Problems in Application of Modern Tectonic Hypotheses to Cuba and Caribbean Region

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Abstract Within the framework of the Caribbean, structures may be classified according to the type of crust and the character of its Mesozoic-Cenozoic development. Magmatic activity associated with Benioff zones has undergone a continuous clockwise rotational movement from Paleozoic until recent time. Within Cuba, it is proposed that the original crust was of the modified oceanic type. The Benioff zone of Cuba, no longer active today, dipped from north to south beneath the island. The geologic evolution of Cuba can be divided into three stages: (1) an oceanic stage until Tithonian time; (2) an island-arc stage from Tithonian until middle Eocene time; and (3) a platform stage from the late Eocene until the recent.

INTRODUCTION

During recent years, many authors have tried to explain Caribbean geology according to the modern version of continental drift known as the new global tectonics. However, very few of these workers have analyzed carefully all of the implications that Cuba has for the analysis of the problem. As a result of not studying these implications, conclusions drawn by most authors are necessarily incomplete. It is perfectly safe to say that none of the published works has been successful in interpreting correctly the geology of Cuba in terms of plate tectonics; and none has analyzed the problem through to the ultimate consequences of plate tectonics. One principal purpose of this paper is to propose a model to resolve this problem. In addition, another purpose is to apply the fracture-contraction hypothesis to the resolution of the problems of Cuban and Caribbean geology, thus seeking alternate solutions. The writer maintains an impartial position during the testing of each hypothesis, each by itself, so that he will avoid arriving at premeditated or prejudged conclusions. The application of the “method of multiple working hypotheses” is, without any doubt, the best method of investigating problems, particularly when one considers the actual state of knowledge of most problems.

CARIBBEAN REGION

Many syntheses have been published during the last 10 years on the geology of Cuba. Generally speaking, most of them are current and they tend to complement one another. Among them are the works of Furrazola et al. (1964), Khudoley (1967), Pushcharovskiy et al. (1967), Khudoley and Meyerhoff (1971), and many others. Some of the recently published works, as well as others in press, present new data which permit, to a certain extent, a better understanding of some points concerning the constitution and geologic structure of Cuba. Because of this, even though the works cited will give the reader a more complete overview of the problems, the new knowledge acquired permits the revision of some facets of the problems that are of vital importance in the analysis developed in the succeeding paragraphs. Moreover, because the geology of Cuba is related closely to that of the entire Caribbean-Antillean-Central American region, I commence by giving a broad overview of the principal large structural elements of the entire area between North and...
South America, without making any pretense of delving deeply into the problems.

Figure 1 is a general sketch of the elements which comprise the crust and the structure of the crust in the Caribbean-Antillean-Central American region, according to my interpretation based on the works of Butterlin (1956), Weyl (1966), Ju
dole and Furrazola (1967, 1971), Meyerhoff (1967), Khudoley and Meyerhoff (1971), Wilson (1974), and others. This sketch is not an attempt to make a "classic" classification of the region, but only to show its more fundamental and essential characteristics. The larger structures of the region have been subdivided according to the character of the underlying crust, its composition, and its evolutionary trends during the Mesozoic-Cenozoic. Detailed description of the diverse structures can be found in the works already cited, as well as in the works of Khain (1971), Meyerhoff and Meyerhoff (1972a), and others. Certain comments are inescapable.

With respect to the areas underlain by continental (sialic) crust, it is notable that those areas are contiguous with the continental masses of North and South America; this is to say that they constitute a submarine prolongation of the two continents. It is of considerable interest and importance that, in spite of their spatial association, the Greater Antilles, between Cuba and the Virgin Islands, and north of Venezuela, between the Goajira Peninsula and Trinidad, are developed in the Lesser Antilles, and in Central America between Costa Rica and Mexico. Ju
dole and Furrazola (1971, p. 137-139, Figs. 32-35) showed the same general history, although they did not include the Aves Ridge, although such volcanism is severely restricted in the western part of Cuba. Volcanism of the same age is present between Colombia and Costa Rica in Central America. The effusive rocks of the last cycle, middle Eocene to recent, are developed in the Lesser Antilles, and in Central America between Costa Rica and Mexico. Ju
ndole and Furrazola (1971) clearly indicates the high mobility of these basins. The greater part of magmatic migration can be described more correctly as continuous clockwise rotational movement, from Late Jurassic (Tithonian) time until the recent. In my opinion, this conclusion has great importance as I shall attempt to demonstrate in succeeding pages. The greater part of this magmatic belt is broken up by faults, particularly those parts with volcanic rocks older than middle Eocene. The earth's crust in this whole area is of oceanic and modified oceanic types, even though the crust may be overprinted grossly by sedimentary and magmatic processes. Of considerable importance is the fact that the belt of volcanic rocks is rimmed by active (associated with an active volcanic arc and Benioff zone) or inactive oceanic trenches.

North of the magmatic belt of the Greater Antilles is the inactive ancient leptogeosynclinal (sediment-starved; see Trumpy, 1960) trench of pre-late Eocene time (Fig. 1). This trench, which
FIG. 1—Geologic sketch of Caribbean-Antillean-Central American region. Legend: (1) stable zones tending to rise and sialic continental crust; (2) mobile zones tending to subside, oceanic crust, and modified oceanic crust; (3) zones of prolonged subsidence underlain by continental crust; (4) mobile zones without Mesozoic-Cenozoic volcanism and having continental-oceanic crust; (5) compressed inactive trench; (6) structure of uncertain types; (7) volcanic zone, mainly Cretaceous; (8) volcanic zone, Cretaceous-middle Eocene; (9) volcanic zone, Eocene to recent.

crops out in Cuba, can be extended, on the basis of a band of gravity minima, to the Puerto Rico Trench. The Puerto Rico Trench, although it is no older than middle Eocene, could have originated on the weakened tectonic zone of the ancient trench, today inactive. However, the present Puerto Rico Trench is not of the island-arc type.

East of the Aves Ridge, the Granada Trough may have been localized on an ancient island-arc trench which was active from Late Cretaceous to middle Eocene time. The Tobago-Lesser Antilles Trench is active today, is an island-arc type trench, and is explained as a result of its association with the modern magmatism of the Lesser Antilles. In northern South America, north of Venezuela, geophysical data indicate the presence of an ancient island-arc trench between the Venezuelan basin and the volcanic belt (Bunce and Fahlquist, 1962; Worzel, 1965). In the area from Colombia to Costa Rica, the existence of an ancient trench is not so evident, but a detailed study of the geology of the region could reveal its presence. Along the Pacific margin of Central America, the Central American Trench (Middle America Trench) is present, active, and associated with active magmatism. In this area it is evident that there is a close relation between the trench and the volcanic arc, not only spatial but also temporal, and this indicates that the origin of the magmatic belt of the Caribbean region is a response to the same general processes that formed the island arcs of the Pacific Ocean.

