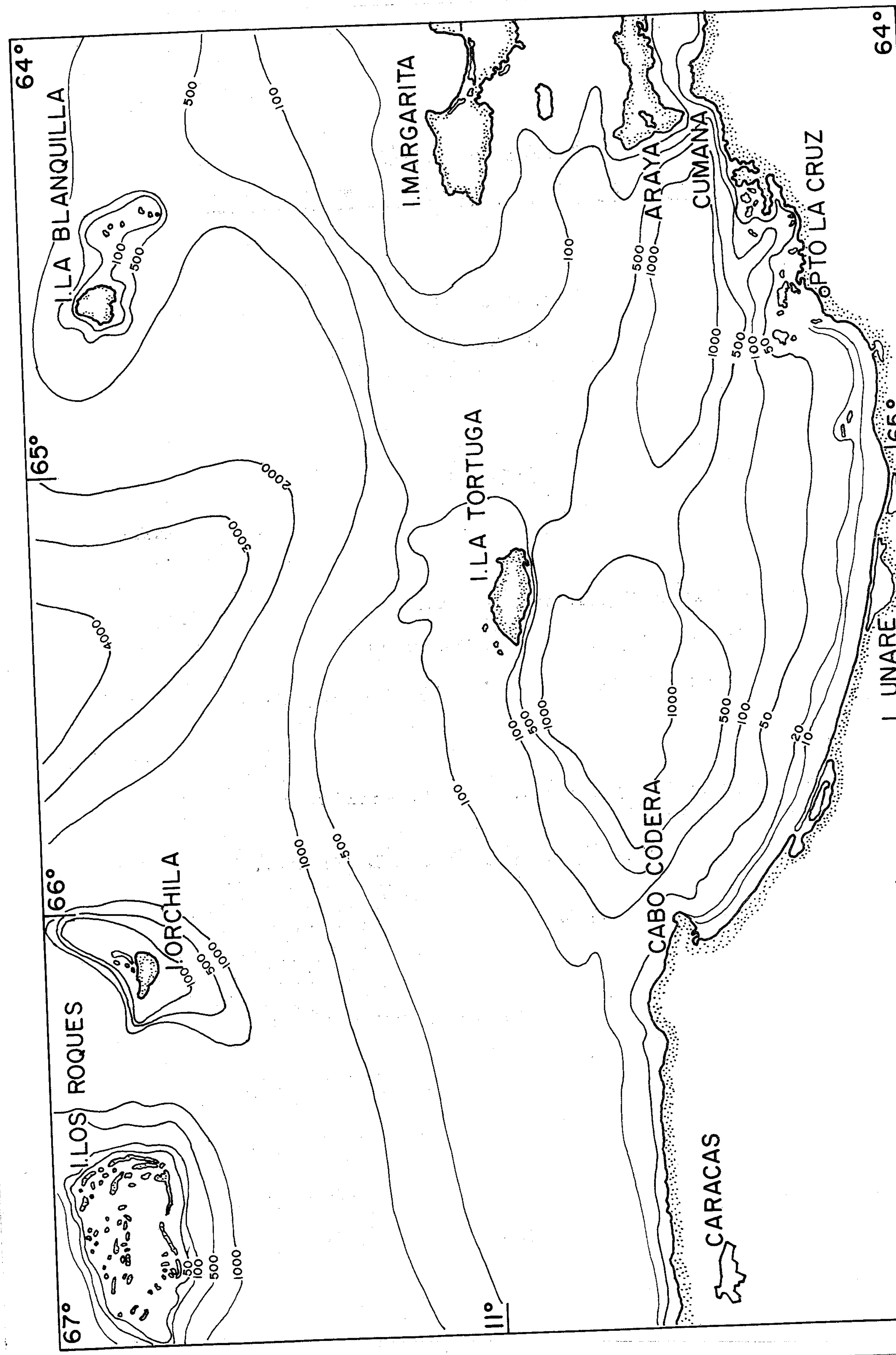

Figure 1. Location map of La Tortuga Island. Bathymetric contours in meters.

ARTICULO

GEOLOGY OF LA TORTUGA ISLAND, VENEZUELA

(GEOLOGIA DE LA ISLA LA TORTUGA, VENEZUELA)

by N.J. Maloney[1] and O. Macsotay[2]

ABSTRACT

La Tortuga Island is located on the submarine bank that extends from Cabo Codera to Margarita Island. It is 25 Km. long, 10 Km. wide, and has a maximum elevation of about 45 m.

The Early Pliocene marls, exposed as a thin strip along the southern coast, are here named the Cerro Gato Formation and correlated with the Playa Grande Formation of Cabo Blanco. The outcrop is at least 26 m. thick and consists of algal marls with interbeds of rose marlite and fossiliferous marl containing Lyropecten arnoldi (Aguerrevere). The Cerro Gato Formation is disconformably overlain by the Pleistocene coral reef and associated clastic limestones of the Tortuga Formation. It is 0.5 to more than 8 m. thick and is exposed over more than 80% of the island. Two terrace levels occur in the south. The lower terrace is here separated as the Punta Piedras Member because of its greater fossil content and less recrystallized nature. Recent coral and clastic carbonate sediments are present in the coastal and nearshore marine areas.

The island is located on the uplifted block of a submarine fault which occurs 7 to 10 Km. to the south. The block appears to be tilted slightly to the north.

INTRODUCTION

La Tortuga Island, located at 10°55'N latitude, 65°20'W longitude, forms the highest area on the submarine bank passing from Cabo Codera to Margarita Island (Fig. 1). It is 90 Km. west of Margarita, 85 Km. north of Laguna de Unare, and forms a portion of the northern border of the Cariaco Basin. The island has a subelliptical shape with its long axis oriented east-west. It is 25 Km. long, 10 Km. wide, and has a maximum elevation of about 45 m.

La Tortuga has no permanent residents. Fishermen from Margarita camp at Carenero Bay, Punta Delgada and Cayo Herradura (Fig. 2) for periods of up to a month. They have to import food and water. A few unmaintained jeep trails and an air field are present near Garambeo on the south-central coast.

