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FORAMINIFERS AND CARBONATE COMPONENTS OF SEDIMENTS OFF THE ISLOTE NORCO NP–1 SITE SUPPLEMENTARY REPORT

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FORAMINIFERS AND CARBONATE COMPONENTS OF SEDIMENTS OFF THE ISLOTE NORCO NP-1 SITE

by

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INTRODUCTION

This report concerns living and dead foraminifers and grain composition in relation to the origin of the sediments off Islote.

The Islote site is the area where the Puerto Rico Water Resources Authority plans to build a nuclear power plant (NORCO NP-1). This investigation forms part of the ecological and paleontological studies of the area. The Islote site is located about 11 kilometers west of Arecibo.

Special preference has been given to foraminifers because they constitute the only group of microscopic animals whose shell is preserved and also because they are the most abundant group found off Puerto Rico with the exception of nematodes in most muddy environments and crustaceans on algae. Surface salinities in the study area range from 34.0 to 38.2 ppt and temperatures from 26°C to 28.2°C. Currents are alternating to the east or to the west in the area. Sediments are constituted by detrital and carbonate sands. The sediments, constituted mainly by detrital sediments, consist of fine and very fine sands and the carbonate sediments consist of medium sand and minor amounts of coarser and finer sediments.

FIELD AND LABORATORY METHODS

Five rows of five stations were located off the land in south-north directions. The distance between rows is 500 meters. Each row consists of five stations located about 200 meters from each other. Stations range in depth from three to six meters (see Figure 1).

Sediment samples were taken with a Petersen dredge. The upper centimeter of sediment was taken from the undisturbed surface with a tube measuring 10 cm^2 (inside area). Divers took other samples directly from the sea bottom with a tube measuring 10 cm^2 in area. The samples were preserved in 33 percent alcohol in sea water. The protoplasm of the foraminifers in the samples was stained with bengal rose by use of standard procedures. The samples were then washed with a No. 230 U.S. Standards sieve. All living foraminifers were identified and counted in wet samples. The samples were dried to count at least 200 dead foraminifers per sample. More than 300 grains were counted per sample to determine the percentages of organic, inorganic, polished and unpolished parts.

LIVING MEIOFAUNA

Several groups of organisms were identified and counted; Table 1 shows their number per station. The total number of individuals per sample is lower than in the Mayaguez Bay (Seiglie, 1974), and Guayanilla and Jobos Bays (Seiglie, 1974). The Islote area is located in a high energy environment where sediments are being continuously transported. This is the cause of the scarcity of all meiofaunal organisms compared to areas like the Mayaguez, Guayanilla and Jobos Bays.

