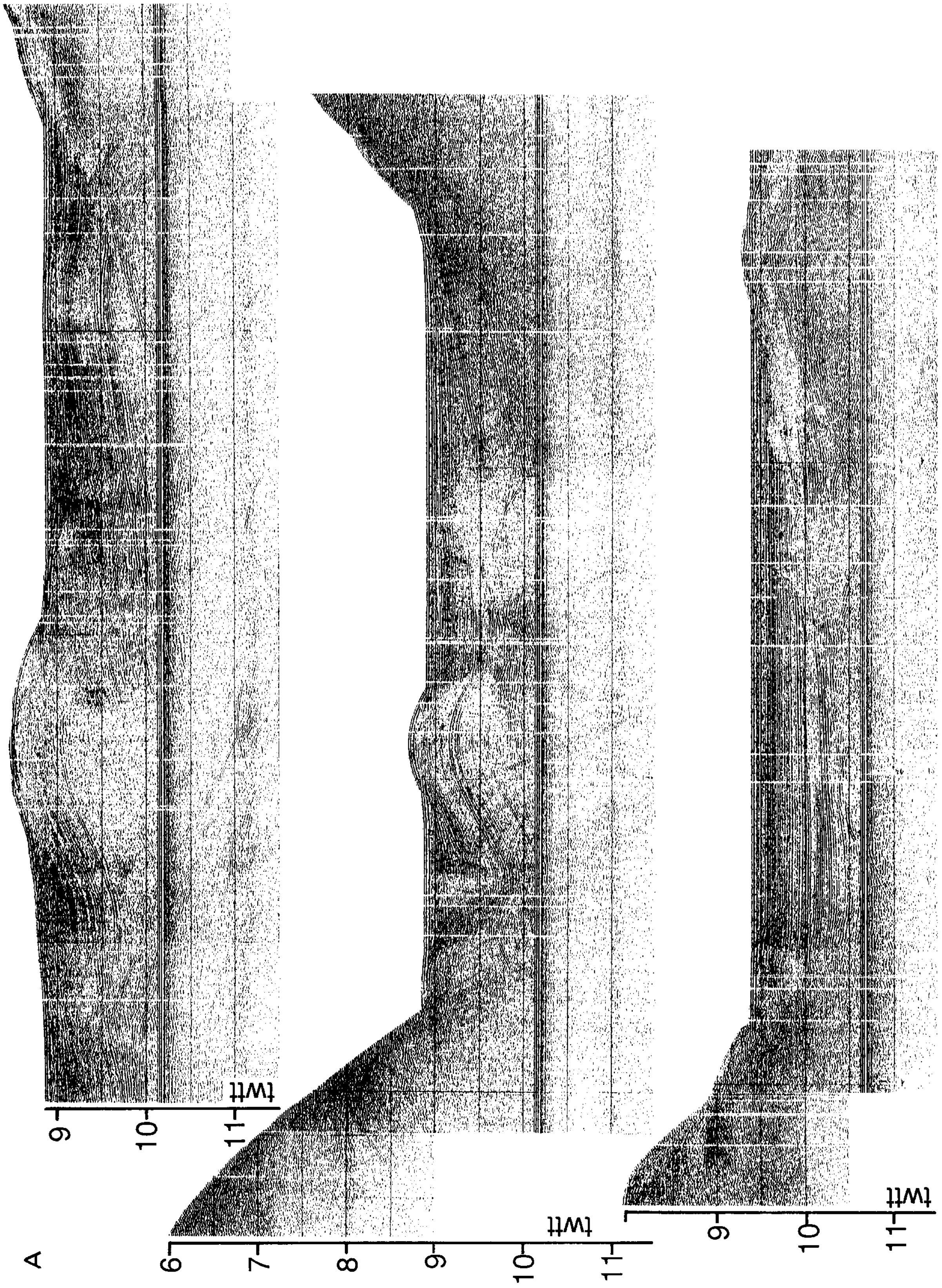


Fig. 4. Seismic profiles 103, 59 and 105 and their interpretation (location in Fig. 1B).