Geological interest in the island was aroused by Sievers (1898) and Rutten (1940). They described La Tortuga as a low, limestone-covered island. Patrick (1959) gave a brief description of the rock formations and listed the most important fossils. He named the capping coralline limestone the Tortuga

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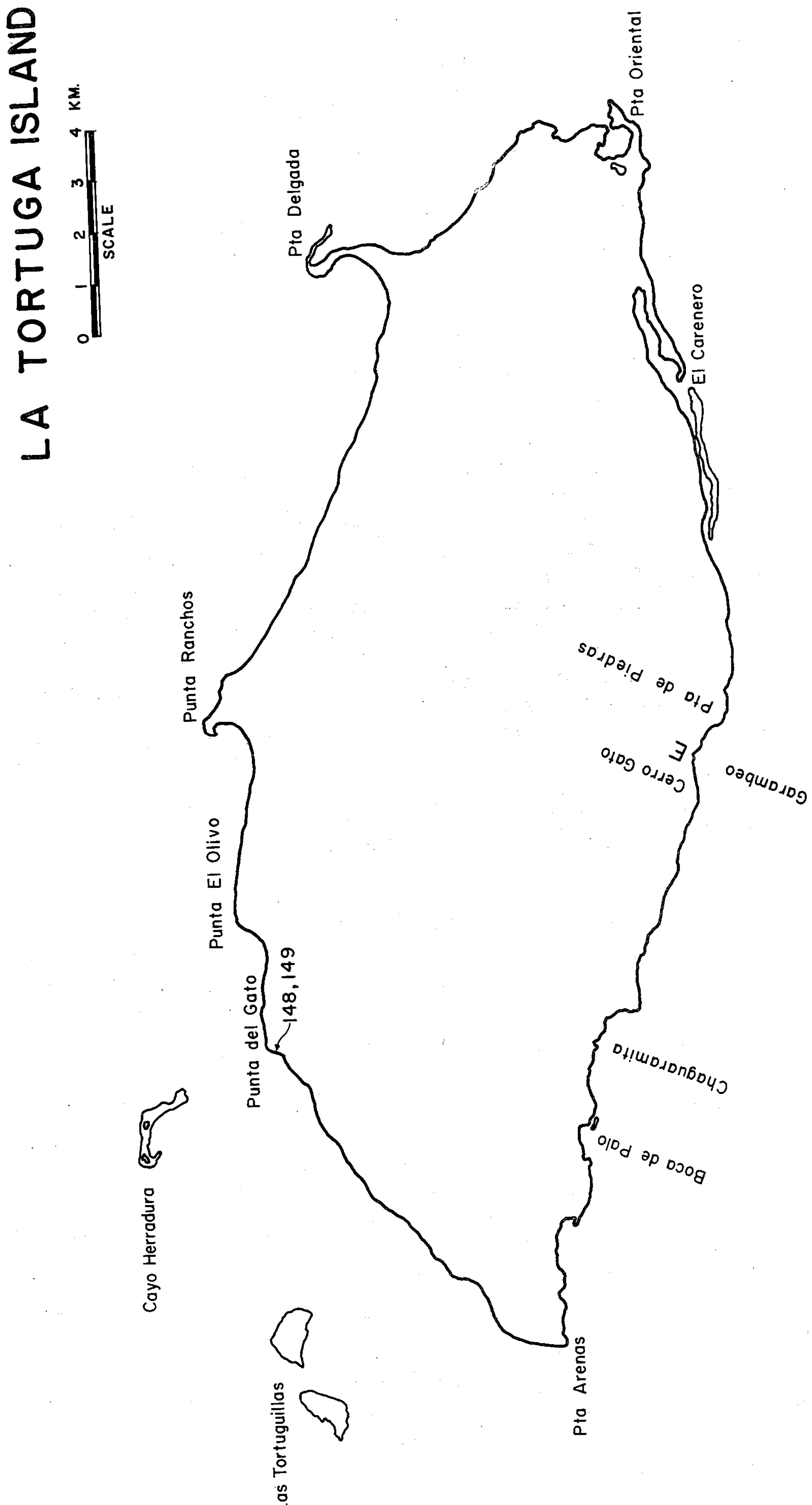

Figure 2. Map showing place names on La Tortuga Island. "E" marks type locality of Cerro Gato Formation.

Formation and correlated the underlying marls with the Cumaná Formation. Bermúdez (1966) also presented a brief description of the stratigraphy in his discussion of the Upper Tertiary of eastern Venezuela.

The present investigation was initiated to map the island geologically, describe the coastal and near-shore marine sediments, and investigate the fossils and biostratigraphy of the formations. This paper treats the general geology and stratigraphy of La Tortuga Island.

ACKNOWLEDGEMENTS

The geological mapping was done during the first two weeks of August, 1966. Transportation to the island and field expenses were provided by the Universidad de Oriente. Mr. Nelson González did the transit surveys, and Mr. Matías Antón served as field assistant.

One of the authors (Macsotay) had the opportunity of previously visiting the island on April 26-29, 1966 with Dr. Pedro J. Bermúdez. He wishes to thank the Fundación La Salle for ship transportation and gratefully acknowledges many beneficial discussions with Dr. Bermúdez.

GEOGRAPHY AND BATHYMETRY

La Tortuga Island is elliptical in shape with its long axis directed east-west subparallel with the submarine bank. The northern, eastern and western portions of the island are gently sloping areas, pocked with karst topography. By contrast, the southern portion contains steep scarps and two or three terraces. Table I gives the terrace elevations along three measured profiles; the profiles are located on Figure 4.

TABLE I

Terrace	Profile	Range of Elevation	Formation
1	A-A'	7-11 m.	Tortuga, Punta Piedras Mb.
2	"	34-36 m.	Cerro Gato
3	"	44-45 m.	Tortuga
1	B-B'	6-13 m.	Tortuga, Punta Piedras Mb.
2	"	Absent	
3	"	+32 m.	Tortuga
1	C-C'	0-12 m.	Tortuga, Punta Piedras Mb.
2	"	Absent	
3	"	+14 m.	Tortuga

The lower terrace (1) is continuous for the length of the southern coast. It has a pronounced southerly slope, going from 11 to 13 m. at its northern boundary to 0 to 7 m. at the southern coast. This inclination may be simply due to the initial slope of the coralline limestone, or it may have resulted from uplift of the island.

The intermediate terrace (2) is erosional in origin. It is located on top of the Lyropecten zone of the Cerro Gato Formation, which is more resistant to erosion than the overlying marls. This terrace is restricted to the central part of the southern coast.