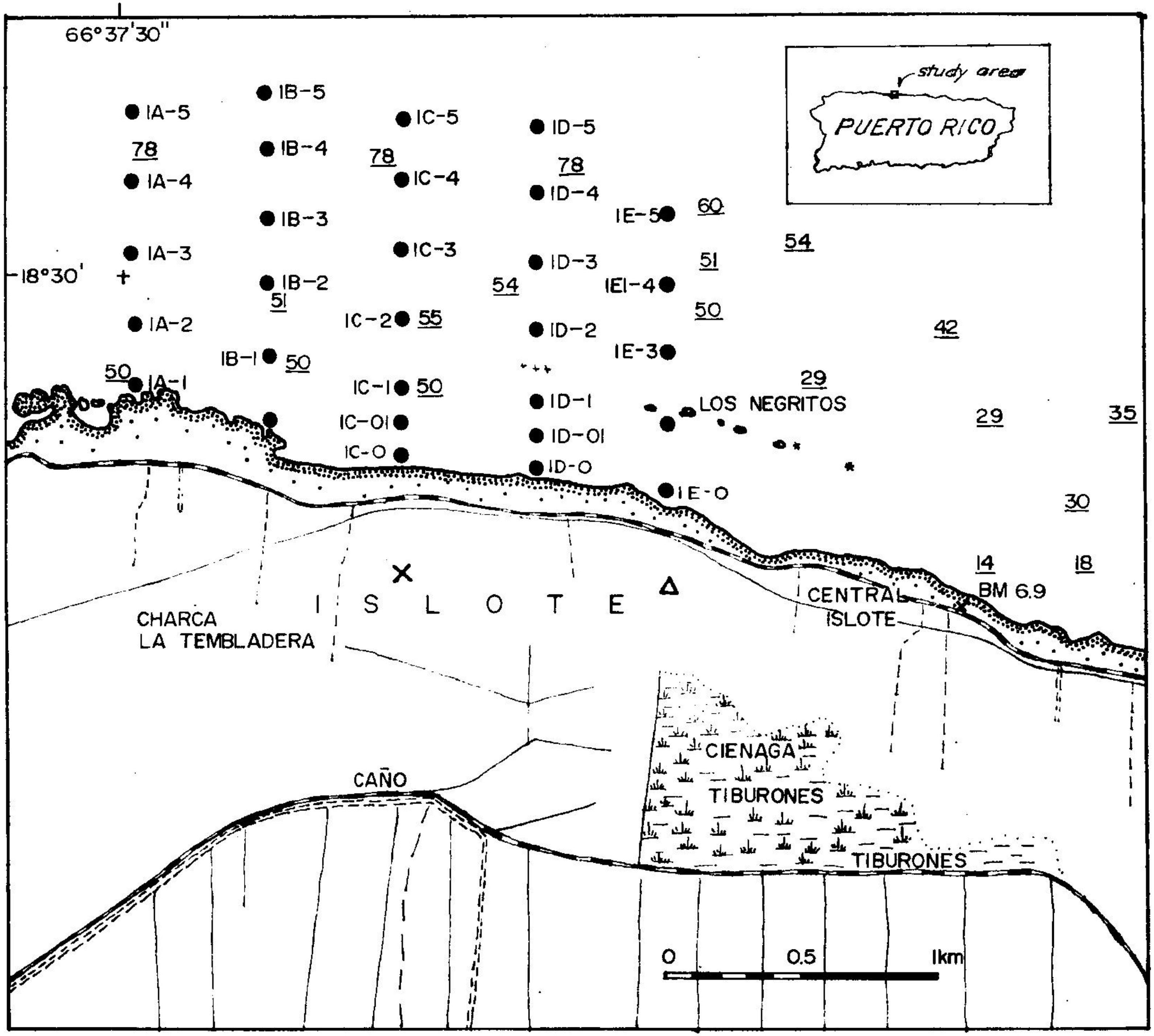


Figure 1. Location of stations in the study area. Underlined numbers indicate depths in feet.

TABLE 1

MEIOFAUNA. NUMBER OF ORGANISMS PER SAMPLE.

Meiofauna	1A-1R	1A-2	1A-3r	1A-4	1A-5	1B-1a (1)	1B-1b	1B-2	1B-3R	1C-01R	1C-3	1C-4	1D-01R	1D-1	1D-2 (1)	1D-3R (2)	1D-4R	1E-4 (1)	1E-5
Foraminifers	1	55	36	9	2	84	51	21	5	3	10	4	4	4	202	107	11	120	36
Nematodes	1	67	26	2	10	XX	15	29	10	11	6	7	5	12	80	24	29	2	5
Other worms	2	5	6		10	X	1	2	7		2	1				7	3		2
Crustaceans	3		14	2	5	X		9	9	6	7	3	6	2	110	65	11	17	18
Ostracods		5	1			X	2	3	2			2			6		1		1
Bivalves**	1		2		3	X			3							1	1	2	
Gastropods**		3	2	1		X		1	1			1			2	2	1		3
Scaphopods			2												2				
Bryozoans							1								*				4
Ophiuroidea**															2				
Celentereans***															*				

XX More than 300 individuals
X Present, not counted
* Colony
(1) Algae and sediments
(2) Algae

** Juvenile
*** Microscopic

FORAMINIFERS

Three different groups of foraminifers occur in the study area: living foraminifers, dead unpolished foraminifers, and dead polished foraminifers. The specific content of the three faunas does not show significant differences. However, the differences in percentages of the species in the three faunas are significant and they are the consequences of environmental changes in the area since the Pleistocene epoch.