The Bartlett Trough is not an island-arc type of trench, but the possibility cannot be eliminated that it was an island-arc trench during the Paleozoic (Meyerhoff, 1966)—if the Cayman Ridge and Nicaragua Rise were Paleozoic magmatic belts.

To complete this general overview, it is necessary to mention the structure described by Baie (1970) in the Caribbean margin adjacent to the Yucatan Peninsula. Baie defined the structure
which was found through seismic studies as a probable link between Yucatan and Cuba. Bale's findings later were confirmed in more detail by Pyle et al. (1973). Khain (1971) believed that a marginal fault extends along the east side of the Yucatan Peninsula and continues north of Cuba. Pyle et al. (1973, Figs. 1, 2) showed that this structure strikes northeast-southwest, and that the structure consists of the following elements: (1) a north-northeast-striking ridge crest which probably extends beneath the island of Cozumel; (2) a double ridge with a shallow trough between the two crests; this double ridge forms an arc extending from Cape San Antonio in Cuba to the western margin of the Yucatan Basin, paralleling the coast of Quintana Roo in Mexico. Levchenko (1970) found two zones, without seismic-reflection data, north of Guanahacabibes Peninsula. The two zones are separated by an area filled with sediments of probable Mesozoic and Cenozoic ages. The facts enumerated here are evidence for the structural continuity between the Greater Antilles island arc and the northern Central America orogen.

CUBAN AREA

Having reviewed the principal characteristics of the structure of the region that bear on the geology of Cuba, I can now go into more detail concerning the territory of the Cuban Archipelago.

The Bahamas platform north of Cuba extends into the north coast of Cuba in a few areas (Fig. 1). The southern border of this large structure was named by Ducloz and Vuagnat (1962) as the Remedios zone. The crust underlying this zone is continental (Ipatenko et al., 1971; Khudoley and Meyerhoff, 1971). The base of the Mesozoic-Cenozoic section in the area consists probably of terrigenous sediments (Meyerhoff and Hatten, 1968; Dietz et al., 1970). Since at least Late Jurassic time, carbonate and evaporite rocks have been deposited here in shallow water. The monolithic character of this huge platform structure imparts to it a relatively simple tectonic character where nearly vertical faults predominate (Ducloz and Vuagnat, 1962; Meyerhoff and Hatten, 1968; Levchenko, 1970).

South of the Bahama platform–Remedios zone is the Camajuani zone of Ducloz and Vuagnat (1962). This zone extends from one end of the island of Cuba to the other (Levchenko, 1970). The Camajuani zone has been interpreted classically as an ancient oceanic trench or leptogeosyncline, and the writer has had the opportunity to study it in several localities where it crops out within the island of Cuba. The sedimentary sequence in the trench includes terrigenous sedimentary rocks and evaporatic facies of the pre-Tithonian Jurassic, which were deposited in very shallow water. Between Tithonian and Paleocene times, sedimentation took place in much deeper water and both carbonate rocks and cherts were deposited. These are intercalated in the section with chaotic clastic rocks of the Cenomanian–Turonian and of the Paleocene. The younger sequence is terrigenous below and carbonate rock above, deposited in bathyal to neritic waters. After middle Eocene time, the rocks deposited across this zone generally are not differentiated from those in surrounding areas.

Other descriptions and sections of the Camajuani zone are found in the studies by Ducloz and Vuagnat (1962), Meyerhoff and Hatten (1968), Khudoley and Meyerhoff (1971), Knipper and Cabrera (1972), and others. This zone acquired the character of a trench beginning with Tithonian time and was filled and compressed by the end of Paleocene time, with the whole process culminating by middle Eocene time. The actual structure is very much like that of a melange in many respects, having acquired this characteristic as a result of the "Laramide" orogenesis (Ducloz and Vuagnat, 1962).

South of the ancient trench and partly covering it with overthrust sheets is the classic eugeosynclinal zone of Cuba that has been described by many geologists. The nature of the crust in this region remains in doubt. Soloviev et al. (1964), Furrazola et al. (1964), Meyerhoff and Hatten (1968), Ipatenko et al. (1971), Somin and Millán (1972), and others have implied or proposed the existence of continental sialic crust in Cuba, even though they are not in agreement whether this crops out or not, or where or how it may crop out. During the same period, Kozary (1968), Meyerhoff and Hatten (1968), Boiteau et al. (1972), Knipper and Cabrera (1972), Somin and Millán (1972), and others also have proposed the existence of outcropping oceanic crust in various parts of the country. None of these authors is in agreement concerning the places where the oceanic crust crops out, nor are they in agreement concerning which rocks represent the oceanic crust. Actually, there is general agreement that geophysical layer 3 should be metamorphosed, at the very least, in the greenschist facies (Christensen, 1970; Wyllie, 1971; Meyerhoff and Meyerhoff, 1972b; and others). However, the presence of an ophiolitic sequence does not imply that it is an outcrop of oceanic crust.
Proposed Composition of Crust beneath Cuba

In the following proposal, I utilize the works published recently on metamorphic rocks in Cuba and suggest the composition of the terrestrial crust in Cuba.

Upper mantle—Represented by ultramafic rocks which crop out in various parts of Cuba and which contain fragments of eclogite, garnet schist, actinolite schist, etc.

Geophysical layer 3—Amphibolites of Sierra del Purial (Oriente Province), of area marginal to Sierra del Escambray (Las Villas Province), and other localities in Cuba (Cech and Mathemy, 1966; Somin and Millán, 1972; Boiteau and Campos, 1974).

Geophysical layer 2—Tuffs, lavas, jasper, sandstones, carbonate and other rocks which have been metamorphosed into greenschist and glaucophane schist facies; in Sierra del Purial (Boiteau and Campos, 1974); Sierra del Escambray (Millán, 1973); Pinar del Río (Millán, 1972a); and other parts of country.

Geophysical layer 1—Mildly metamorphosed carbonate-terrigenous complex (Somin and Millán, 1972), San Cayetano Formation, and probably all pre-Tithonian sedimentary rocks.