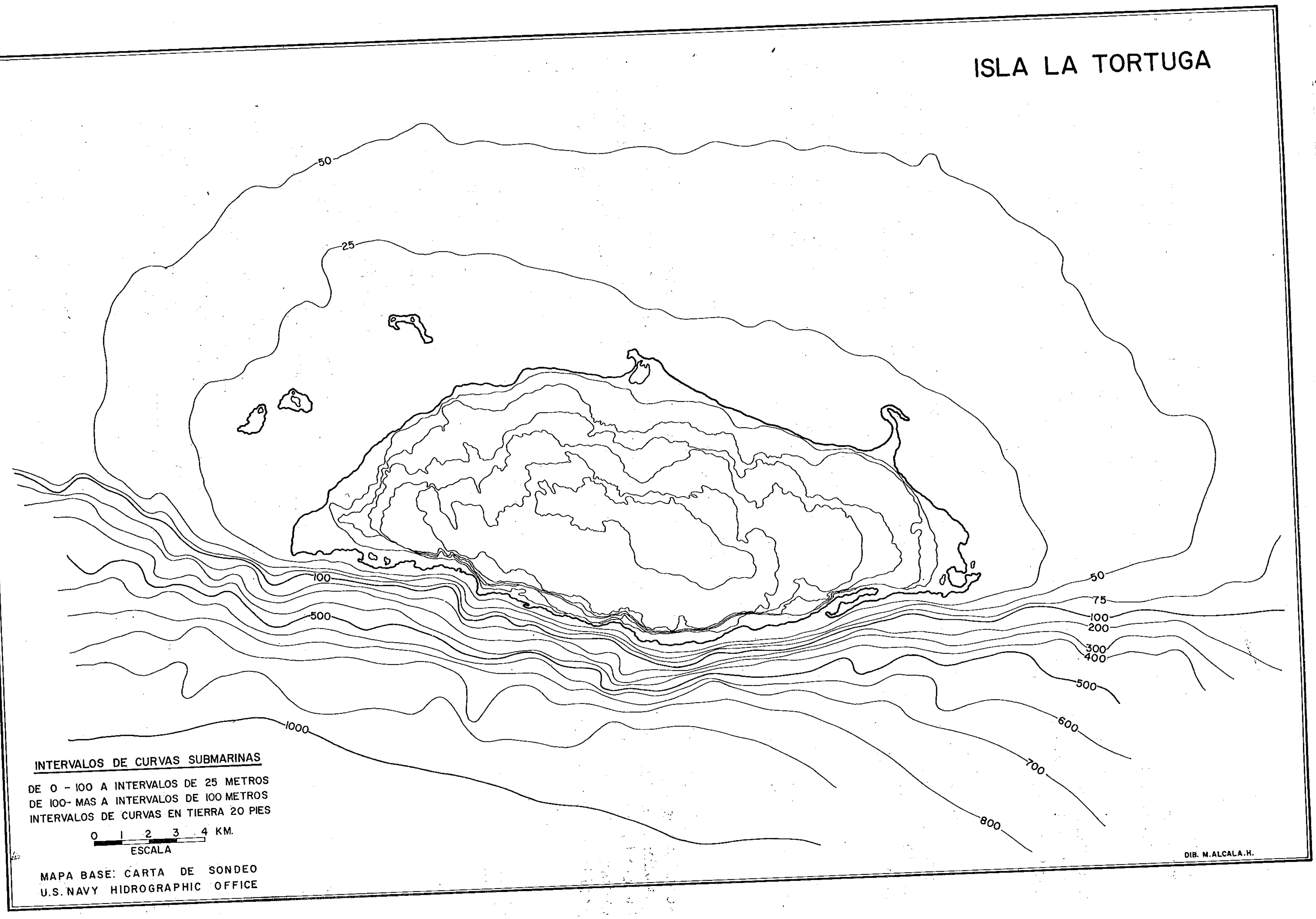

Figure 3. Topography and bathymetry of La Tortuga Island.

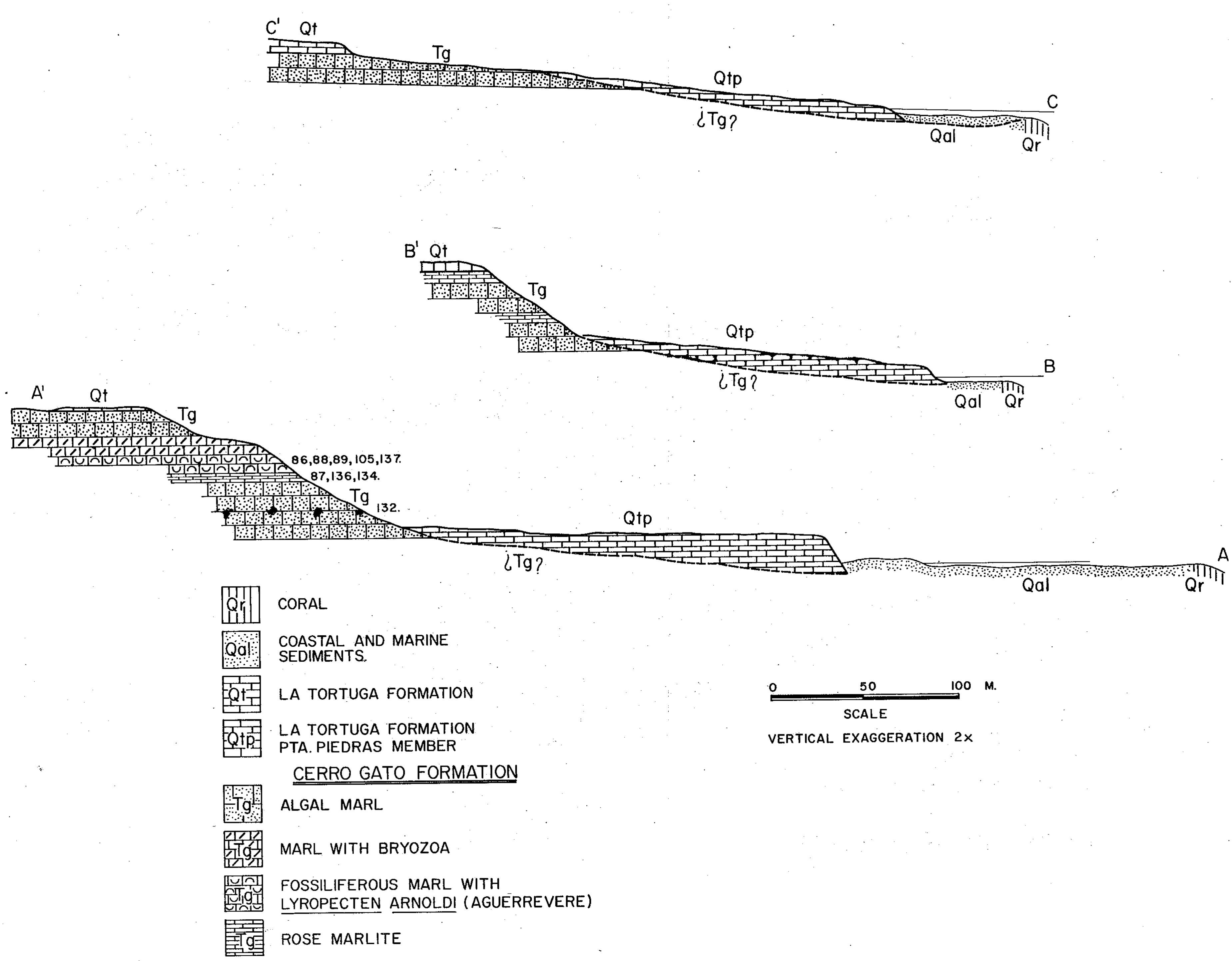

Figure 4. **Three profiles** showing **relationships** of the Cerro Gato Formation, Tortuga Formation (undifferentiated) and Punta Piedras Member. For locations **see Figure** 5.