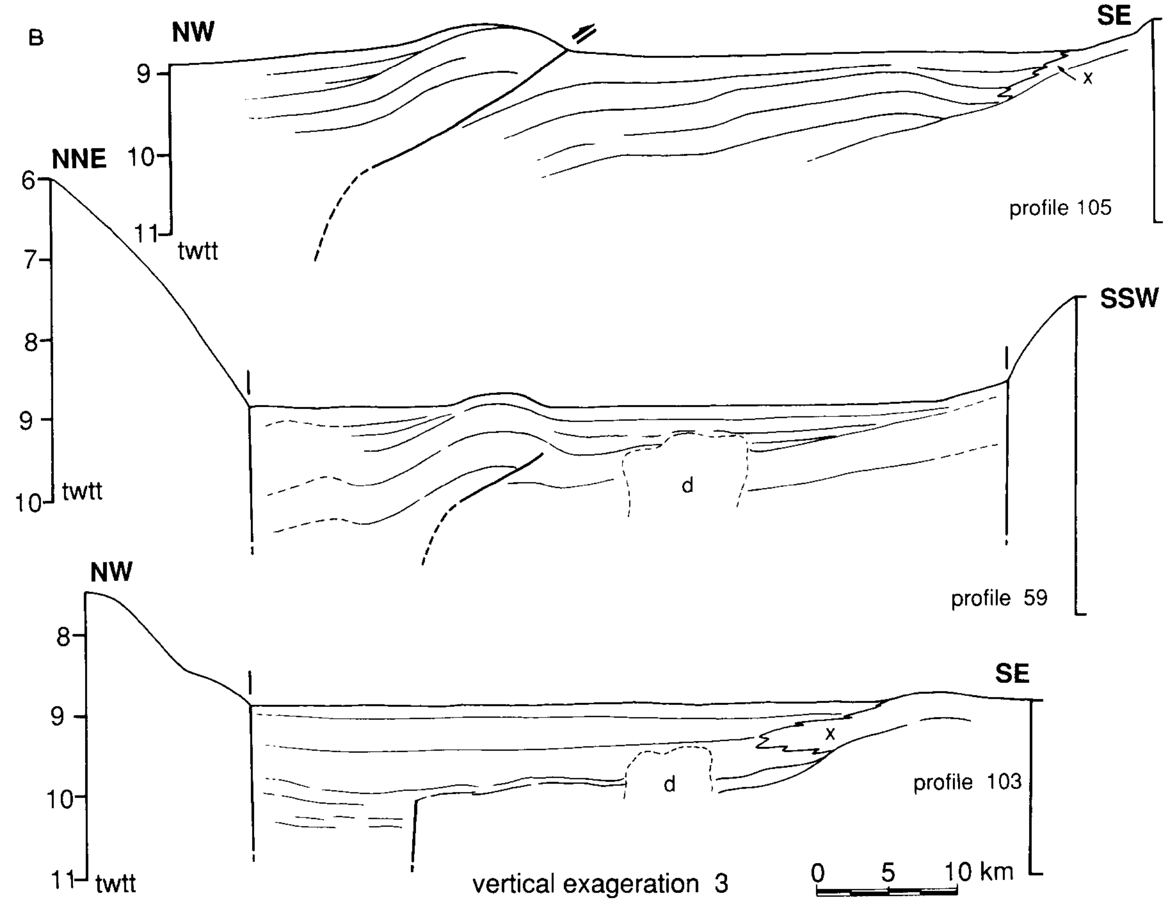


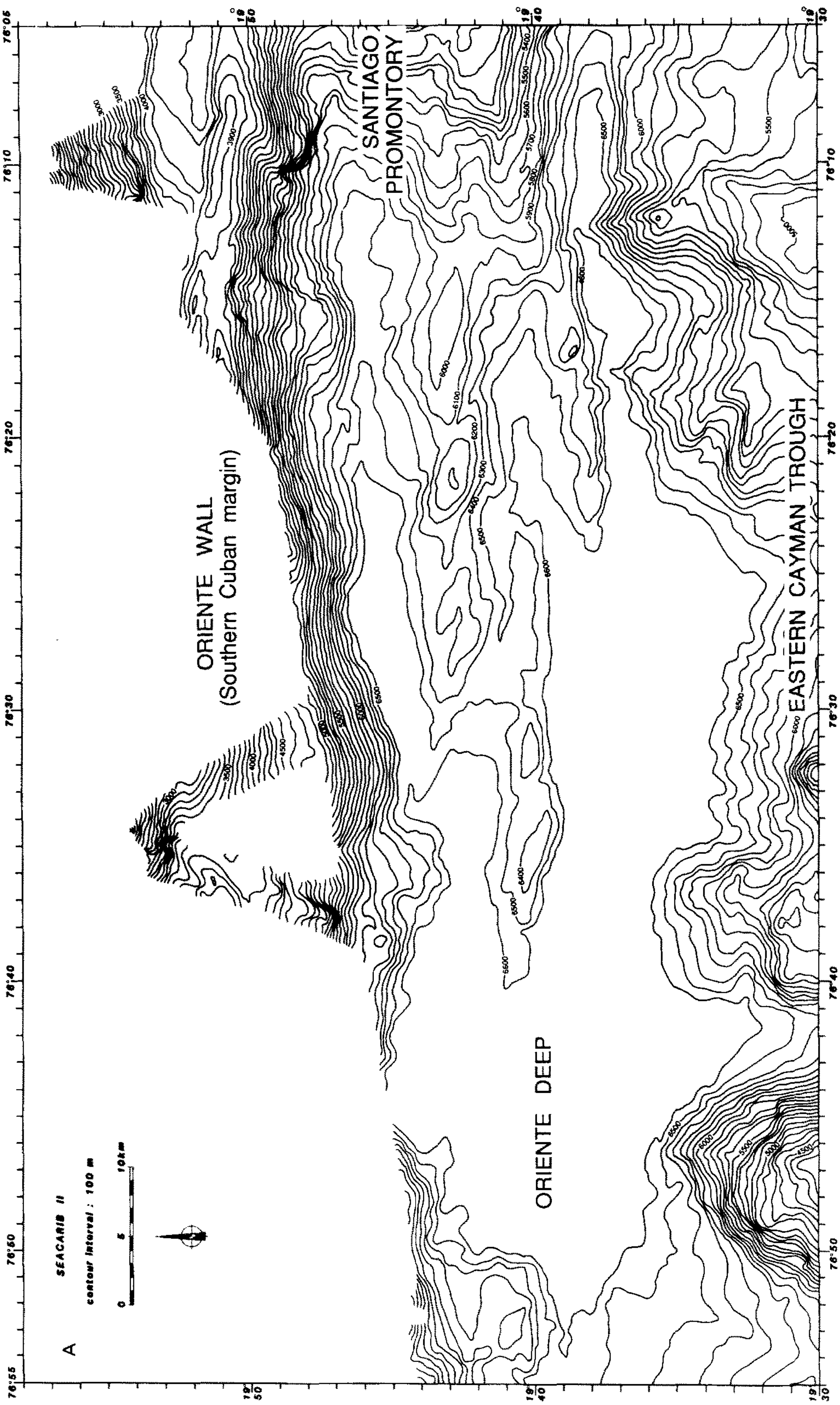
Fig. 4 (continued).

fault and the subduction front of the Atlantic oceanic lithosphere beneath Puerto Rico and Hispaniola. This arrangement, previously assumed from seismological data (Molnar and Sykes, 1969; Kelleher et al., 1973; Sykes et al., 1982), is here confirmed for the first time by geological information. To the east, this major fault zone continues on land in Hispaniola along the northern border of the Cibao basin. The strike-slip fault zone is marked there by the active transpressive structure of the Cordillera Septentrional of the Dominican Republic (Mann et al., 1984; De Zoeten, 1988; Calais and Mercier de Lépinay, 1989).

The Windward Passage Deep is not located at a relay area of the Oriente fault, but along a rectilinear segment of this fault. The fault bounding this basin to the south is not connected to the Oriente fault, as suggested by Mann et al. (1983), neither to the thrust front of the Santiago Deformed Belt, as proposed by Goreau (1983). Thus, the Windward Passage Deep cannot be interpreted as an active pull-apart, as was previously assumed. The tectonic regime along the northern Caribbean plate boundary in the Windward Passage area is rather pure strike-slip.