According to the proposed composition sequence, before the island-arc stage began in Cuba, the crust was of modified oceanic type. The data and concepts which support my interpretation are: (1) the ultramafic suite generally is related to the upper mantle, and the presence of greatly metamorphosed rocks within the ultramafic rocks supports their deep origin; (2) Somin and Millán (1972) have proposed that the amphibolites are the most ancient of the metamorphic rocks of Cuba, and Boiteau and Campos (1974) have demonstrated that they are the oldest in the Purial massif; (3) the amphibolites and the ultramafic rocks are closely related in outcrops. In the region of Gran Tierra, Sierra del Purial (Purial massif), between La Tinta and Los Naranjos, Oriente Province, these rocks are interstratified and are separated by tectonic breccias that contain elements of the amphibolites and the ultramafic rocks. These breccias are present along thrust-fault planes. In certain localities a probable "transition" between serpentinite and amphibolite is present; (4) the age of the greenschists (tuffs, lavas, etc.) is not determined; Somin and Millán, and Boiteau and Michard (1974), believe that they are Cretaceous, but their arguments are not convincing; (5) the greenschists and the rocks of the carbonate and mildly metamorphosed terrigenous complex have undergone a very similar deformation history, with three episodes of compression superimposed (Somin and Millán, 1972; Millán, 1972a, b; Boiteau and Campos, 1974); (6) the age of metamorphism of the carbonate-mildly metamorphosed terrigenous rocks appears to be Cretaceous (Meyerhoff et al., 1969), and the age of the principal metamorphism of the greenschists also seems to be Cretaceous (Boiteau and Michard, 1974); (7) the age of the various pre-Tithonian rocks appears to be no greater than Middle Triassic and no younger than Late Jurassic (Somin and Millán, 1972); (8) the different grades of metamorphism within the various pre-Tithonian units of Cuba do not imply necessarily that they are of greatly different ages; (9) oceanic sediments do not have to be deposited necessarily at oceanic depths; (10) within the ocean basins, such as on the Mid-Atlantic Ridge, sialic or intermediate intrusive rocks have been found (Meyerhoff and Meyerhoff, 1972b); (11) the gravimetric interpretation of Cuba requires the existence of up to 12 km of low-density rocks in some places (Soloviev et al., 1964). I believe it would be useful to reinterpret the gravimetric data from Cuba on the basis of the concepts elaborated here and then to check the reinterpretation against the conclusions which I reach; (12) the carbonate-metaterrigenous complex exhibits metamorphism corresponding to the greenschist and garnet-amphibolite facies. The greenschist-facies rocks include both the true greenschists and the glaucophane-lawsonite facies. These facts show that the metamorphism was not of the regional load type with a defined geothermal gradient. Nevertheless, the present positions of these metamorphic rocks demonstrate that they probably resulted from horizontal tectonic displacements. Consequently, their spatial relations do not fit the model proposed here.

Since Tithonian time, there has been effusive activity in Cuba. This effusive activity has gone on through various times of maximum and minimum activity until the middle Eocene. In general, the magmatic rocks become less mafic upward in the section, from tholeiitic below to dacitic and rhyolitic above. During the Late Jurassic (Tithonian)-Cretaceous (Senonian) cycle, magmatism took place throughout Cuba south of the marginal trench (Camajuani zone). The thickness of the volcanic and volcanic-related rocks increases southward (Furrazola et al., 1964; Khudoley and Meyerhoff, 1971). During the Senonian, there were intrusions of intermediate and acidic rocks, such as small dikes in the north and batholithic types of intrusions in the south (e.g., Manicaragua batholith, Las Villas Province). After Turonian time, magmatic activity decreased markedly but continued sporadically until the Maestrichtian (Furrazola et al., 1964; Furrazola, 1969). Since Paleocene time or before, the major development of volcanic rocks was in the southeastern part of the island (Fig. 1). This magmatism belongs to the
Late Cretaceous-middle Eocene cycle. In general the magmatism of this cycle took place in all of Cuba (Laverov et al., 1967; Meyerhoff and Hatten, 1968; Semenov et al., 1968), but in very localized areas except for Oriente Province and part of Camaguey Province, where this cycle is presented most fully. From southern Oriente and Camaguey Provinces, the volcanic prism wedges out toward the north and west. In the Sierra Maestra of southern Oriente Province, the sequence of volcanic rocks is estimated to reach a thickness of 6,000 m. Intermediate and acidic intrusives are characteristic—diorites and granodiorites—forming batholiths in Camaguey and northern Oriente (Nagy, 1973), as well as small dikes of Paleocene and middle Eocene ages. In southern Oriente, batholithic bodies and dikes of diorite, granodiorite, and aplitic are present; these are of middle Eocene age (Tijomirov, 1967).

During Cuba’s geologic history, one can recognize three orogenic events. The “Nevadan” orogenesis profoundly fractured the crust and led to the development of the island arc (Khudoley and Meyerhoff, 1971); the “Subhercynian” orogenesis metamorphosed the basement, fractured the crust, and folded all rocks up to the Turonian; and the “Laramide” orogenesis caused an intense dislocation of all rocks through middle Eocene age, including great thrust sheets propelled from south to north. It was during the “Laramide” orogenesis that the entire arc was thrust against the Bahama platform, locally overriding its southern margin. After middle Eocene time, the entire Cuban Archipelago began to stabilize, and vertical movements predominated among the large tectonic blocks. As a result of vertical displacements, localized compressive stresses were built up so that the overlying middle Eocene and younger sequence was fractured and gently folded, forming flexures around the margins of blocks of different sizes (Iturralde-Vinent, 1972). These facts suggest that tectonic stresses in the region had deeper effects at the beginning, and that the magnitude of stresses decreased from Jurassic to recent time.

Thus, the geologic history of Cuba—according to the data in concepts reviewed to this point—can be divided into three stages: (1) the oceanic stage of development which lasted until Tithonian time; (2) the island-arc stage which lasted from Tithonian to middle Eocene time; and (3) the platform stage of late Eocene-recent, above the folded “Laramide” basement.