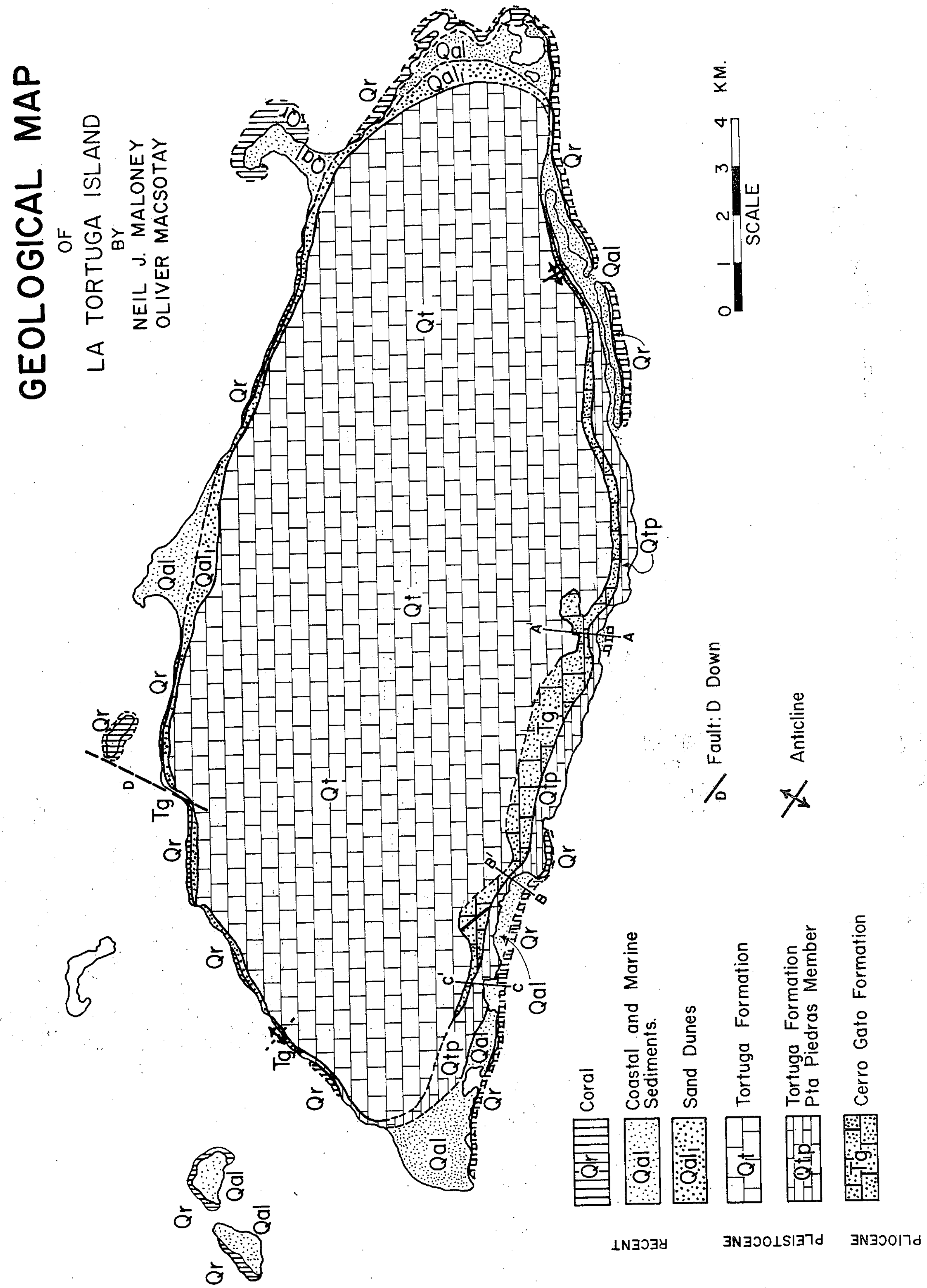

Figure 5. Geologic map of La Tortuga Island.

The upper terrace (3) forms the highest elevations on the island. It slopes east and west from the central portion of the coast and merges with the lower terrace at the eastern and western ends of the island. The terrace is sedimentary in origin, and its curvature may have been caused by uplift or simply the initial dip of the coralline limestone.

A sea-level, coralline terrace with elevations of +1 to -1 m. occurs along all of the coast. Sand dunes are present behind the reef in the north, and sand spits, bars and lagoons are situated behind the southern reefs. A tombolo has formed behind an off-shore reef patch and the island at Punta Delgada.

The bathymetry is similar to the island topography in that the ocean bottom slopes gently to the east, north and west, but is inclined steeply to the south (Fig. 3). The southern scarp has local cliffs of more than 30° inclination, and the -1000 m. contour is as close as 7 Km. south of the island. In contrast, water depths of only 35 to 40 m. are encountered 7 Km. north of La Tortuga.

The southern scarp is interpreted as a fault scarp. The gentle north slope of the submarine bank and the island have led us to believe that the fault block is tilted slightly to the north.

STRATIGRAPHY

More than 80% of the island is covered with a thin coralline limestone which is separated into two terrace levels near the southern coast (Fig. 4). A thin strip of marine, algal marl is exposed beneath the limestone on the scarp between terraces (1) and (3) near the southern coast (Figs. 4, 5). The capping limestone is covered by sediments and younger coral reefs in the coastal regions.

Cerro Gato Formation

Introduction. The marine marls which crop out between terraces (1) and (3) near the southern coast are the oldest rocks exposed on the island. Patrick (1959, p. 94) and Bermúdez (1966, p. 360) correlated these exposures with the Cumaná Formation and called them by that name. G. Ascanio and H. Pérez Nieto (fide Bermúdez, 1966, p. 368) described the type section of the Cumaná Formation from the Caigüire Hills. The bottom 155 m. consists of sandstone and gravel intercalated with some marl. The middle 240 m. contains interstratified sandstone gravel, and shale, and the upper 110 m. has fine-grained sandstone, which is conglomeratic in places, and marls with conglomerate lenses. The Cumaná Formation is thus characterized as consisting, in order of abundance, of sandstone, conglomerate, shale and marl.

The outcrops on La Tortuga Island consist of marl which contains very little detrital sand and no conglomerate. Therefore, because there is a distinct lithological difference between these outcrops and the described type section of the Cumaná Formation, we have discontinued using this name on La Tortuga, and here propose the new name Cerro Gato Formation for the beds in question.