The Cabo Cruz basin

The Cabo Cruz basin is bordered to the north and to the south by two N80°E trending faults. It is divided by N45–50°E trending normal faults into a series of oblique horsts and grabens. The basin's southern border is the eastward extension of the Oriente fault, which to the west forms the northern limit of the Cayman Trough. To the east, this fault disappears around 77°05′, as shown by the progressive eastward disminishing of its corresponding fault scarp (Fig. 2). In contrast the fault which borders this basin to the north does not


A
SEACARIB II
contour interval : 100 m
0 5 10km
ORIENTE WALL
(Southern Cuban margin)
SANTIAGO PROMONTORY
ORIENTE DEEP
EASTERN CAYMAN TROUGH
76°05
76°10
76°20
76°30
76°40
76°50
76°55
19°50
19°40
19°30

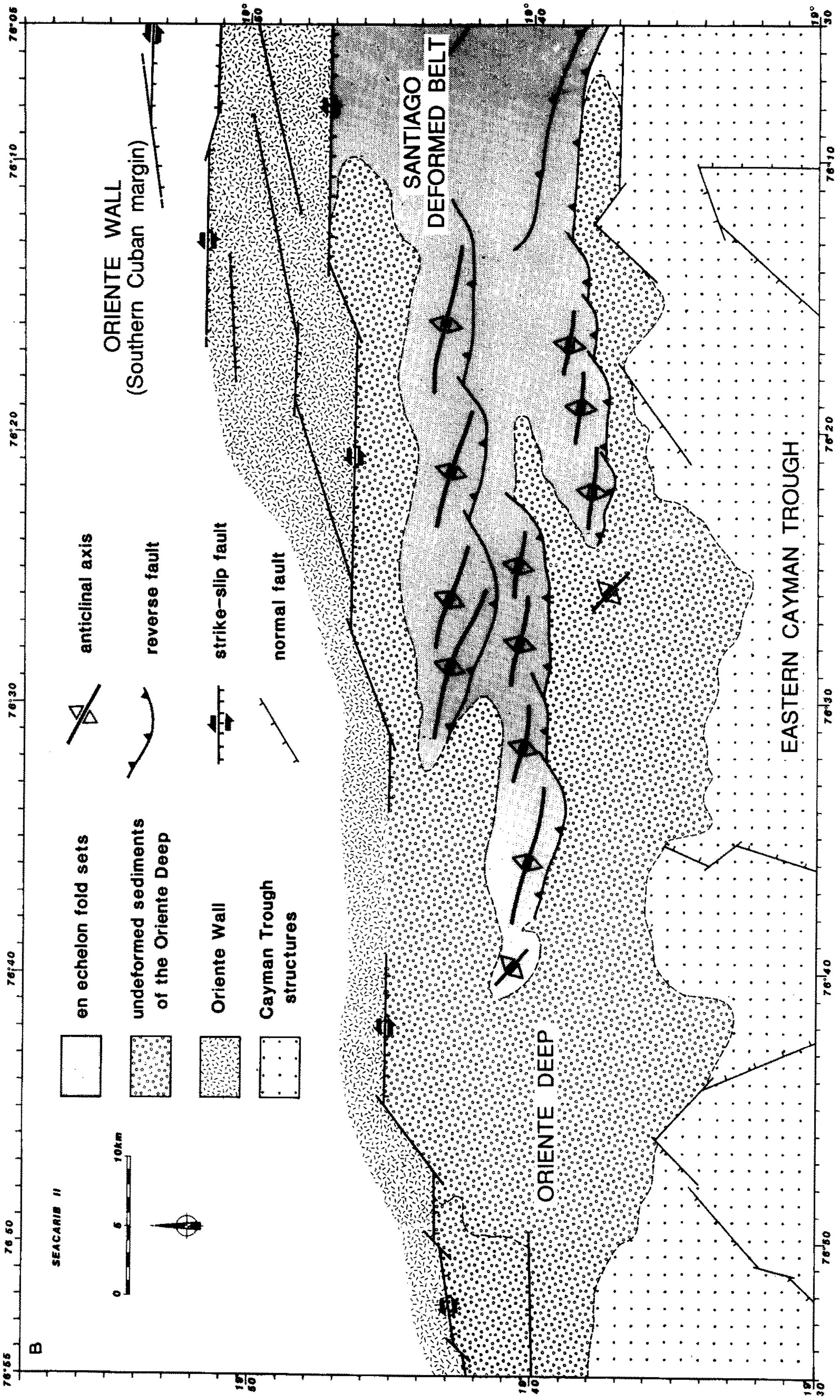


Fig. 5. Detailed Seabeam mapping of the eastern part of the Santiago Deformed Belt. B. Structural interpretation of the Santiago Deformed Belt.