Living Foraminifers

Fifty-two species of living benthic foraminifers and two species of living plantonic foraminifers were found on the sediments and algae of the study area. The number and species of foraminifers per sample are shown in Table 2. Because of the constant movement of the sand, the number of foraminifers is low. The most abundant living species is *Rotorbinella rosea*, which is generally more abundant than all other foraminifers together. *R. rosea* is also dominant in Yabucoa Bay (southeastern Puerto Rico) and the number of foraminifers is low because this bay is a high energy area (Seiglie, 1970). *Asterigerina carinata* is the second in abundance and it is also abundant in the high energy areas of Batabanó Gulf, Cuba (Bandy, 1964) and the Cabo Rojo Platform (southwestern Puerto Rico) (Seiglie, 1971). *R. rosea*, *Neoconorbina* cf. *orbicularis*, *Rosalina* cf. *floridana* and several species of small *Quinqueloculina*, *Miliolinella* and *Triloculina* live on algae and they constitute the most abundant groups of foraminifers living on algae. However, Miliolidae are scarce compared to faunas of Jobos Bay (Seiglie, unpublished data), where they are the most abundant group, and *Rotorbinella rosea* is absent because Jobos Bay is an area protected from the open sea.

TABLE 2.

NUMBER AND SIGNIFICANT SPECIES OF LIVING FORAMINIFERS PER SAMPLE.

	IA-1R	IA-2	IA-3R	IA-4	IA-5	IB-1a (1)	IB-1	IB-2	IB-3R	IC-01R	IC-1	OC-2	OC-3	IC-4	IC-5	ID-01R	ID-1	ID-2 (1)	ID-3R (2)	ID-4R	IE-3 (1)	IE-4 (1)	IE-5
Amphistegina gibbosa			1			1					1				1			8					1
Archaias angulatus																		1					
Articulina? mexicana																							1
Asterigerina carinata		1	14	3	1	2		4	1						6			4					1
Homotrema rubrum			1																				
Miliolids		10	3					2										28	10	1		3	1
Neoconorbina cf. orbicularis					1	1												4		2		4	2
Rosalina cf. floridana			1		1			1										6	62			15	2
Rotorbinella rosea		26	3	2		71	46	10		2	14	4	10	1	12	3	4	120	30	5	82	95	26
Other species	1	13	9	1	4	7	1	1	2	1				2	8	1		31	6	2	10	8	3
Planktonic foraminifers			1			1		1							1			1		1			
Total number of foraminifers	1	50	33	4	7	83	47	19	3	3	15	4	10	3	28	4		203	108	11	92	125	55
Total number of species																							

(1) Algae and sediment; (2) Algae

Amphistegina gibbosa and Archaias angulatus are common foraminifers of carbonate areas, but living specimens are rare in the study area.

Most of the living species of foraminifers off the Islote site are small, generally smaller than the average size of Rotorbinella rosea. These small size foraminifers are not present in the dead or polished fauna, probably because sediment grains are generally of larger size than the smallest foraminifers, and also because they have been sorted by transportation.

Dead Unpolished Foraminifers

Sixty-four species of dead benthic unpolished foraminifers and five species of dead planktonic unpolished foraminifers were found in the study area. The dominant species of the dead unpolished foraminifers is Rotorbinella rosea (see Table 3). However, its percentages in relation to total dead unpolished foraminifers are lower than percentages of living R. rosea, in relation to total living foraminiferal assemblages. The percentages of Archaias angulatus also appear to be higher in the unpolished assemblage. However, its number is small for an appropriated interpretation. Amphistegina gibbosa shows the highest decrease in percentage from unpolished to living foraminiferal assemblages (compare Tables 2 and 3). Asterigerina carinata in the dead unpolished assemblage shows a significantly lower percentage than the living A. carinata (compare Tables 2 and 3). The distribution of dead unpolished A. gibbosa in the study area is shown in Figure 2.