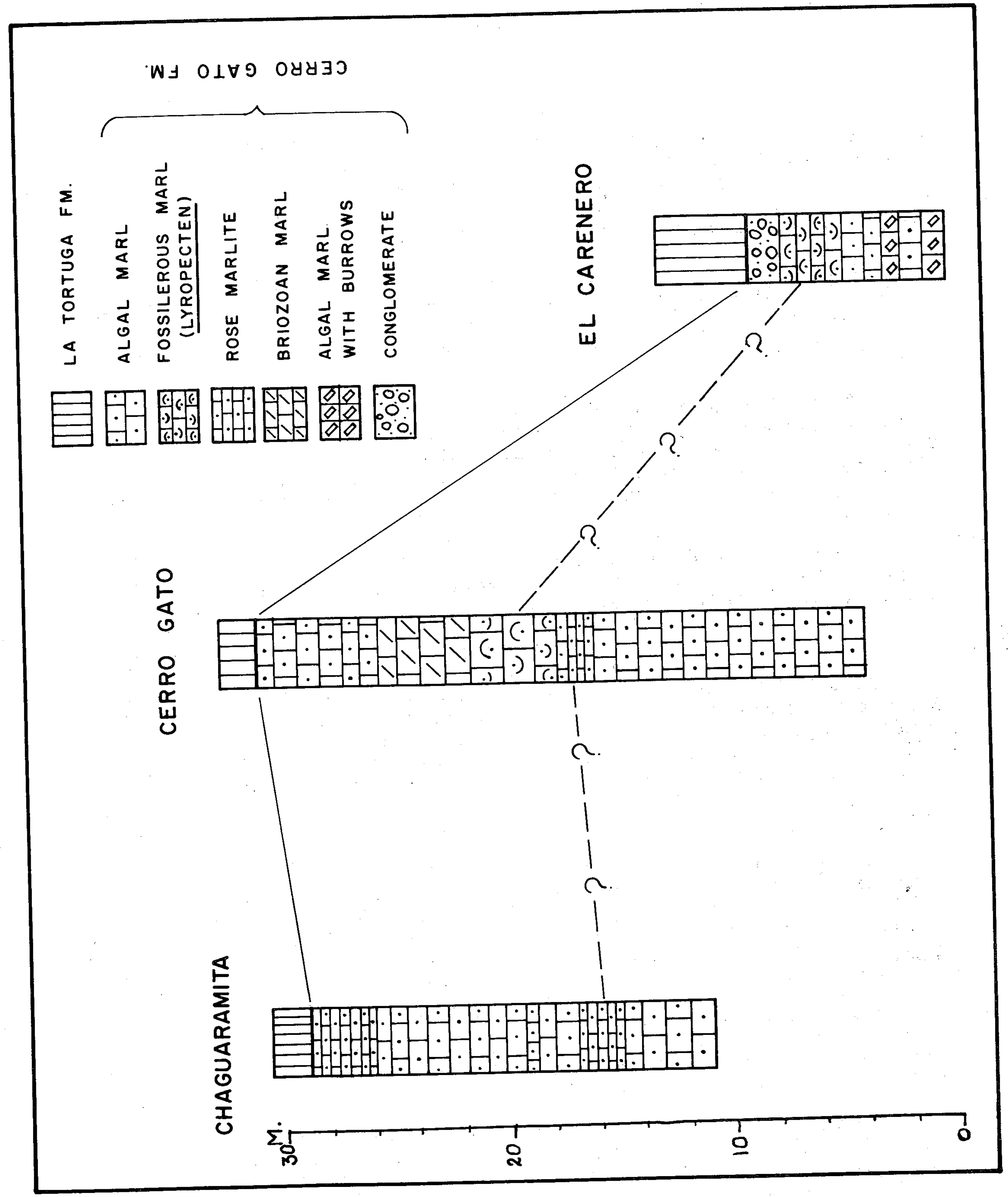

Figure 6. Columnar sections of Cerro Gato Formation. For locations see Fig. 2.

Description. The Cerro Gato Formation is named for exposures on the south side of the hill named Cerro Gato, where the type section is established (Figs. 2, 6). A section 26.6 m. thick crops out on the south side of the hill. The base of the formation is covered by the younger limestone of the lower terrace (1), and the total thickness of the formation is unknown. The bottom 11 m. of section consists of porous, tan to cream colored, medium to coarse grained, algal marl which weathers light gray. It contains abundant algal "heads" up to 7 mm. in length, pores, and a matrix of carbonate clay and organic material.

The tan marl is overlain by 2.5 m. of salmon red to rose colored, fine-grained, impermeable, algal marlite. This well cemented rock is composed mainly of a fine-grained matrix of carbonate, detrital clay and organic matter. Small fragments of algae are abundant. The rose marlite is in turn overlain by 4 m. of light gray fossiliferous marl. Pelecypods, including *Lyropecten arnoldi* (Aguerrevere), are very abundant, though much of the material has been leached from the surface exposures and only the casts and molds remain. The rock is porous and of low to medium density. Microscopically it is made up of abundant shell fragments, miliolid foraminifera, algal "heads" and scattered carbonate grains in a matrix of fine-grained calcite and clay. Patches of the groundmass are recrystallized to sparry calcite.

The next 4 m. of section is a cream-colored, algal, clastic limestone containing abundant bryozoans. Shell fragments, echinoid spines, miliolid foraminifera, hydrozoans and detrital calcite are present. The groundmass consists of fine-grained carbonate, with organic matter and small patches of sparry calcite. Silt-sized grains of detrital quartz are scattered throughout.

The top 5 m. of the type section consists of cream-colored, algal marl similar to the marls in the lower part of the section. It lacks the bryozoans and abundant invertebrates of the beds immediately below.

To the east, at Carenero Bay, only 7.5 m. of section are exposed (Figs. 2, 6). The bottom two meters is a compacted, algal marl containing *Lyropecten, Encope, Argopecten* and *Lithothamnium*. The lower part of the bed contains tubes which are the burrows of *Ophiomorpha* sp. The next bed is 2.5 m. thick and is almost a repetition of the bottom bed. The upper portion is a soft algal marl containing oysters, and the lower portion contains the same burrow tubes. The top 3 m. is a cream to light brown, algal marl. It is a well cemented, medium density, porous marl which weathers gray. Algal "heads" are very abundant; pebble-sized, red and orange algal "heads" occur in this bed. Echinoid spines, benthonic foraminifera and pelecypods, including *Lyropecten arnoldi* (Aguerrevere), are present. The lower portion of the bed differs from the upper in having a rich microfauna and lacking the macrofauna.

The entire section at Carenero Bay may correlate with the *Lyropecten* beds at the type section. If this is true then the pecten beds are 25 m. lower in elevation at Carenero and there is an apparent eastward dip of 0°10'.

A third section was measured at Chaguaramito on the western part of the southern coast (Figs. 2, 6). There, 18.0 m. of Cerro Gato Formation are exposed. Most of the section consists of cream to tan-colored, algal marl. The algae occur as "heads" and as encrusting forms. Detrital quartz, microcline, plagioclase and muscovite are present. The rock is somewhat friable, of low to medium density and coarse to medium grained. Rose to salmon red, dense marlite occurs as a discontinuous bed 4 m. above the lowest exposure