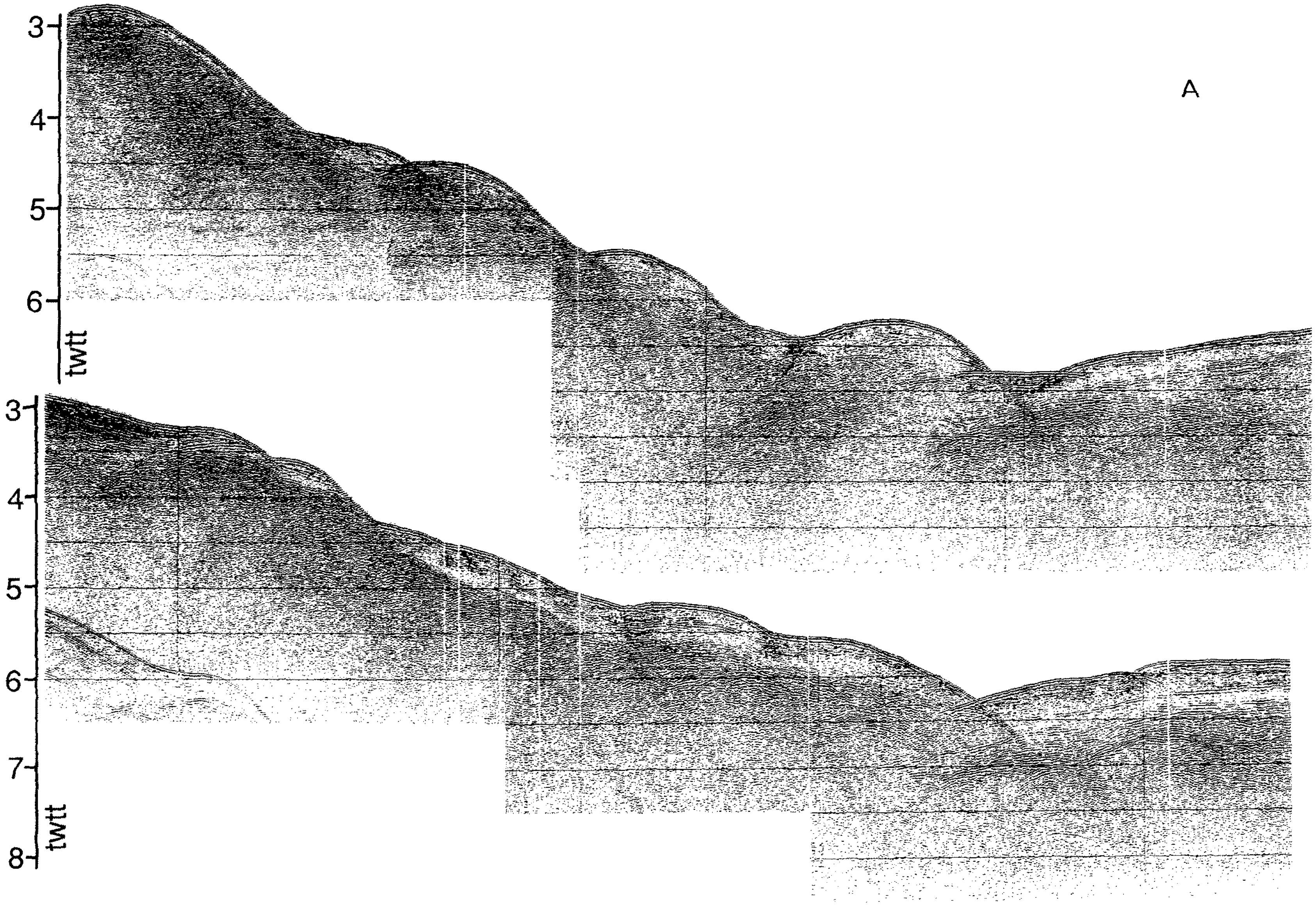


Fig. 6. Seismic profiles 176 and 180 and their interpretation (location in Fig. 1B).

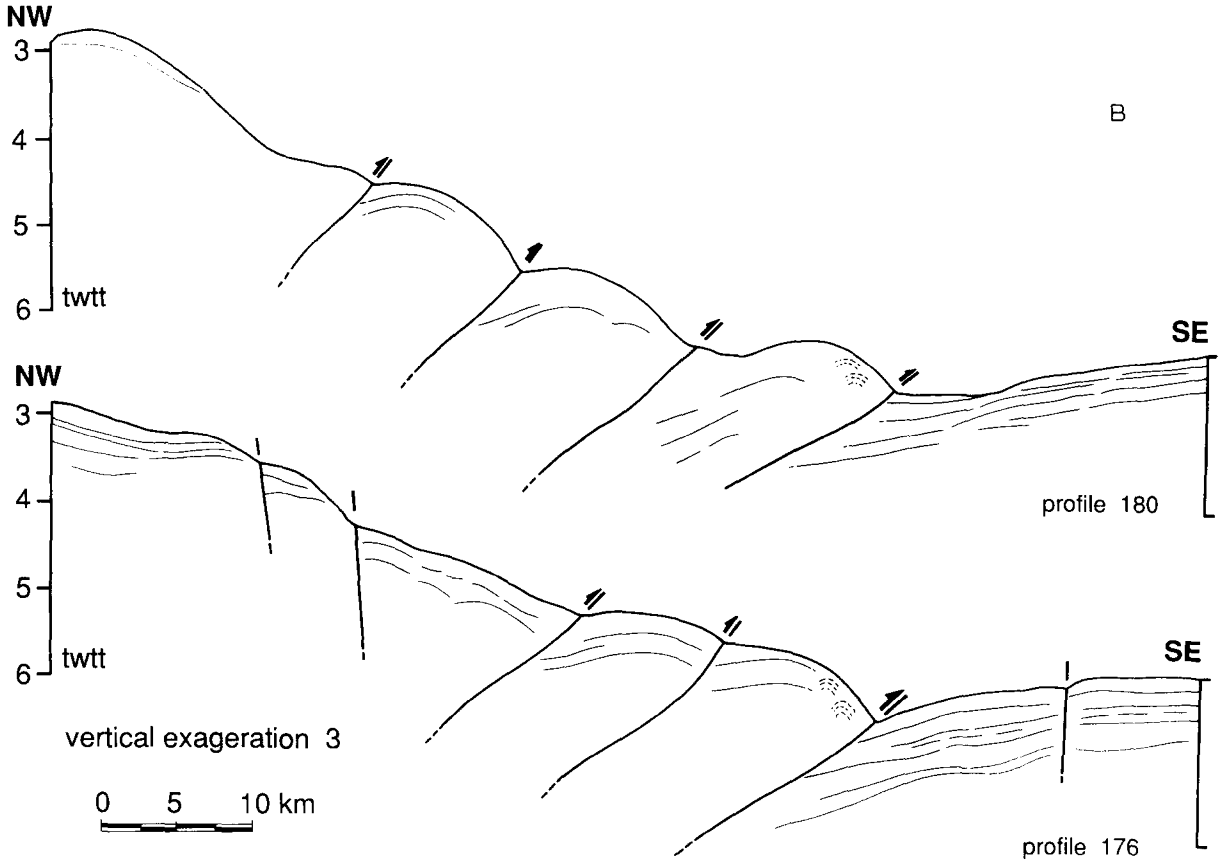


Fig. 6 (continued).

extend westward of 78°20′, but from this point continues to the east along the Cuban margin.

Thus, the Cabo Cruz basin is located on a significant dextral offset of two Oriente fault segments. Based on its location, the general shape of the basin and to its structural pattern, we interpret it as a typical pull-apart. In this framework, the N45–50°E trending oblique faults crossing this basin can be interpreted as Riedel faults, which developed in a sinistral shear regime along the N80°E trending Oriente fault.