Tithonian-Middle Eocene Benioff Zone in Cuba

To understand the regional geotectonic analysis which follows, it is necessary to recognize the orientation of the Benioff zone beneath Cuba from Tithonian through middle Eocene time. Khudoley and Méyérrhoff (1971) and Malfait and Dinkelman (1972) proposed, without providing any proof, that the Benioff zone of Cuba dips from south to north. In contrast, Nagy (1972) and Mattson (1973) stated that the Benioff zone dips from north to south, from the north coast of Cuba; like Khudoley and Meyerhoff, and Malfait and Dinkelman, neither Nagy nor Mattson documented their case. I agree with Nagy and with Mattson that the Benioff zone dips from north to south, and I consider that the Benioff zone is no longer active. My reasons for having it dip from north to south are the following: (1) the ancient marginal trench is in northern Cuba (Fig. 1), and the volcanic rocks are south of it; (2) the volcanic rocks increase in thickness southward; (3) the intermediate and acidic intrusive rocks are largest in the southern part of the island; (4) the preponderance of the youngest magmatism is essentially south of the older magmatism; (5) there is a southward increase in the content of K_{2}O and Na_{2}O in the intermediate and acidic Cretaceous intrusives of Las Villas Province. This statement is based on a comparison of 10 chemical analyses by Semonov et al. (1968). An additional nine analyses from similar intrusives of the Paleogene in southern Oriente Province show an intermediate distribution with respect to the distribution from north to south in Las Villas Province. Because of the scarcity of data, the facts given here have no statistical importance, but they are very suggestive. (6) The major gravity-minimum belt (of Bouguer anomalies) is in the northern part of the island, whereas the maximum Bouguer values are in the southern part of the island (Soloviev et al., 1964); (7) with the exception of Oriente Province, seismic activity is most intense in the northern part of the island and least in the southern part. (8) Boiteau and Michard (1974) have demonstrated that the present relations among the various metamorphic rocks of Cuba do not correspond to those of other island arcs, where the “scar” marking the former position of the Benioff zone crops out. This does not mean that such a “scar” does not crop out in northern Cuba; the ancient Benioff zone does crop out (Camajuaní zone) where erosion has not exposed metamorphic basement. In any case, the relations among the metamorphic rocks of southern Cuba show that they are not associated with a former Benioff zone and, because of this, the southern metamorphic rocks must be interpreted in some other manner.

Against the concept that the Benioff zone formerly dipped from north to south is the general rule that Benioff zones dip beneath continents. Khudoley and Meyerhoff (1971) also made the
point that the Cuban arc was convex toward the south. However it is not a general rule that all Benioff zones dip beneath continents, and the original convexity of the arc is highly conjectural. If the Benioff zone dipped south, the island arc (which was active from Tithonian through middle Eocene times) probably was convex toward the north.

REGIONAL GEOTECTONIC ANALYSIS

Analysis According to New Global Tectonics

As is well known, the geologic evolution of island arcs, according to the new global tectonics, is a function of the interaction between two lithosphere plates. According to this hypothesis, where two plates converge, one underrides the other and the "plane" of contact between the overriding and underriding plate is the Benioff plane or zone. The relative movement of one plate beneath the other causes the sinking of the lower plate into the mantle, fusion, and formation of the magmas which intrude the overriding plate and extrude upon its surface in island arcs. The marginal oceanic trench extends the full length of the zone of convergence between the two plates and is the surface expression of the place where one plate underrides the other plate. Various models of plate convergence and the formation of island arcs have been proposed—such as those by Dewey and Bird (1970), Mitchell and Reading (1971), and others. To develop the subsequent discussion, I start from Cuba and, by deductive reasoning, integrate the whole Caribbean region within the analysis. In this manner I build a hypothesis composed of a series of completely interdependent elements.

I have stated that the Benioff zone beneath Cuba dipped from north to south. The marginal trench occupied a position intermediate between the volcanic arc on the south and the Bahama platform on the north. Given these conditions, the model which must be used for analysis is that of Dewey and Bird (1970, their Fig. 12). This model deals with the interaction between a plate of oceanic crust and a plate of lighter rock, with the plate of oceanic crust plunging beneath the lighter plate.

First of all, because of the present position of Cuba adjacent to the Bahama platform, it is necessary that, in the plate-tectonics model, Cuba advance from the southwest toward a collision with the Bahamas. Therefore, between Cuba and the Bahamas there originally must have been some oceanic crust which has been consumed beneath Cuba during Tithonian-middle Eocene time (Figs. 3, 4). If the Bahamas always have occupied their present position with respect to North America (which seems to be generally accepted and indicated by the geologic data), and if we take North America as a fixed reference point, then it is clear that pre-Tithonian rocks in Cuba were deposited in some location southwest of the present position of the island. Therefore, it is necessary at this point to locate the predrift position of Cuba.

In Figure 2 I have followed the proposal of Malfait and Dinkelman (1972) and have placed Honduras, Guatemala, and part of the Nicaragua Rise along the Pacific Coast of Mexico. This opens a place for Cuba in Central America. If this reconstruction is correct, the pre-Cretaceous sediments of Cuba were deposited east of Mexico and the facies found in Cuba, Mexico, Honduras, and adjacent areas ought to be correlatable after placing these different land areas in their predrift positions.

In Pinar del Rio Province, western Cuba, the San Cayetano Formation is present, consisting of terrigenous continental and marine strata which range in age from Early Jurassic (Triassic?) to Late (Kimeridgian) Jurassic (see Judoley and Furrazola, 1968). In the salt diapirs of northern Cuba, Meyerhoff and Hatten (1968) reported the presence of red bed inclusions of probable Late Triassic-Late Jurassic age; the exact age is not known. Meyerhoff (1967) and Meyerhoff and Hatten (1968) proposed to correlate these rocks with the Todos Santos and El Plan Formations of Mexico, Guatemala, and Honduras. Meyerhoff (1967) noted that the San Cayetano Formation of Cuba in unweathered exposures is very similar to the El Plan of Honduras, but very unlike the Todos Santos which consists of red beds and other terrigenous sediments of continental and marine facies (particularly in the upper part of the sequence; Erben, 1956; Hoffstetter, 1960). In the area of Enriquito, Honduras, above the El Plan Formation, terrigenous beds are present with a fauna similar to that of the San Cayetano (Meyerhoff, 1967).

Additional evidence which might place Cuba in the Central American area is derived by the presence of the Yucatan Peninsula, which is underlain by Paleozoic rocks whose composition would satisfy the requirements of a source for the mineral components of the San Cayetano Formation. Additional argument favoring a former position of Cuba in what is now Central America includes the molluscan faunas of the Upper Jurassic of Cuba, which show a close affinity with those of the Pacific Ocean (Judoley and Furrazola, 1968). One should also note the presence of aptchlyi in
Cuba which, only in Neocomian time, had Mediterranean-province characteristics (V. Houša, personal commun., 1973).