TABLE II. FAUNAL LIST, CERRO GATO FORMATION

SPECIES (in taxonomic order)	138	86,88,89, 105,137	87,136	135	134	132	130	103	104	148	149	STRATIGRAPHIC RANGE
SCLERACTINIA												
Stephanocoenia michelini M.-Edw.			R				F	F	F			Mio.?Plio.-Rec.
Colpophyllia sp.				F*								
Manicina areolata (Linnaeus)			S*	A*			F*					Plio.-Rec.
BRYOZOA												
Species undifferentiated	A	F	S									
GASTROPODA												
Astraea cf. A. brevispina (Lam.)		R										Plio.-Rec.
Turritella maiquetiana Weisbord		A*										Plio.
Architectonica nobilis Röd.	S*								S*			L.Mio. --- Rec.
Cerithium cf. C. algicola Adams								F*				Plio.-Rec.
Cypraea (Muracypraea) sp.		S*										Mio. -- Rec.
Semicassis granulatum (Born)		F*							F*			U.Mio.?Plio.-Rec.
Fasciolaria sp.		R*										Tertiary - Rec.
Oliva sp.							S*		F*			Tertiary - Rec.
Conus sp.	S*											Mesozoic - Rec.
Terebra protexta (Say)							A*					U.Mio. -- Rec.
Bulla sp.		A*					F*					Tertiary - Rec.
PELECYPODA												
Anadara sp.							S*		S*			Tertiary - Rec.
Glycimeris decussata (Linn.)		R*					F		F			U.Mio. -- Ree.
Amusium cf. A. papyratius (Gabb)		F										Olig. -- Rec.
Pecten zigzag caboblanquensis Dr.		F	F	R								Plio.
Pecten cf. P. archon Maury	S	A	F	F								U.Mio.
Argopecten circularis caucanus (H.)	F	A	F	S	F	F			A	F	F	Mio.-Plio.
Argopecten demiurgus (Dall)	A	F							S			U.Mio.-Plio.
Chlamys cf. C. benedicti V. & B.			F									Plio.-Rec.
Lyropecten nodosus (Linn.)		A									F	U.Mio.?Plio.-Rec.
Lyropecten arnoldi (Aguerrevere)	R	A	?			F	R	A	F	S	F	Plio.
Alternopecten sp.		?										U.Eoc.-Mio.
Spondylus americanus Hermann	F	F			S				S			Plio.-Rec.
~~Plicatula gibbosa Lamarck~~			S									Plio.-Rec.
Anomia sp.		S										Jur. -- Rec.
Placunanomia cubaguana Macsotay		A		S	S					A		U.Mio.-Plio.
Ostrea antecursor Weisbord			R									Plio.
Ostrea disparilis fredeai F.Hods.		F	S									U.Mio.-Plio.
Ostrea frons Gmelin			F									Plio.-Rec.
Ostrea caboblanquensis Weisbord		A	F		F				F			Plio.
Ostrea vespertina venezuelana W.		A	A		F			F	A	F	F	Plio.
Ostrea cf. O. virginica Gmelin					S							Plio.-Rec.
Codakia cf. C. orbicularis (Linn.)									F*			M.Mio. -- Rec.
Periglypta cf. P. rigida (Dall)		A*	F*			F*		S*				Plio.-Rec.
Dosinia sp.								F*				Tertiary -- Rec.
Trachycardium cf. T. isocardia (L.)							F*		F*			Plio.-Rec.
Laevicardium laevigatum (Linn.)		F*										Mio. --- Rec.
Chione cancellata (Linn.)			F*				A*		F*			Mio. --- Rec.
Chione (lirophora) sp.					R*							Mio. --- Rec.
Cyrtopleura cf. C. costata (Linn.)		F*										Mio.?Plio.- Rec.
Cyathodonta rectangulata Macs.		A*	F*	S*			A*					Plio.-Rec.
Cyathodonta sp.		F*			S*			S*				Mio. --- Rec.
ECHINOIDEA												
Cidaris tribuloides (Lamarck)		F			S							Mio.? --- Rec.
Lytechinus variegatus (Leske)		F										Plio.-Rec.
Clypeaster subdepressus (Gray)		F			S							U.Mio. --- Rec.
Encope michelini Agassiz		A			F		F	A	A	F	F	U.Mio. --- Rec.
Encope cf. E. michelini Agassiz								F				Plio.
Cassidulus falconensis (Jeannet)		F			F			A				U.Mio.
Brissus unicolor (Leske)								F				L.Mio. --- Rec.
Plagiobrissus grandis (Gmelin)		S										Mio. --- Rec.
ICHNOFAUNA												
Domichnia (undifferentiated)			F						F			Silurian -- Rec.
Ophiomorpha cf. O. nodosa Lundgr.								F	A			Cret. -- Rec.

and as a continuous bed in the upper 2.9 m. of the section. The rose marlite is poorly sorted; it contains rounded to angular clastic calcite grains. Silt-sized quartz grains are present; pelecypods and other fossils are widely scattered throughout the bed. Textularia and miliolid foraminifera were found in this sections.

If the upper rose marlite correlates with the rose marlite of the type section then there is essentially no dip between the two profiles as the beds are at almost the same elevation. However, at Bahía de Palo, 2.3 Km. to the west, the rose marlite is 4 m. lower than in the Chaguaramito section; this indicates an apparent west dip of 0°04'.

On the north side of the island the Cerro Gato Formation was encountered only at Punta El Olivo where 3 m. of section is exposed. The lower 2 m. is a fossiliferous marl containing Lyropecten arnoldi (Aguerrevere). The upper meter consists of a cream-colored, angular, algal marl. Pelecypods, gastropods and rotalid foraminifera are scattered throughout. Detrital quartz is present; potassium feldspar, plagioclase and hornblende were found in lesser quantities. If the Lyropecten bed is the same as that occurring on Cerro Gato then there is an apparent north-northwestward dip of 0°08'.

Another small exposure was found on the northwest coast, east of Las Tortuguillas Islands. A one meter section of the Lyropecten, fossiliferous marl is exposed at the base of the sea cliff. It is a yellowish-brown marl that is rich in foraminifera. Detrital quartz and rock fragments are included in the marl.

In summary, the Cerro Gato Formation consists of at least 26 m. of algal marls with interbeds of fine-grained, rose marlite and fossiliferous marls containing Lyropecten arnoldi (Aguerrevere).

Fossils and Age. Megafossils are abundant in some portions of the Cerro Gato Formation. Table II is a list of the megafauna identified from 16 samples; the locations of the samples are shown in Figures 2, 4 and 5. The relative abundance of the species is indicated by the letter shown under the station number in Table II, as follows:

$\underline{A}$	-	Very abundant	: More than 50 specimens
$\overline{A}$	-	Abundant	: 7 to 49 specimens
F	-	Frequent	: 4 to 6 specimens
S	-	Scarce	: 2 to 3 specimens
R	-	Rare	: 1 specimen
*	-	Occurs as internal or external molds	

The known stratigraphic ranges of the species are listed in the right-hand column. Question marks are used where the age is in question and where the species is present only in fragmental form in rocks of the age indicated.

We can estimate the age of the Cerro Gato Formation by determining the percentage of species still living (Marks, 1952 and Weisbord, 1962, 1964). Table III shows the percentages of the 42 identified species that extend to Recent.

TABLE III

Species	Percent Living	Number of Species Living
Gastropods 6	83.5	5
Pelecypods 25	64.0	16
Echinoids 8	75.0	6
Corals 2	100.0	2
Ichnofauna 1	100.0	1

If we discount the groups having slow evolution, such as the corals, and use the mollusks only, we find that 67.7% of the fauna continues to Recent indicating that the rocks are Late Pliocene in age.

It should be noted, however, that a large percentage of the fossils are present only as molds, and many of the more delicate fossils may have been leached out of the rocks. Thus, a sizeable portion of the molluscan fauna may be unlisted and the actual percentages may be considerably different.

If we use genera and subgenera and determine the level of evolution of each species, the age is Early Pliocene. Seven species of pelecypods, one gastropod and one echinoid are restricted to the Pliocene; and one pelecypod and one echinoid are Late Miocene index fossils. In general, the fauna is more similar to the Miocene than to the Pleistocene or Recent.