The Santiago Deformed Belt

The Oriente Deep is an E–W trending depression, filled from 77°W to 76°40′W by a great thickness of undisturbed sediments (Fig. 4). At 76°40′W, however, these sediments are affected by a fold (Fig. 4), trending N130°W and verging toward the south. Topographically, this fold corresponds to an elliptical ridge, 300 m high above the flat bottom of the surrounding basin. Further to the east the section of the Oriente Deep involved in this compressional tectonic regime becomes progressively larger: we see here the emergence of an area undergoing compression, the Santiago Deformed Belt (SDB) (Fig. 2).

The SDB is an east–west marine range showing clear evidence of compressional tectonics, beginning in the west within the Oriente Deep sediments and stretching toward the east as far as the Windward Passage area. This belt is 300 km long (76°40′W–73°50′W) and ranges in width from 10 to 30 km. It is bounded to the north by the Oriente fault system whereas its southern limit is a lobate deformation front. This deformation front corresponds either to frontal folds or, more often, to a north dipping tectonic contact. The constituent structures of this deformed belt are of three types: folds, thrusts and reverse faults, with strike-slip faults cutting the other structures.

A detailed study of the SDB allows us to divide it longitudinally into three different domains, each one characterised by its own tectonic style:

(a) *The western part of the SDB* forms a narrow band of hills stretching in a general east–west direction within the Oriente Deep. The seismic profiles clearly show that these hills correspond to anticlinal folds affecting the sediments of this basin (Fig. 4). Most of these folds have vertical axes, although some of them dip towards the south. Their axes trend in average N100–111° E and mostly display a curved trace with a stretched "Z" shape. These folds are set within three N80–90 ° E trending alignments and clearly show within each alignment a dextrally offset "en échelon" arrangement (Fig. 5) (Calais and Mercier de Lépinay, 1990).

The seismic reflection data reveal that the bottoms of these anticlines often correspond to a thrust trace (Fig. 4). These thrusts mostly dip to the north; only the contact of the deformed zone with the northern part of the Oriente Deep can be interpreted as a minor, south-dipping thrust. The N45–60 ° E trending faults which offset these structures are limited to areas confined between two thrusts. Since they do not cut them but tend to connect one thrust with an other, we interpret them as part of the strike-slip offsets forming lateral thrust systems.

As shown by profile 105 (Fig. 4), the top of the acoustic basement is a continuous, rectilinear, south-dipping reflector, covered by an on-lapping and slightly folded seismic sequence. This arrangement strongly suggests the existence of a décollement surface between the acoustic basement and the folded sequence above. This décollement has significant consequences for the structure of this part of the SDB: it probably explains the location of these "en échelon" folds off the main strike-slip fault (Oriente fault), in the middle of the Oriente Deep (Calais and Mercier de Lépinay, 1989).

Thus, the general E–W trend in this domain is only apparent: it is determined by an "en échelon" arrangement of N100–110 ° E trending structures.

(b) *The central part of the SDB* corresponds to the Santiago Promontory, a southward projection of the Cuban margin. On the seismic profiles, the Santiago Promontory displays an important acoustic basement covered by a thin sedimentary sequence (Fig. 6). As shown during the SEACARIB II cruise (Mercier de Lépinay et al., 1988), its magnetic and gravimetric characters are clearly different from the Oriente Deep ones and rather like those of the Cuban island. It seems therefore that the deformed material is not the sediments of the Oriente Deep, but the basement of the Cuban margin itself. Thus, we probably are here beyond the eastern boundary of the Oriente Deep.

Some folds can locally be identified in this area, but its major structural feature is the predominance of thrusts. These are particulary clear at the bottom of the slope as exhibited on profiles 176 and 180 (Fig. 6). Thus, the Cuban margin is thrusting southwards the infillling of the depression located at its bottom. In addition some irregularities of the Cuban slope can be interpreted as thrusts affecting the Cuban margin material. These thrusts seem to cut the Cuban margin into a series of discontinuous imbricated tectonic slices. They are exclusively north-dipping and also display an "en échelon" arrangement.

In this area, the structural trend clearly changes, from N100 ° E west of 75 ° 30′ W to N80 ° E east of this longitude. At the same time, the width of the deformed zone progressively decreases toward the east, ranging from 45 km around 75 ° 50′ W to 25 km around 75 ° W.

(c) *The eastern part of the SDB,* located between 73 ° 50′ W and 74 ° 50′ W, is less than 15 km wide. Its deformation front is not a flat thrust but a series of reverse faults, which rapidly become vertical with depth (Fig. 7). Moreover, we find here, as in the western part of the deformed zone, a well-developed narrow sedimentary basin, the Imias basin, (Mercier de Lépinay et al., 1988), extending in an east–west direction (Fig. 2). The compressional tectonics are not very intense and essentially affect the sediments of the northern part of this basin, where there are reverse faults and some smooth folds. The structural trends, essentially corresponding to these reverse faults, display a N70–80 ° E orientation.

To the east, no continuity exists between the SDB and the active structures observed on land in the northwestern peninsula of Haiti (Desreumaux, 1988) or at sea at the bottom of the southern slope of this peninsula (Goreau, 1983). Both domains