The differences between the living and dead assemblages indicate that environmental changes have occurred recently. These changes have decreased the number of Amphistegina and probably Archaias and increased the number of Rotorbinella and Asterigerina.

Dead Polished Foraminifers

Sixty-one species of benthic polished foraminifers and three species of planktonic polished foraminifers were found in the assemblage of the study area. Most of these foraminifers have highly polished surfaces. They were coated with calcite and polished by the wind during the formation of dunes in the Pleistocene epoch. The worn, yellowish foraminifers at Stations ID-4, IE-4 and IE-5 are included in the polished assemblage because they are also of an older age than the unpolished fauna described above (see Table 3).

Rotorbinella rosea is dominant in 22 stations while Amphistegina gibbosa is dominant in three stations. However, in many stations where A. gibbosa is not dominant, its percentages are close to those of R. rosea. The percentages of polished Amphistegina gibbosa in the polished assemblage are larger than those of unpolished A. gibbosa in the unpolished assemblage (see Table 4, IA and IC). The percentages of polished Asterigerina carinata are larger than the percentages of the unpolished A. carinata. The distribution of polished A. gibbosa in the study area and the percentages of unpolished Archaias angulatus are shown in Figure 3.

Special reference is made to Articulina mexicana. All specimens of this species are highly polished or worn and glauconitized in the study area. I did not find any living specimens of this species in Yabucoa Bay where it is

TABLE 3

PERCENTAGES POLISHED AND UNPOLISHED FRAGMENTS IN RELATION TO TOTAL NUMBER OF GRAINS IN THE SAND SIZE FRACTION. ALL ORGANIC FRAGMENTS ARE CARBONATE EXCEPT THE SPONGE SPICLES (0% to 3.6%) ARE SILICEOUS.

	IA-1		IA-2		IA-3R		IA-3		IA-4		IA-5		IB-1b		IB-2	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Foraminifers	3.0	1.1		0.2	3.6	2.1			4.8	0.2	7.4	1.1	5.4	0.7	1.5	0.9
Coralline algae (articulate)	47.0	2.5	44.9	4.4	54.3	6.3	71.4	1.0	57.9	3.9	47.7	12.1	53.6	8.8	61.5	3.7
Other organic fragments	18.2	9.8	24.4	6.5	30.4	26.7	11.4	13.0	19.0	8.3	18.7	20.1	23.3	16.9	24.6	8.4
Inorganic fragments	31.8	86.6	30.6	88.9	11.6	64.8	17.1	85.9	18.0	87.6	29.3	66.7	17.8	73.6	12.3	87.0
Percentages of (1) & (2) relative to each other	9.7	90.3	8.0	92.0	52.7	47.3	8.0	92.0	32.4	67.6	32.4	67.6	17.0	83.0	12.3	87.7

	IB-3		IB-4		IB-5		IC-OIR		IC-1		IC-2		IC-3R		IC-4	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Foraminifers	5.3	0.9	1.2	1.4	1.7	2.1	1.9	1.6	5.7						3.0	0.8
Coralline algae (articulate)	56.8	5.2	69.1	5.2	56.2	7.3	35.3	5.2	46.1	4.2	64.5	5.2	75.9	2.5	68.7	2.7
Other inorganic fragments	15.8	11.3	15.0	19.4	29.7	20.4	18.4	17.5	17.7	5.8	19.4	9.9	20.4	12.3	9.0	8.8
Inorganic fragments	22.1	82.5	14.8	73.9	12.4	70.2	44.4	75.7	30.5	89.9	16.1	84.9	3.7	85.3	19.3	87.6
Percentages of (1) & (2) relative to each other	30.9	69.1	23.2	76.8	38.8	61.2	45.2	54.8	68.8	31.2	7.1	92.9	14.2	85.8	15.5	84.5