Microfossils were separated from a few samples of the marl exposed below the fossiliferous zone on Cerro Gato. Dr. Pedro J. Bermúdez identified the following foraminifera from the samples:

Amphistegina angulata (Cushman)	A
Bigenerina textularoidea (Göes)	R
Elphidium poeyanum d'Orbigny	R
Florilus sloanii d'Orbigny	R
Globigerina cf. G. bulloides d'Orbigny	S
Globigerinoides elongatus (d'Orbigny)	F
Globigerinoides triloba (Reuss)	F
Globorotalia dutertrei (d'Orbigny)	A
Gypsina globulus (Reuss)	R
Orbulina universa d'Orbigny	A
Peneroplis proteus d'Orbigny	R
Quinqueloculina auberiana d'Orbigny	F
Quinqueloculina cuvieriana d'Orbigny	S
Rotalia rosea (d'Orbigny)	A
Textularia agglutinans d'Orbigny	F
Textularia barretti (Parker & Jones)	R
Textularia conica d'Orbigny	A

Ostracods, calcareous algae and fragmental material were also obtained from the samples. All of the species range from Pliocene to Recent.

Based upon the above, we date the Cerro Gato Formation as Pliocene, probably Lower Pliocene.

Correlation. The Cerro Gato Formation is most similar to the calcareous facies of the Playa Grande Formation at Cabo Blanco, which Weisbord (1962, 1964) referred to the Lower Pliocene. It may also correlate with the Cumaná and Barrigón formations to the east as suggested by Patrick (1959) and Bermúdez (1966). Macsotay (1965) tentatively dated the Barrigón as Upper Pliocene. If this is correct, then the formations in the east are younger than the exposures on La Tortuga.

Environment of Deposition. The algal marls are thought to have been deposited on a shallow platform or shelf area. The area was probably a topographic high, 10 to 20 m. deep, where the rate of sedimentation was slow. It had a muddy, soft bottom and was subjected to normal marine conditions but no strong currents.

The rocks above, the rose marlite, were deposited at a still lower rate of deposition, on a hard bottom exposed to currents. Lyropecten, Argopecten, Spondylus, Periglypta, echinoid spines, and large quantities of bryozoans, all suggest good circulation of normal oceanic water and little sedimentation. The larger number of gastropods in this sequence suggests that the water was clearer than prior to deposition of the rose marlite.

The sedimentation at Carenero was probably even slower than at the type section. This is suggested by the abundance of Domichnia-type burrows and the occurrence of burrowing pelecypods and echinoids. The sedimentation took place in clean water and the environment was about the same throughout the section.

Tortuga Formation

Introduction. The greater portion of the island is covered by a thin layer of coralline limestone. Patrick (1959) named the limestone the "Formación Tortuga" and correlated it with the reef terraces of Margarita Island. He also suggested that the limestone correlated with the "Coral Rock" of Barbados and the Seröe Formation of Curazao. Bermúdez (1966) later referred to the unit as the "Formación La Tortuga" and suggested a probable maximum thickness of between 8 and 20 m.

The Tortuga Formation is separated into two parts near the southern coast (Fig. 4). The lower terrace (1), at elevations of 13 to 0 m., is highly fossiliferous with corals and mollusks. It contains unrecrystallized beds of back-reef and lagoonal facies. The upper terrace (3) differs in that it has much less fossil material and is more recrystallized. These differences have led us to separate the lower terrace as a member. It is here named the Punta Piedras Member for its exposures on the point of the same name located on the central part of the south coast (Fig. 2).

The north coast lacks the terraces of the south and the exposures are much poorer. The limestone cropping out near the coast does appear to be more fossiliferous than the island exposures. However, we were unable to determine whether distinct lithological differences exist in the north and for this reason the limestone is here mapped as undifferentiated Tortuga Formation.

Undifferentiated Tortuga Formation. The upper terrace (3) is capped by limestone which extends east, north and west to the coast (Fig. 4). In the south the limestone is 0.5 to 2.0 m. thick and disconformably overlies the

Cerro Gato Formation. The thickness of the undifferentiated portion of the Tortuga Formation is unknown in the north as it is covered by recent sediment and coral in the coastal areas. It is 2 m. thick on the fault scarp at Punta El Olivo.

Cream-colored, porous, low to medium density, clastic limestone, which weathers to a distinctive gray, is exposed at Cerro Gato. Hydrozoans are present, and pelecypod fragments, foraminifera and echinoid spines occur in recrystallized forms. Algae encrust most of the larger grains and the matrix is composed of organic matter and calcium carbonate. Detrital quartz, hornblende and plagioclase occur as widely scattered silt-sized grains.

The rocks are very similar in the north. They consist of hydrozoan-reef limestones and clastic, back-reef limestones. Many of the fossils, including the algae, appear to be displaced suggesting that the deposition took place behind a reef buttress.

Brackish-water marls are exposed near the eastern and western ends of the island where the upper terrace appears to merge with the lower. In the west it is a fine-grained, colored, algal marl. Mollusks and foraminifera are abundant in this low density rock. Detrital quartz, plagioclase and rock fragments occur in small percentages.

Punta Piedras Member. The Punta Piedras Member comprises the lower terrace (1) exposed near the southern coast. The name is taken from Punta Piedras (also called Punta de Garambeo), a rocky point located on the central part of the south coast where exposures typical of the member are present on the sea cliff.

The Punta Piedras Member is at least 7 m. thick at the sea cliff where the base of the formation is concealed by Recent sediment. The northern contact with the Cerro Gato Formation is at an elevation of 12 to 13 m., and the member slopes south. The slope is probably the initial inclination of the reef. Mesolella (1967) noted elevation differences of 10 to 34 m. in the exposed reef terraces of Barbados.

The limestone is made up of fore-reef, back-reef and lagoonal facies. The reef zone consists of a head-coral facies and an Acropora cervicornis facies. The head-coral facies consists chiefly of coral with some pelecypods and a little carbonate sediment. Thin sections contain, in addition to the coral, echinoid spines, broken shell fragments, transported algal heads and angular, transported, fragments of calcite. The limestone is low in density, porous, white to cream colored and weathers to a distinctive gray.

The back-reef facies contains up to 75% Acropora cervicornis. Pelecypods, gastropods, echinoid spines, algal heads and sand-sized clastic grains of calcium carbonate occur in addition to the corals. Much of the shell material is broken and the carbonate sediment is probably derived from erosion of the reef.

The rear zones of the reef are poorly exposed as most of the outcrop area is along the sea cliff, parallel with the coast, and only two gullies penetrate into the reef. White to cream colored, friable, clastic limestone crops out north of Punta Piedras. The carbonate sediment is detrital in origin and poor in fauna. It is similar to the sediment presently accumulating in the lagoons behind the exposed or near-surface reef zone.

Age and Environment of Deposition. The Punta Piedras Member contains a large fossil assemblage. Thus far 247 species of the megafossils have been identified; approximately 90% of these species are still living. Using the percentages of living fauna from Weisbord (1962, 1964) we estimate a Late Pleistocene age.

The Punta Piedras Member is characterized by fore-reef, back-reef and lagoonal and brackish water facies. Table IV shows the relative abundance of the most common megafossils in different facies.