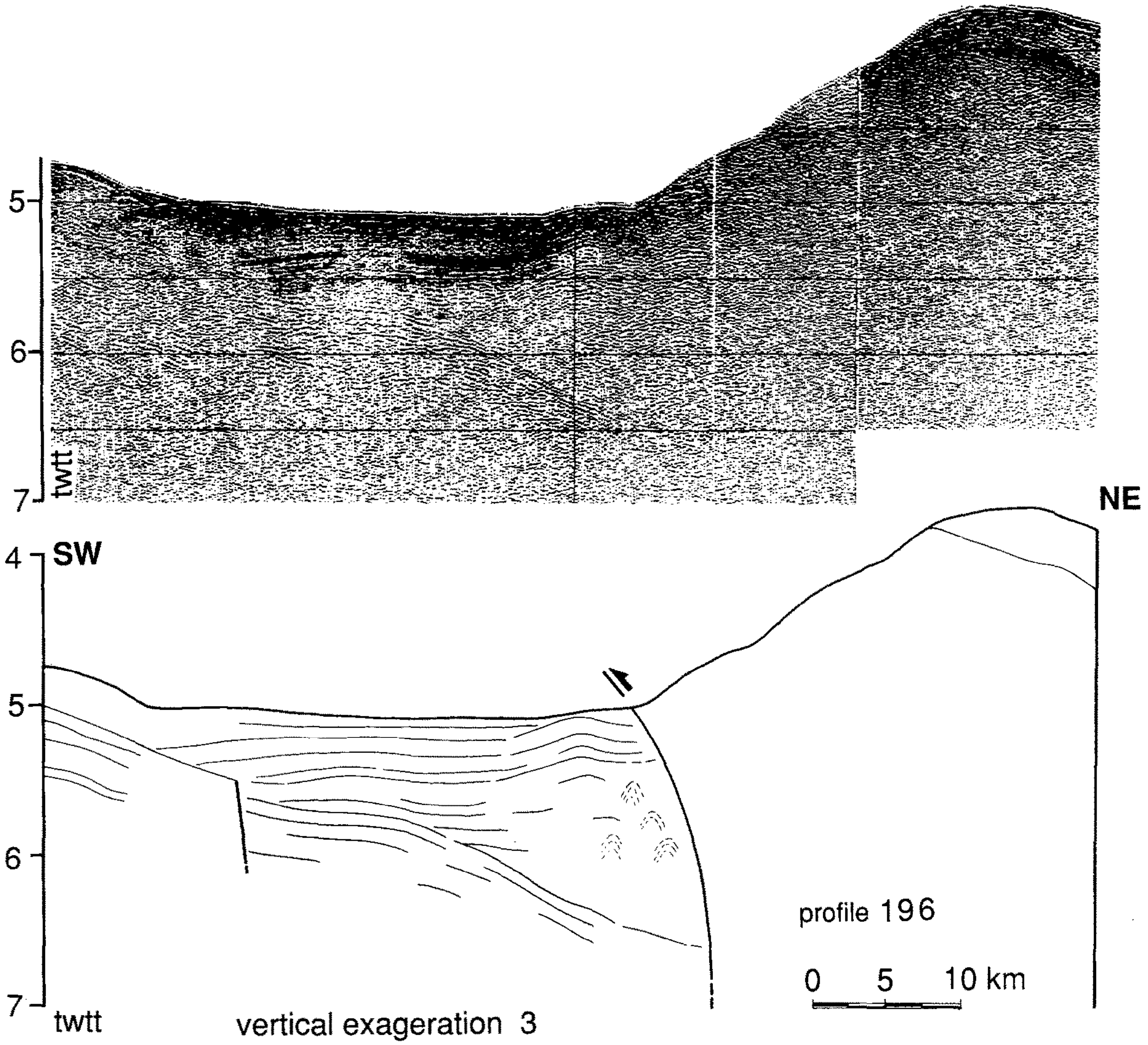


Fig. 7. Seismic profile 196 and its interpretation (location on fig. 1B).

rather seem to form two independant structural arrangements. Thus the SDB fades at the entry to the Windward Passage, an important and still unclear articulation of the northern Caribbean transcurrent plate boundary.

Discussion

Active transpression and transtension

As previously stated, the SDB is a real submarine range, very narrow and parallel to the Oriente fault, showing clear evidence of southward compressional tectonic tectonic features. As this compressional tectonism involves the youngest deposits of the Cuban margin, we can infer that it is active. On the other hand, the Oriente transcurrent fault is also an active feature, as shown by the study of natural seismicity in the Caribbean domain (Molnar and Sykes, 1969; Sykes et al., 1982). Both phenomena, compression and strike-slip, are therefore working simultaneously. It is therefore logical to relate the structure of the SDB to an active transpressional tectonic regime occurring along the southern Cuban margin. One of the major proofs for this transpressional mechanism is the "en échelon" arrangement of the SDB structures, visible over the greatest part of the SDB.