The terrigenous sediments just described from Central America grade northward into the evaporites of the Saline formation of the same age in southern Mexico and parts of adjacent Guatemala (probably Late Cretaceous). Just above the Saline is the Chinameca Limestone of Late Jurassic-Early Cretaceous (Kimeridgian-Neocomian) age. North of Cuba the San Andrian and Punta Alegre Formations are composed of evaporites of Late Jurassic age (Oxfordian to Kimeridgian) in the opinion of the writer. However, they may be older Jurassic as suggested by Meyerhoff and Hatten (1968) and Khudoley and Meyerhoff (1971).

From the foregoing information it can be concluded that, until Tithonian time, the distribution of sedimentary facies in Cuba and Central America was similar; that the rocks possibly are correlative; and, finally, that the spatial distribution shown in Figure 2 might be correct. If this conclusion is a valid one, it has various implications.

In Cuba, the crust underlying the oldest sediments, which may range downward into the Triassic, is at the very least Paleozoic (Tijomirov, 1967; Meyerhoff and Hatten, 1968; Khudoley and Meyerhoff, 1971; and others). If the Paleozoic age is completely certain, as now it appears to be, the predrift reconstructions of Bullard et al. (1965), Dietz and Holden (1970), Dietz et al. (1970), Le Pichon and Fox (1971), and others are incorrect, because their reconstructions leave no space for Cuba and Central America, leave no space for Central America south of the Great Valley of Mexico, and no space for Cuba in its present position. It is, in the opinion of the writer, absolutely necessary that the reconstruction of the continents prior to alleged drift—reconstructions which pretend to take Cuba into account—be far more precise than those reconstructions proposed by the authors listed. No predrift reconstruction has taken into account Central America (where large areas of Precambrian and Paleozoic rocks are known) and Cuba.

If Cuba actually occupied a position in Central America until Tithonian time and reached its present position in Paleocene time, then Cuba moved about 1,200 km in approximately 85 m.y. From these figures one obtains an average rate of drift of 1.4 cm/year, less than the averages for the Pacific (4-6 cm/year) and similar to rates for the Atlantic (1-2 cm/year). Because Cuba would have to be moved on a plate from the Pacific, the value of 1.4 cm/year is unexpectedly small, although it would be greater if one adds to it the component of movement of the North America plate from east to west. The low figure still would be explicable if there exists on the south another convergent zone parallel with Cuba, where part of the Pacific crust is consumed. This zone would not have to have the same age as the zone in Cuba, but could be younger; such a zone is necessary later.

Also necessary to explain the drift of Cuba is a transcurrent fault between North America and the western Caribbean Sea. This fault, inactive today, could coincide with the structure which Baie (1970) found off of Yucatan, but the data presented by Pyle et al. (1973) do not conform well with this suggestion. The structure reported by Baie and by Pyle et al. seem to be related to compressive stress, not to transcurrent faulting as suggested by bottom morphology.

If the plate-tectonics hypothesis is correct, then the "Laramide" structure of Cuba is the result of a frontal collision between Cuba (advancing along the leading edge of the Caribbean plate) and the Bahamas (fixed to the North American continent). This collision explains the following tectonic phenomena: (1) the compression and
collapse of the marginal trench; (2) the overthrust sheets containing volcanic rocks, directed from south to north and overriding the trench (Meyerhoff and Hatten, 1968); (3) the thin-skinned tectonic thrust sheets in Pinar del Rio, as first thrust from south to north during the compression and collapse of the trench, and later from north to south after the trench was closed (Rigassi, 1963, 1965, Piotrowska, 1972; and others); (4) the tear faults which cut the longitudinal structures of the island (Rigassi, 1961; Hatten, 1967; and others); and (5) the chaotic-clastic deposits of northern Cuba and elsewhere.

One problem which arises from the foregoing interpretation is to explain the interstratification of the volcanic facies of the southern part of the island with the carbonate facies of the northern part. Such interstratification has been recorded by Meyerhoff and Hatten (1968) and by Khudoley and Meyerhoff (1971). It is possible that the interstratification is illusory, but the field evidence reported by Meyerhoff and Hatten, by Khudoley and Meyerhoff, as well as by others, is quite strong. Obviously, if such interstratification does exist, the plate-tectonic hypothesis is damaged severely. However, I do not believe that the interstratification is proved.

A small problem arises in attempting to explain the distribution of the magmatism on the island. Magmatic activity was reduced markedly in western Cuba beginning with Late Cretaceous time. This could be explained as the result of the decrease in velocity of the Caribbean plate as it advanced, and at the same time the development of the transverse transient fracture zones such as the Bartlett fault system, the La Trocha fault, and related faults at the beginning of middle Cretaceous time (Meyerhoff, 1966). The important magmatic activity in eastern Cuba during Paleogene time probably can be explained as the result of more active movement of the southeast Cuba sector of the Caribbean plate and a large consumption of crust beneath the plate. If one adds together the displacements along the transverse faults of eastern Cuba, he will obtain a minimum of 50 km additional movement toward the north. In this manner one can explain the eastward migration of magmatism in Cuba—by a process similar to that proposed by Malfait and Dinkelman (1972, their Fig. 9). The minor deformation of the volcanic belt of the Sierra Maestra of Oriente Province, contrasted with the deformation in the volcanic rocks of the rest of Cuba, is explained by the fact that this range is somewhat removed from the convergence zone farther north (Fig. 1).

The preceding paragraphs in general present the most logical solution, in accord with available data, to the application of plate tectonics to Cuba. I propose now to extend this analysis to the rest of the Caribbean.

As the Cuba sector of the Caribbean plate margin advances toward the northeast (Fig. 3), it is necessary that, at the same time, Honduras, Guatemala, and part of the Nicaragua Rise be brought along to their present positions. The movement of this fragment of the crust—the fragment bearing Honduras, Guatemala, and part of the Nicaragua Rise—probably commenced during middle Cretaceous time when the Bartlett fault formed. The total displacement along this fault and its associated fault systems adds up to about 1,400 km. Malfait and Dinkelman (1972) proposed an offset of 800 km. The sector of the Caribbean plate north of the North Bartlett fault (Meyerhoff, 1966) was not displaced much more than a maximum of 100 km, and the model given here requires that the movement be largely prior to middle Eocene time. Because the movement on the faults north of the Bartlett fault system cannot be much greater than about 100 km, the amount of movement along the North Bartlett fault and the South Bartlett fault must be in the order of 1,000 km (left-lateral) along the present strike of the fault. If Meyerhoff (1966) is correct in his interpretation, this is impossible. Even though the Bartlett fault dies out before reaching Haiti (Meyerhoff, 1966; Meyerhoff and Meyerhoff, 1972a), the Greater Antilles must have occupied before middle Cretaceous time a more southerly position than they do today. Nevertheless, I accept this requirement in a plate-tectonics model because, by locating the Greater Antilles south of Cuba, one may explain the low spreading rate calculated in preceding paragraphs for Cuba.