TABLE IV

Fore-Reef Facies	
Coelenterata	
Dendrogyra cylindrus Ehrenberg	A
Acropora palmata (Lamarck)	A
Solenastrea bournoni (Milne-Edwards & Haime)	F
Montastrea annularis (Ellis & Solander)	F
Eusmilia fastigiata (Pallas)	F
Pelecypoda	
Glycymeris undata (Linnaeus)	A
Codakia costata d'Orbigny	A
Petricola lapicida Gmelin	A
Periglypta listeri (Gray)	F
Pseudochama radians (Lamarck)	F
Divalinga quadrisulcata Linnaeus	F
Ostrea frons Linnaeus	A
Gastropoda	
Strombus gigas Linnaeus	A
Astraea phoebia Röding, var.	A
Cypraea cinerea catiana Wesibord	S
Cassis madagascariensis Lamarck, var.	S
Coralliophila abbreviata Lamarck	F
Echinoderma	
Cidaris tribuloides (Lamarck)	F
Back-Reef Facies	
Coelenterata	
Montrastrea cavernosa (Linnaeus)	A
Colpophyllia natans (Müller)	F
Acropora cervicornis (Linnaeus)	A
Agaricia agaricites (Linnaeus)	F
Porites porites (Pallas)	F

Pelecypoda	
Barbatia tenera Adams	A
Glycymeris pectinata Gmelin	A
Spondylus cf. S. americanus (Hermann)	F
Diplodonta punctata Say	F
Codakia orbiculata (Montagu)	A
Semele proficua (Pultney)	F
Gastropoda	
Tectarius muricatus Linnaeus	F
Cypraea zebra Linnaeus	F
Strombus pugilis Linnaeus	A
Oliva shepmani Weisbord	F
Hemitoma aff. H. octoradiata (Lamarck)	A
Echinoderma	
Diadema antillarum (Philippi)	A

Lagoonal Facies

Coelenterata	
Porites porites (Pallas)	A
Pelecypoda	
Diplodonta mediamericana Brown & Pilsbry	F
Americardia cf. A. guppyi (Thiele)	A
Pitar arresta Dall & Simpson	F
Gastropoda	
Pallacera guadelupensis (Petit)	A
Cerithium variabile Adams	A
Melongena melongena (Linnaeus)	A
Bulla occidentalis Adams	A
Bulla striata Bruguiére	F

The fore-reef facies was deposited in 5 to 10 m. of warm, normal marine water having good circulation. The back-reef facies was deposited between the reef crest and the lagoonal facies, where there was less than 2 m. of depth. The fauna indicates even warmer water with normal salinity and good circulation.

The lagoonal faunas occur at the extreme western and eastern ends of the island. They indicate large variations of salinity, restricted circulation, warm water, low oxygen content, and a calcareous bottom less than a meter deep. These sediments were probably deposited in lagoons, isolated behind reefs exposed by uplift of the island or lowering of sea level. The other small exposures of lagoonal facies were barren of megafossils.

Citherium pica (Linnaeus) and Purpura patula Linnaeus, occur in breccias from near the base of the terrace. They are living species, common along rocky coasts and shallow reefs. We believe that they were incorporated in the rock after the brecciation and are not part of the original fauna.

The upper terrace, undifferentiated Tortuga Formation, contains a small fauna, predominantly of corals, as follows:

Coelenterata

- Actinastraea pectinata (Pourtales)
- Colpophyllia natans (Müller)
- Dichocoenia stokesi (Milne-Edwards & Haime)
- Millepora complanata Lamarck
- Montrastrea cavernosa Linnaeus

Pelecypoda

- Spondylus sp.
- Lucina sp.

Gastropoda

- Cerithium sp.
- Astraea sp.
- Leycozonia sp.

The upper terrace is about the same age as the lower terrace. Differences in the faunas probably resulted from differences in the environment of deposition and modification of the upper terrace by weathering.

RECENT SEDIMENTS

The coastal and near-shore marine areas are covered by recent carbonate sediments of unknown thickness. Most of the coast is bordered by coral reefs. The upper portions of the reefs are exposed during low tide, and they form breakers. All of the corals with the exception of Millepora are dead at the reef crests. Living reefs are present at depths of 5 to 10 m. seaward of the crest. Lagoons less than 2 m. deep occur on the landward side of the reefs along the southern coast. The lagoons are covered with white, calcareous, fine-grained sand to silt sized sediment. Finely divided algal material is present in the surface sediments. The lagoonal beaches are covered with calcareous sand.

Sand and gravel spits have formed behind the reef in some areas. The gravel is located on top of and directly behind the reef crest, and is composed of eroded reef limestone. Away from the reef the sediment is increasingly finer grained. Mangrove thickets grow in the sandy shoreline area.

The reef forms the shoreline along most of the northern coast. It is bordered by a thin strip of sand dunes. The small islands located north and west of La Tortuga are patch reefs and their associated sediments. Punta Delgada is a coral island connected with the main island by a tombolo. Punta Arena is a sand spit, protected on the south by the emergent reef.

The crestal reef rock is generally a very poorly sorted aggregate of reef material including corals, mollusks, echinoid spines, and algae. The components of the sediment are increasingly harder to identify away from the reef-crest towards the lagoon.

GEOLOGIC STRUCTURE

Few structural features can be observed on the island. The elevations of the rose marlite and Lyropecten beds of the Cerro Gato Formation indicate that it is gently arched with its summit in the south-central part of the island. Two small faults and two fold were found in the Cerro Gato Formation, but these appear to be small-scale features.

The bathymetry (Fig. 3) shows a steep scarp south of the island. We believe that the scarp, which is more than 1000 m. high and slopes as much as 30°, is a fault scarp. The submarine fault is located 7 to 10 Km. south of the island and has an east-west strike.

We believe that the separation of the upper Pleistocene terrace (3) from the lower (1) was accomplished by a northward tilting of the island during the Late Pleistocene. This tilting may have been a result of offshore faulting. The differences in elevation of the lower terrace (1) around the island may reflect post-Pleistocene arching of the island or the initial slope of the reefs.

GEOLOGIC HISTORY

The island was submerged as a very shallow, normal-marine shelf or bank during the Pliocene. It was a topographic high upon which little clastic sediment was deposited, and algal muds accumulated at a very slow rate.

The island was exposed above sea level and arched gently sometime between the Late Pliocene and the Late Pleistocene. It remained an area of non-deposition and/or erosion until the last interglacial stage, when sea level rose and covered the island to depths of less than 20 m. Coral reefs and their associated sedimentary facies were deposited during the submergence. Offshore faulting raised the southern part of the island and the limestone was exposed as a terrace above sea level. The reef continued to grow along the northern coast and a new, lower reef developed along the southern coast.

The lowering of sea level during the last glacial stage exposed the island. It may have been arched slightly and uplifted during this stage. Coral reefs began to grow in the coastal areas again during the Holocene rise in sea level. They continue to live at depths of 5 to 10 m., but the reef crests, which are now exposed at sea level, are dead. The exposure of this new reef terrace may be the result of recent uplift of the island.

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