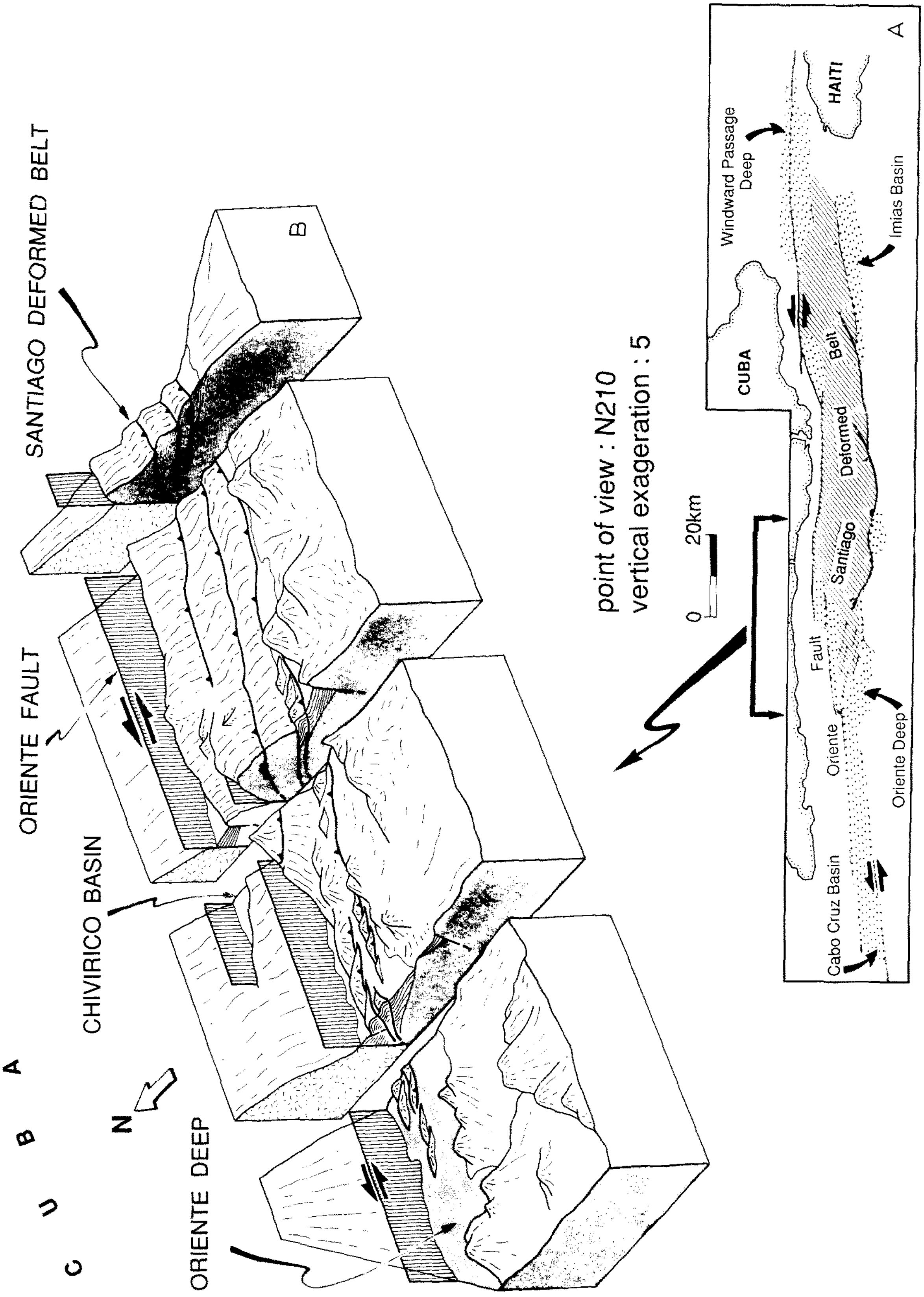


Fig. 8. A structural sketch map of the southern Cuban margin and the Windward Passage. B. Block diagram showing structural interpretation of the area.

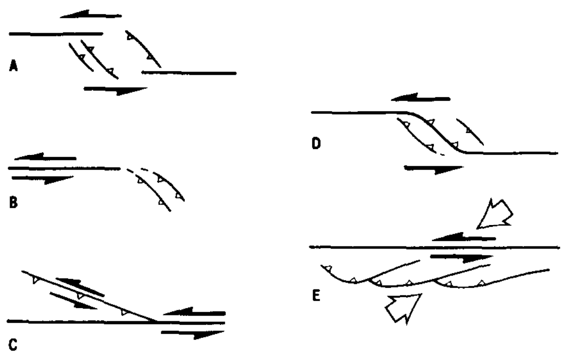


Fig. 9. The different mechanisms responsible for transpressive structures.

This observation is particularly clear in the western part, which exhibits sinistrally offset fold sets typically produced by sinistral wrenching (Fig. 5). We conclude therefore that the SDB is a typical submarine range caused by transpression and propose a three-dimensional "positive flower structure" interpretation for the western part of the SDB (Fig. 8).

The tectonic regime responsible for the development of transpressive ranges, and in this case for the development of the SDB, could be caused by several different mechanisms (Fig. 9):

(a) A discontinuity of the major transcurrent fault. This discontinuity can be: (1) a cross-cutting compressional fault; (2) the end of the transcurrent fault; (3) two non-parallel transcurrent faults.

(b) An oblique relative motion of both blocks involved in the strike-slip movement. This oblique movement can occur: (1) locally, along a bend in the major transcurrent fault, forming a restraining bend; (2) regionally. The origin of the compression is thus the oblique relative motion of both blocks along a rectilinear strike-slip fault.

(c) A combination of these mechanisms.

Consideration of the southern Cuban margin, shows that the trace of the Oriente fault allows us to eliminate the "end of a transcurrent fault" and "two non-parallel transcurrent faults" hypotheses. Between 76°10′W and 75°30′W, the Oriente fault displays a sinistral offset, which could be responsible for transpression. However, this geometry of the Oriente fault seems too local to be responsible for the structure throughout the whole deformed area and especially to the east of the area. Therefore, we think that the transpressive structure of the SDB must be related to a regional oblique relative motion along the Oriente transcurrent fault. While the southern Cuban margin undergoes this regional transpression, it is also subject to local transtension, as documented by the Cabo Cruz, Chivirico and Baitiquiri basins. This transtension is restricted to well deliminated basins, always located at the tensioned dextral offsets of the Oriente fault.

The southern Cuban margin provides evidence that extensional and compressional structures can be in operation at the same time, under the same kinematic regime and over short distances, when occuring along a strike-slip fault. In the case of the Oriente fault, the predominant tectonic regime, found along the entire southern Cuban margin, is transpression, as evidenced by the great development of strike-slip related compressive structures (SDB). Consequently, the southern Cuban margin clearly illustrates that structures associated with a strike-slip fault are governed by two main parameters: (1) the geometry of the fault —its present trace, off sets and bends; and (2) the relative motion of both blocks along the fault. All along the fault the tectonic regime (pure strike-slip, transtension or transpression) is controlled by the synergy of these two parameters.

Timing of recent tectonic evolution

Our observations concerning the timing of the tectonic evolution of the northern Caribbean plate boundary off Cuba, allow us to infer the existence of two major periods, each one characterised by a distinct tectonic regime. A general transtensional regime probably occurred first, accompanied by a large subsidence of the Oriente Deep and the Imias basin. The sedimentary fill of these basins then began to undergo compressional tectonics during a transpressional regime, which is still active. Thus, our observations strongly suggest that a tectonic reorganisation recently occured along this part of the northern Caribbean plate boundary. Such a recent tectonic reorganisation is also described on land in Jamaica (Mann et al., 1985), in Puerto Rico (Heezen et al., 1985) and in Hispaniola

(Bourgois et al., 1983; Mann et al., 1984; Boisson, 1987), where it is Pliocene–Quaternary in age. In the northern Dominican Republic, recent investigations have shown that it occurs after the lower part of the Upper Pliocene (Calais and Mercier de Lépinay, 1989). We infer that the development of the SDB is related to the same tectonic event and propose a Late Pliocene age for this reorganisation.

Implications for the present-day motion along the northern Caribbean transcurrent plate boundary

As stated by Stein et al. (1988), the present-day motion of the Caribbean plate remains one of the more poorly known of all major plates. In particular, the paucity of structural knowledge along the greatest part of its northern boundary, especially at sea, prevents good geological control of kinematic hypotheses. These hypotheses, mostly deduced from geophysical data, have always assumed a simple and almost straight trace for both the Swann and Oriente transform faults, but have never taken into account their associated structures. However, as demonstrated above, geometry, structure and kinematics are three fundamental parameters which must be studied together in order to understand the strike-slip fault mechanism. Consequently, in such a context, an accurate kinematic model cannot be calculated without a precise knowledge of both geometry and structures along the fault.