	IC-5		ID-OIR		ID-1		ID-2		ID-3		ID-4R		ID-5		IE-3	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Foraminifers		0.4	2.8	0.9	2.4	0.8		1.3	1.9		5.2	1.5	2.5	0.2		0.9
Coralline algae (articulate)	66.7	1.1	43.8	1.8	36.5	4.2	59.5	9.0	63.0	4.0	46.5	17.7	64.6	2.3	55.0	8.4
Other organic fragments	16.7	10.8	16.0	22.0	17.6	17.9	14.3	22.1	14.8	16.3	18.7	39.1	19.0	8.1	20.0	17.9
Inorganic fragments	16.6	87.7	37.4	75.2	43.5	77.1	26.2	67.6	20.4	79.7	29.7	41.5	13.9	89.3	25.0	72.8
Percentages of (1) & (2) relative to each other	26.9	73.1	72.1	27.9	59.0	41.0	8.1	91.9	15.3	84.7	59.6	40.4	15.2	84.8	8.6	91.4

	IE-4		IE-5	
	(1)	(2)	(1)	(2)
Foraminifers	6.2	1.6	4.8	1.4
Coralline algae (articulate	62.1	11.0	69.2	23.0
Other organic fragments	14.3	36.4	6.7	12.3
Inorganic fragments	17.4	51.0	19.2	63.3
Percentages of (1) & (2) relative to each other	43.3	56.7	27.2	72.8