According to Malfait and Dinkelman (1972), Jamaica is a fragment of crust brought from Mexico together with the Nicaragua Rise. This explanation is unacceptable. Because Jamaica (Fig. 1) is underlain by igneous rocks ranging in age from Cretaceous to the middle Eocene, the origin of the island is related necessarily to a Benioff zone. Moreover, Jamaica's geologic history is very similar to that of Haiti, and the conclusion is almost inescapable on geologic grounds that the magmatism of Haiti and Jamaica took place in relation to the same Benioff zone. This postulate requires that the movement of Jamaica toward the west-northwest (as proposed by Meyerhoff, 1966) occurred after middle Eocene time.

Malfait and Dinkelman (1972), Mattson (1973), and others have proposed that the development of the island arc of the Greater Antilles (Hispaniola, Puerto Rico, and the Virgin Islands)
Fig. 3—Sketches showing evolution of Caribbean-Antillean-Central American region based on new global tectonics tenets (see text for details). Arrows show direction of plate movements. Dots are shown at leading edges of overriding (obducting) plates. Convergence zones are present wherever lines and dots are shown. Transcurrent faults are shown with arrows indicating relative directions of movement.

is related in origin to a convergence zone between two plates, where the northern plate plunges from north to south beneath the volcanic arc, just as I have postulated for Cuba. Under this assumption—i.e., the postulate of Malfait and Dinkelmann (1972), Mattson (1973), and others—there does not exist any alternative but to conclude that this branch of the island arc originated in some place southwest of its present position.

The Aves Ridge, according to Meyerhoff and Meyerhoff (1972a), is an example of Cretaceous-middle Eocene magmatism. As one may see on Figure 1, the Aves Ridge is bounded on the east by the Granada Trough. One then can conclude that the Aves Ridge originated in association with a Benioff zone dipping from east to west beneath the crest of the Ridge, and that the present Granada Trough formed above this ancient tectonic zone or Benioff zone, which has been inactive since middle Eocene time. This in turn implies that the Aves Ridge originally was farther west than at present.

The entire northern margin of South America, between Trinidad and Panama, is underlain by a sequence of volcanic and associated rocks which becomes younger from east-southeast to west-northwest (Late Jurassic to middle Eocene). The Benioff zone generating the magmas dipped beneath the South American continent, as indicated by the position of the ancient marginal trench (Fig. 1). This generalized sketch shows that an oceanic plate had to pass beneath the South American continent, but that subduction was not simultaneous along the entire margin of the continent, but progressive. If one can accept the postulate by Dietz and Holden (1970) and others that the South American plate underwent a clockwise rotation, the displacement of the age of magmatism from east-southwest to west-southwest along the northern margin of the continent is an almost necessary consequence. This rotation, if it took place, should have had its major movement during the Cretaceous.

With the preceding in mind, it is now possible
to reconstruct the history of movement of the Caribbean plate as a segment originating from the Pacific Ocean (Figs. 3, 4).

Before Late Jurassic (Tithonian) time, the continents of North America, Africa, and South America occupied a position such that a zone of oceanic crust was in the position of the present Caribbean Sea, Gulf of Mexico, and Central America. During Tithonian time, the subduction zone found today in Cuba originated while Cuba was still part of Central America, and Cuba commenced its advance from the Pacific toward the north-northeast (Fig. 3). As the front of this plate advanced (see Fig. 3), a southeastern branch or subduction zone began to form in Albian time (Mattsson, 1973). The subduction of the southeastern branch—Hispaniola, Puerto Rico, Virgin Islands—began when the Greater Antilles were farther south, and they produced from the beginning a new island-arc system south of Cuba. At the same time that this island arc formed, or shortly thereafter, the interaction between the North American and Caribbean plates set up a force couple which resulted in the fracturing of the crust, and gave rise to the Bartlett fault system separating the Cuban part of the plate from the remainder of the Greater Antilles. In this manner, the lateral movement of the Hispaniola-Virgin Islands commenced, and the part of the plate to which Cuba is attached abutted the continent of North America (Bahama platform), with a resulting reduction in spreading rate of the Cuban part of the Caribbean plate. This reduction in spreading rate is particularly noticeable in central and western Cuba.

In the meantime, the eastern margin of the Caribbean plate continued to be faulted, as well as to be inserted beneath the South American plate—while the latter was rotating in a clockwise manner. Between Late Cretaceous and Paleocene times, the Cuban arc approached the Bahamas and collided with them. The Hispaniola-Virgin Islands continued to drift toward the east-northeast and subduction commenced beneath the Aves Ridge. Farther south, along the northern boundary of South America, the plate continued to be inserted beneath the South American continent, and restricted transcurrent faulting took place where subduction had terminated. Since Paleocene time (or slightly earlier), the spreading rate of the plate east of the Bartlett fault probably increased, which would explain why magmatism developed along its margins and why southeastern Cuba is underlain by younger volcanic rocks than the rest of Cuba. During the same period of time, the clockwise rotation of South America almost ended and the system of transcurrent faults developed along the southern side of the Caribbean plate. These faults now delimit the southern margin of the Caribbean plate. In middle Eocene time, all movement of the plate ceased and the configuration of the Caribbean Sea and its surroundings was approximately the same as that today.

The culmination of movement during the middle Eocene is explained by the following: (1) the advance of Cuba, as well as of Hispaniola, was stopped on colliding with the Bahamas; (2) the Central American (Middle America) Trench formed and denied further entrance of Pacific crust into the Caribbean (in this new trench, the Benioff zone dips from southwest to northeast beneath Central America); and (3) another subduction zone began to form on the east side of the Lesser Antilles, where the Benioff zone dips from east to west and consumes Atlantic crust.