The southern Cuban margin is now the best studied segment of the northern Caribbean plate boundary, from a geometrical (trace of the Oriente fault) and from a structural (associated structures) point of view. Therefore, it is a prime "test area" to verify the present-day motion of the Caribbean plate relative to North America, that is to test the validity of the different rotation parameters which have been postulated by various authors. In attempting to test these proposed models of motion along the the northern Caribbean plate boundary, we digitized the trace of the Oriente fault from Cuba to Hispaniola, as derived from our Seabeam and seismic data. We then used the three-dimensional kinematic software "Paleomap" developed by M. Ross and C. Scotese at the University of Texas, Institute for Geophysics (UTIG) at Austin (U.S.A.). This software takes into account the spherical shape of the earth surface and the map projection, and thus prevents graphic distortion while simulating plate rotations.

Since the last major geological event recorded along the northern Caribbean plate boundary is Late Pliocene in age (Calais and Mercier de Lépinay, 1989), we infer that the motion of the Caribbean plate relative to North America has been the same for the last 2 Ma. We therefore tested the proposed rotation parameters during this time in an attempt to determine whether they could have led to the most recent structures observed along the southern Cuban margin and in the Windward Passage area.

TABLE 1

Comparison between observed and predicted structures along the southern Cuban margin and the Windward Passage using various authors' rotation parameters (explanations in text)

Observed structures		References	Stein et al., 1988	Jordan, 1975	MacDonald, 1976	Sykes et al., 1982
Cordillera Septentrional	TP	Mann and Burke, 1984 De Zoeten, 1988 Calais and De Lépinay, 1989	Y	Y	Y	Y
Tortue Channel	PSS?	Momplaisir, pers. commun., 1987	N	N	N	N
Windward Passage	PSS	this article	N	Y	N	N
Southern Cuban Margin	TP	this article	Y	N	N	Y
Oriente Wall	TT	this article	N	Y	Y	N
Cabo Cruz Basin	TT	this article	Y	Y	Y	N

TP = transpression; TT = transtension; PSS = pure strike slip.

Four kinematic models have been proposed for the Caribbean/North America relative motion (Jordan, 1975; MacDonald, 1976; Sykes et al., 1982; Stein et al., 1988). These four models, based upon different sets of data and different assumptions of the rate of relative displacement of both plates, lead to significantly different results, as shown in Table 1. As shown in this table, none of these models accounts for all the various tectonic regimes recorded along the Oriente transform fault from Cuba to Hispaniola. Moreover, as determinated by Heubeck (1988), none of these models accounts for the structures observed along the entire strike-slip plate boundary, from Honduras (Polochic–Motagua fault zone) to Puerto Rico. We must therefore conclude that all these models are inaccurate in their description of the actual present-day motion of the Caribbean plate relative to North America.

As clearly presented in Stein et al.'s paper (1988), kinematic models used only to take into account spreading rates, transform azimuth and earthquake slip vectors. Neglecting the structures associated with the transform fault and only using the motion and trend of the main strike-slip fault only enables these models to describe the slip component of the motion along the plate boundary. The evidence for active deformation along this strike-slip plate boundary presented above shows that this slip component has to be complimented by a convergence component to describe the actual motion of the Caribbean plate relative to North America. We think that the discrepancy between this "actual motion" and the "slip motion" provided by the kinematic models explains why these models cannot describe the entire deformation pattern of the northern Caribbean transcurrent plate boundary. An alternative explanation could be to consider that the motion along the northern Caribbean plate boundary must be described by several rotation parameters. However, nothing either in the observed structures, nor in the seismicity allows us to infer such a segmented plate boundary.

If this is the case, the use of the lesser Antilles subduction zone geometry, free from any assumptions about the structures along the transform plate boundary, should give an idea of the motion of both plates which is closer to the actual motion than the use of transform parameters. This could explain the high oblique azimuth of Caribbean/North America motion given by Sykes et al. (1982). Even if their estimation of rate and azimuth of motion is overemphasised (Stein et al., 1988), it probably partly reflects the existence of this discrepancy and the need for a convergence component to describe the present-day motion along the northern Caribbean transcurrent plate boundary.

Conclusion

The data collected during SEACARIB II cruise allowed us to precisely determine the trace of the Oriente strike-slip fault off Cuba and between Cuba and Hispaniola. We have shown that the northern Caribbean plate boundary along the southern Cuban margin is mainly a system of dextrally offset and échelon fault segments. This fault system is responsible for local transtension at the offset areas and leads to the subsidence of small basins located along its trace, at the bottom of the Cuban margin (Cabo Cruz basin) or on the margin slope itself (Chivirico and Baitiquiri basins). Moreover, we confirm here that the Oriente fault continues to the east of Cuba into the Tortue channel and is not connected, through the Windward Passage, with the subduction of the Atlantic oceanic lithosphere under Puerto Rico and Hispaniola.

As regards the tectonic regime along this plate boundary, we describe for the first time the Santiago Deformed Belt, an area showing clear evidence of active compression extending along the bottom of the southern Cuban margin. Its structure is related to a transpressional tectonic regime occurring along this part of the Oriente fault and which has probably existed since the Late Pliocene. According to the shape and extension of the SDB and to the trace of the Oriente fault, the mechanism responsible for this transpression must be a regional, oblique movement along the Oriente fault: a convergence component is associated with the slip displacement along it. Thus, the precise knowledge of both geometry and structures along the Oriente strike-slip fault provides new constraints for the recent kinematic evolution along the northern Caribbean transcurrent plate boundary.

Acknowledgments

The authors would like to thank Paul Mann for providing us with the opportunity to use the Paleomap softwares at U.T.I.G. and for interesting discussions about the "northern Caribbean plate boundary zone". We are also grateful to Rick Herzer and Stacey Tibursky for the helpful comments and advice that they gave us during the writing of this article. We thank the officers and crew of the R.V. *Jean Charcot* for invaluable assistance during the data acquisition phase of the SEACARIB II project. This work was supported by I.N.S.U./C.N.R.S. and IFREMER.

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