NOTE: (1) Polished grains
(2) Unpolished grains

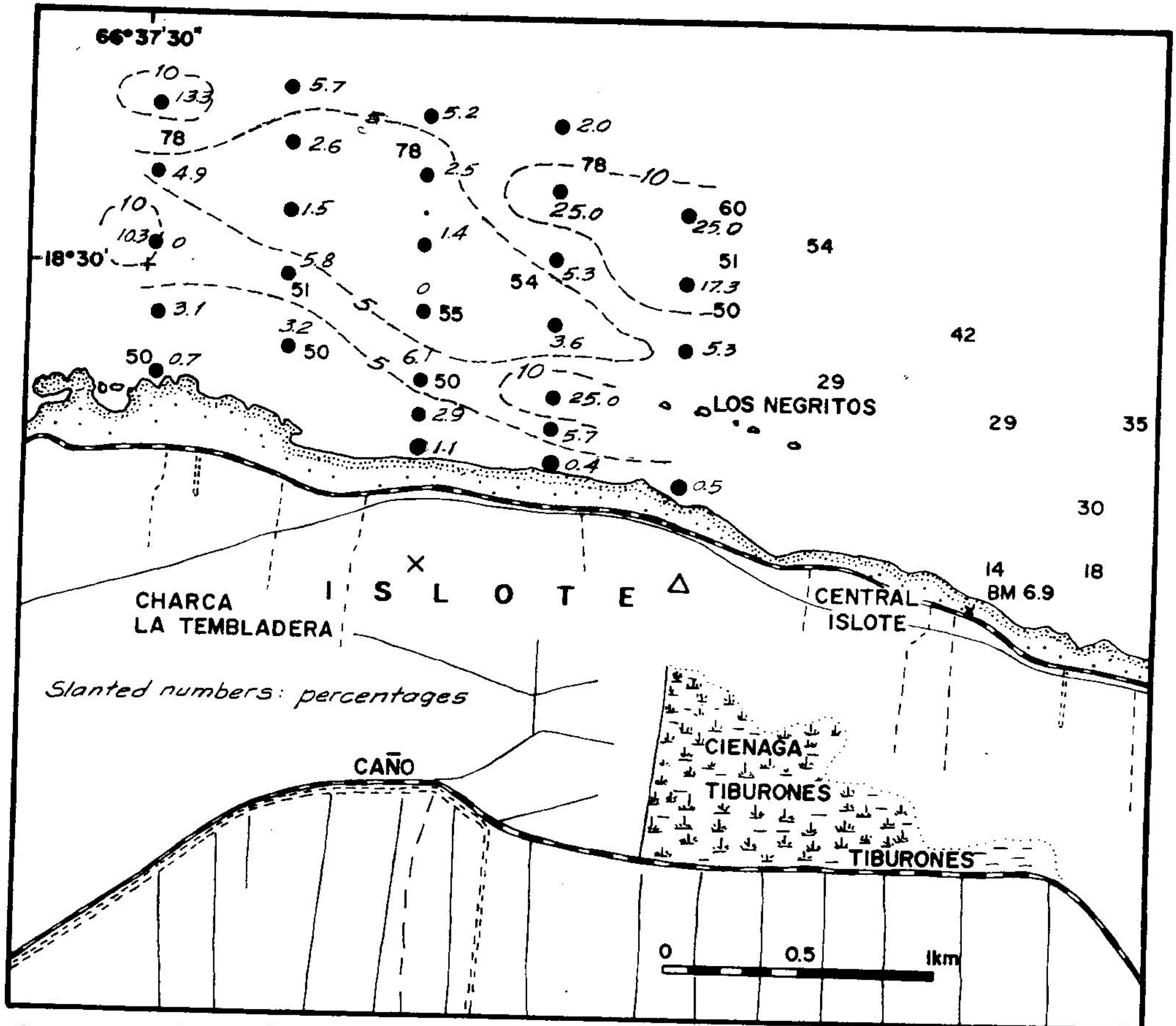


Figure 2. Distribution of unpolished Amphistegina gibbosa. Percentages in relation to total unpolished grains.