The preceding interpretation of the Caribbean-Antillean—Central American region, based entirely on the concepts of the new global tectonics, although not a unique possibility, can be asserted to be essentially correct and it is possible to state that many of its major points cannot be explained by alternative means, if the plate-tectonics hypothesis is correct. The model which I have proposed eliminates a series of problems which afflicted all previous plate-tectonics reconstructions. (1) A North Caribbean transcurrent fault is no longer required; (2) the South Caribbean transcurrent fault is needed only between latest Cretaceous and middle Eocene times, and does not need to be as extensive as postulated in most reconstructions; (3) a spreading center is not required in the Caribbean; (4) there is no implication that the Puerto Rico Trench and the Granada Trough are actually parts of active island-arc systems; the same is true of the Bartlett Trough; (5) it is not necessary to eliminate the Bahamas and integrate them during the plate-tectonic process as a fundamental element; and (6) this hypothesis does not require that the Granada Trough and Puerto Rico Trench sediments be folded after middle Eocene time (Meyerhoff and Meyerhoff, 1972a).

The principal advantages of this model, in addition to the points enumerated in the preceding paragraph, are: (1) it explains the migration pattern of magmatism throughout the region; (2) it explains the existence in Cuba of sedimentary rocks which are more ancient than in the rest of the Greater Antilles; (3) it explains the continuity of the axes of "Laramide" structures in the entire region; (4) it resolves the problem of the origin of Jamaica; (5) it explains the essential elements of the geology of Cuba; and (6) it relates, one to the
other, all of the more important geologic events, showing them to have cause and effect relations.

Regardless of the attractiveness of the hypothesis, the model is not exempt from defects, the most important of which are: (1) it is based on a series of assumptions whose correctness or incorrectness cannot be demonstrated at present; (2) it does not explain the presence of continental crust beneath the Nicaragua Rise, nor the presence of continental crust beneath, nor the origin of the, the Cayman Ridge; (3) from a purely geodynamic viewpoint, the entire scheme is extremely complex geometrically and nearly impossible to explain mechanically; and (4) it does not explain the reason for the position of the Barbados Ridge through such a long period of geologic time. These defects are common to all of the Caribbean reconstructions that are based on the hypothesis of lithospheric plates. The most serious objections, in my opinion, are (3) and (4).

This last conclusion accents the actual limitations of the plate-tectonics hypothesis, but certainly does not demonstrate that it is a false hypothesis.

Caribbean Origin According to Fracture-Contraction Hypothesis

The hypothesis of fracture-contraction was published by Meyerhoff et al. (1972, 1973) as an alternative to the concepts of the new global tectonics. The fracture-contraction hypothesis begins with the assumption that tectonic processes at the earth’s surface are a manifestation of compressive stresses caused by the cooling of the earth. The hypothesis explains the principal features of geology and geophysics around the world. One of its tenets is that the continents have remained essentially fixed in position since Proterozoic time. I have therefore used this hypothesis to see whether it explains the geology of the Caribbean-Antillean-Central American region and to seek alternate explanations for the regularities discussed in the first part of this paper. Although the discussion which follows cannot pretend to be a complete analysis, the ideas derived can be the basis of a more profound study some time in the future. The particular position of the Caribbean area, between two continents and two oceans, imposes the requirement that the processes that take place in this region reflect closely the influence of these four external elements. Nevertheless, the internal processes of the Caribbean have their causes in other external processes as well, processes which act on a worldwide basis on the continents and oceans everywhere.

To find the global processes which affect the Caribbean realm, one can commence by examining the effects of these processes on this area. If it is postulated that the Benioff zones (with their magmatism and associated seismic activity) are
zones for the liberation of the energy in compressive stress fields which act upon the lithosphere, and that the Benioff zones are preferentially oriented perpendicular to the maximum compressive stress, then one obtains a method of analysis for finding the causes of the continuous rotational movement of magmatism in the Caribbean area.

To analyze this rotational movement, it is necessary to review again the regularities of circum-Caribbean magmatism. The first fold belts associated with magmatic events in the Caribbean probably are the Cayman Ridge and the Nicaragua Rise. This magmatic activity presumably dates to the Paleozoic (Meyerhoff, 1966) and the magmatic trend is east-northeast-west-southwest (Tijomirov, 1967). The Mesozoic-Cenozoic magmatism began in Late Jurassic (Tithonian) time along both continental margins—south of the Florida-Bahamas in the north and along the north side of South America. This magmatism shifted through time toward the ocean basins. In the north, the magmatism began at Cuba and migrated eastward toward the Atlantic Ocean. On the south, it began in the offshore part of northern Venezuela and migrated westward toward the Pacific. These two bands of magmatism are approximately parallel and, during the migration of the magmatism, the semiparallelism continued (Fig. 1). Finally, in middle Eocene time, the magmatism shifted to Central America, on the west, and the Lesser Antilles, on the east. This pattern is precisely that predicted by the fracture-contraction hypothesis (see Fig. 5). These regularities of development, like those mentioned in the first part of this paper, alone demonstrate that a common and unique cause for this process existed. This process may have been the rotation of the axes of maximum compressive stresses from Paleozoic time to the recent, in a clockwise direction. This is to say (Fig. 5) that the compressive-stress field acting on the Caribbean rotated approximately 110° in more than 200 m.y. The question is: why?

If we postulate that the earth contracted through cooling, it is reasonable to suppose that, through the process of contraction, North and South America approached one another, producing the generation of intense compressive stress in the Caribbean region as a result of the small dimensions of that region. This compression induced the fracturing of the crust and the formation of Benioff zones perpendicular to the maximum compressive stress axes. Because the compressive stresses also were directed toward the Pacific and Atlantic ocean basins, these ocean basins, because of their great area, accumulated potential energy (even though part of this potential energy was liberated in fracture zones and mid-ocean ridges). According to what I have postulated, the initial formation of fracture zones in the Caribbean was along the northern and southern margins, and because of the accumulation of energy in the Atlantic and Pacific crusts, the fracturing along what is now the Middle America Trench and the Lesser Antilles Trench was produced much later after sufficient energy had been accumulated in the adjacent ocean basins to initiate fracturing. Consequently, the crust of the ocean basins behaved as an "energy accumulator," which primarily absorbed the stresses and later imparted them to the general stress field acting upon the Caribbean area. Because the two ocean basins were areas of energy accumulation, they tended to rotate the north-south axis of compression between North and South America continuously until the axis of maximum stress finally was oriented approximately east-west.

Therefore, the fracture-contraction hypothesis requires that the initial magmatic activity of the Caribbean be in an east-northeast—west-southwest direction and that its later reorientation be in a north-northwest—south-southeast direction. This is explained in the following paragraphs.

During the Paleozoic (late Paleozoic?), the contraction of the lithosphere took place, developing a compressive stress field. As shown on Figure 5, the maximum stress in the Caribbean region was oriented north-northwest—south-southeast. The Benioff zones, therefore, were perpendicular to this stress direction. Along the Benioff zones energy within the stress field began to be liberated.

With the passage of time, energy was accumulated in the Atlantic and Pacific Ocean basins. This accumulation of energy introduced into the Caribbean stress field an east-west component which made the maximum stress direction rotate in a clockwise direction. Thus the original north-south axis of maximum stress (during Late Jurassic time), with major east-west Benioff zones in the northern and southern Caribbean, turned gradually to northeast-southwest during the Eocene and almost east-west between Eocene and recent time. Because of the rotational movement of the maximum stress axis within the Caribbean region, tangential force couples were born within the upper crust and the transcurrent faults of the Caribbean region originated (Bartlett fault, Oca fault, etc.).

In the first part of this paper I proposed that, in Cuba, orogenic stresses became less deep during the passage of time. This is explained by the fracture-contraction hypothesis with its rotation of the axis of maximum stress. When that axis was perpendicular to the original arcs (during Late Jurassic time), its effects were maximal and deepest.
As the stress axis rotated, the components of compressive stress oriented at right angles to Cuba were lessened. (Part of this is a natural result of the spherical shape of the earth.) Finally, when the maximum compressive stress axis was oriented east-west, almost parallel with Cuba, during late Eocene time, orogenic activity definitely ended in Cuba.

On Figure 6, I present a resume of the ideas presented here to explain the geologic structure of Cuba according to the fracture-contraction hypothesis. The figure fits well the concepts elaborated here. All the fundamental phenomena of the geology of Cuba are explained easily by the fracture-contraction hypothesis.

For example, as noted previously, I “demonstrated” that the pre-Tithonian rocks could have originated in Central America. However, an equally good hypothesis is that the rocks were deposited in their present location and that the provenance area for the pre-Tithonian rocks was the Paleozoic massif of the Florida Peninsula (Meyerhoff in Khudoley and Meyerhoff, 1971). It is also much simpler to assume that the Jurassic evaporites of northern Cuba are related to the Louann Salt of the United States Gulf Coast and to the diapirs of the northeastern Bahamas (Ball et al., 1968). In addition, the Jurassic molluscan faunas have close affinities with those bordering the Pacific Ocean, a fact which shows that there
FIG. 6—Sketches showing geologic evolution of Cuba according to fracture-contraction hypothesis. Lines of section extend from Cayman Ridge to Bahama Platform. Dimensions are proportional but without scale. Same legend as in Figure 4.

was a seaway connecting Cuba with the Pacific Ocean across Central America.

In concluding this discussion of the fracture-contraction hypothesis, I point out that in the concepts outlined in the preceding paragraphs, it is not implicit that the process of the rotation of the axis of maximum compressive stress be a global phenomenon. Instead, this rotation is a local phenomenon resulting from the special situation of the Caribbean between North and South America. The fact that the rotation of the axis of maximum stress has been clockwise—until it reached its present east-west orientation—is a confirmation of H. A. Meyerhoff’s original ideas published in 1946 and 1954, and also is a confirmation of the Meyerhoff and Meyerhoff (1972b) postulate that there exists a preferential west-to-east orientation of terrestrial structures resulting from earth rotation.

The preceding interpretation of the Caribbean-Antillean-Central American regions, based on the fracture-contraction hypothesis, explains all of the essentials of the geologic history and structure of this area, and is a very attractive hypothesis because it depends on fundamental laws of physics, something which cannot be said for the plate-tectonic hypothesis.

Regardless of the attractiveness of the fracture-contraction model, two objections to it may be mentioned. (1) Tanner (1973) has noted that the trenches of island arcs form in a tensile stress field, not in a compressive stress field. Tanner’s conclusion is supported by two observations: (a) first-motion studies of modern earthquakes in island-arc systems around the Pacific show that tensional stresses are active in association with Benioff zones. The present first motions, however, do not have necessarily any relation to the past. It is a well-known fact that many ancient island-arc complexes (Japan, New Zealand, California, etc.) include high-pressure low-temperature metamorphic rocks—a fact which suggests the importance of tangential compressive stresses. This observation and structural data indicate that compressive stresses operate within island arcs. (b) Tanner also noted that deep-sea trench sediments are not deformed. However, it should be noted that the structural state of the sediments
below "acoustic basement" is unknown. In connection with this, one may observe that, whereas the sediments of the Granada and Lesser Antilles troughs are essentially undeformed, the rocks of the Lesser Antilles were deformed by compression during the Eocene and late Neogene (Butterlin, 1956; Meyerhoff and Meyerhoff, 1972a, b).

Although Tanner's (1973) point cannot be ignored, it is a point which cannot be accepted as applicable throughout the history of all island arcs. (2) The second objection to the fracture-contraction hypothesis involves the supposed perpendicular relation between the surface trace of the Benioff zone and the axes of maximum compressive stress. If the fracture-contraction hypothesis is correct, the oriented structures, the migration patterns of magmatism, and the tectonic activity of the Caribbean area should represent in themselves a natural-scale model to confirm the hypothesis. In reality, the history of the Caribbean shows great complexity and variability through time. One observes a combination of compression, shear, and tension—conditions not implied by the model. Yet it can be said that, because of local conditions, the stress ellipsoid should not be expected to be as regular as the hypothesis predicts, and all stresses should therefore not be visualized just as vectors, but as tensors.

CONCLUSIONS

In the preceding pages I have developed alternative interpretations for the same set of data available from the Caribbean region. It has been possible to find solutions using each hypothesis, despite the fact that they are completely opposed to one another. If one compares objectively both interpretations, he will note that both contain speculative elements for which there is no easy proof at present. I do not pretend to have found in every case the best solution according to the hypothesis which I utilized, and therefore it is not possible to reach definitive conclusions from the study. Nevertheless, I find that the fracture-contraction hypothesis explains more logically the geology of the Caribbean and of Cuba, because it is based on physical laws. I admit that this is an opinion and that what I have given here is no more than a demonstration of the feasibility of this hypothesis.

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