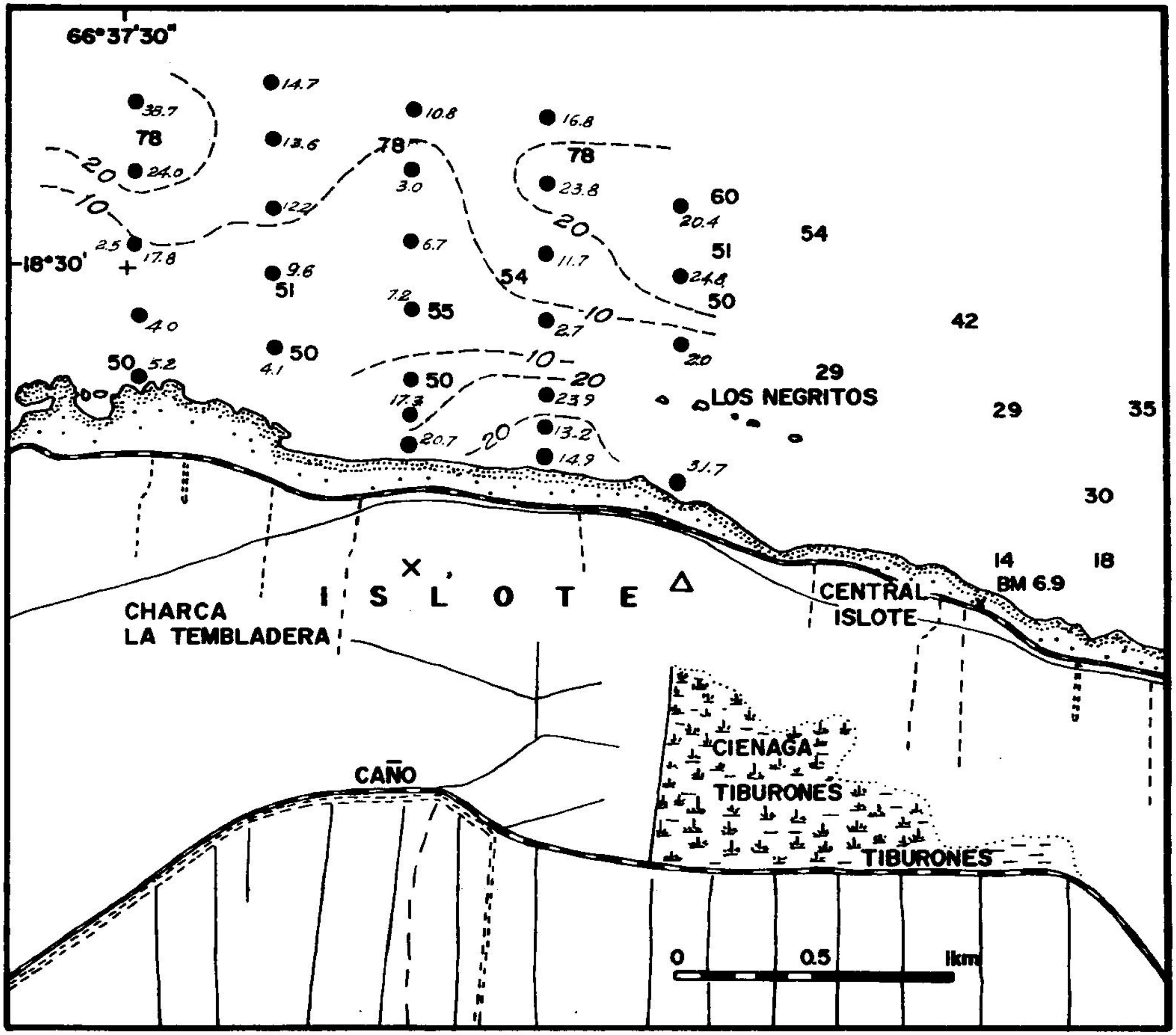


Figure 3. Distribution of polished Amphistegina gibbosa. Percentage in relation to the total number of foraminifers (polished and unpolished).

reported as _Articulina_ sp. A. (Seiglie, 1970), in the Cabo Rojo shelf, (Seiglie, 1970), or off the southern central coast of Puerto Rico. Even more, 90 percent or more of the specimens are glauconitized. This indicates that _A. mexicana_ is disappearing from the coasts of Puerto Rico. Its relation to Pleistocene sediments off the Islote site suggests that it is a relict species of the Pleistocene.

The distribution pattern of all polished foraminifers in relation to the total foraminiferal assemblage is shown in Figure 4. Polished grains are arranged in two belts grossly parallel to the coast line, one close to the coast line and the other in the outer shelf. The only samples in which 100 percent of grains are highly polished occur in the sand dunes of the Islote area.

COMPOSITION IN RELATION TO ORIGIN OF THE SEDIMENTS

The sediments off the Islote site are composed of two different types of grains: highly polished and unpolished. Both types contain organic and inorganic fractions. Some of the highly polished grains were found cemented together as they were originally cemented in dunes or beach rock. The percentage of inorganic and organic grains of both polished and unpolished fractions are shown in Table 4. The other organic fragments in Table 4 do not include either foraminifers or algae. Foraminifers and algal fragments are the only two types of organic grains whose percentages have been found useful for interpretation in this paper.

The percentages of articulate coralline algae are far higher in the polished than in the unpolished grains (see Table 4). This indicates that algae were more important in the past than at present. Figure 5 shows the distribution pattern of polished articulate coralline algae in relation to the total polished and unpolished grains. The pattern suggests two belts of Pleistocene (polished) grains, one close to the coast and the other in the border of the insular shelf. Figure 6 shows the distribution pattern of unpolished articulate coralline algae which resembles the distribution pattern of the articulate coralline algae at present. This pattern also resembles the distribution of polished algal fragments (see Figure 5).

The distribution pattern of polished grains, Pleistocene, shown in Figure 7, is fairly similar to the distribution of polished algae and polished _Amphistegina_.

The distribution pattern of carbonate grains (polished and unpolished) is shown in Figure 8. This pattern resembles the pattern of polished algal fragments (see Figure 5).

Figure 9 shows the distribution of unpolished inorganic grains. The area with low percentages corresponding to Station IE-4 coincides with an algal mat. The percentages and number of inorganic terrigenous grains are higher in the unpolished fraction than in the polished fraction. This indicates that the amount of sediments of terrigenous origin have increased recently.

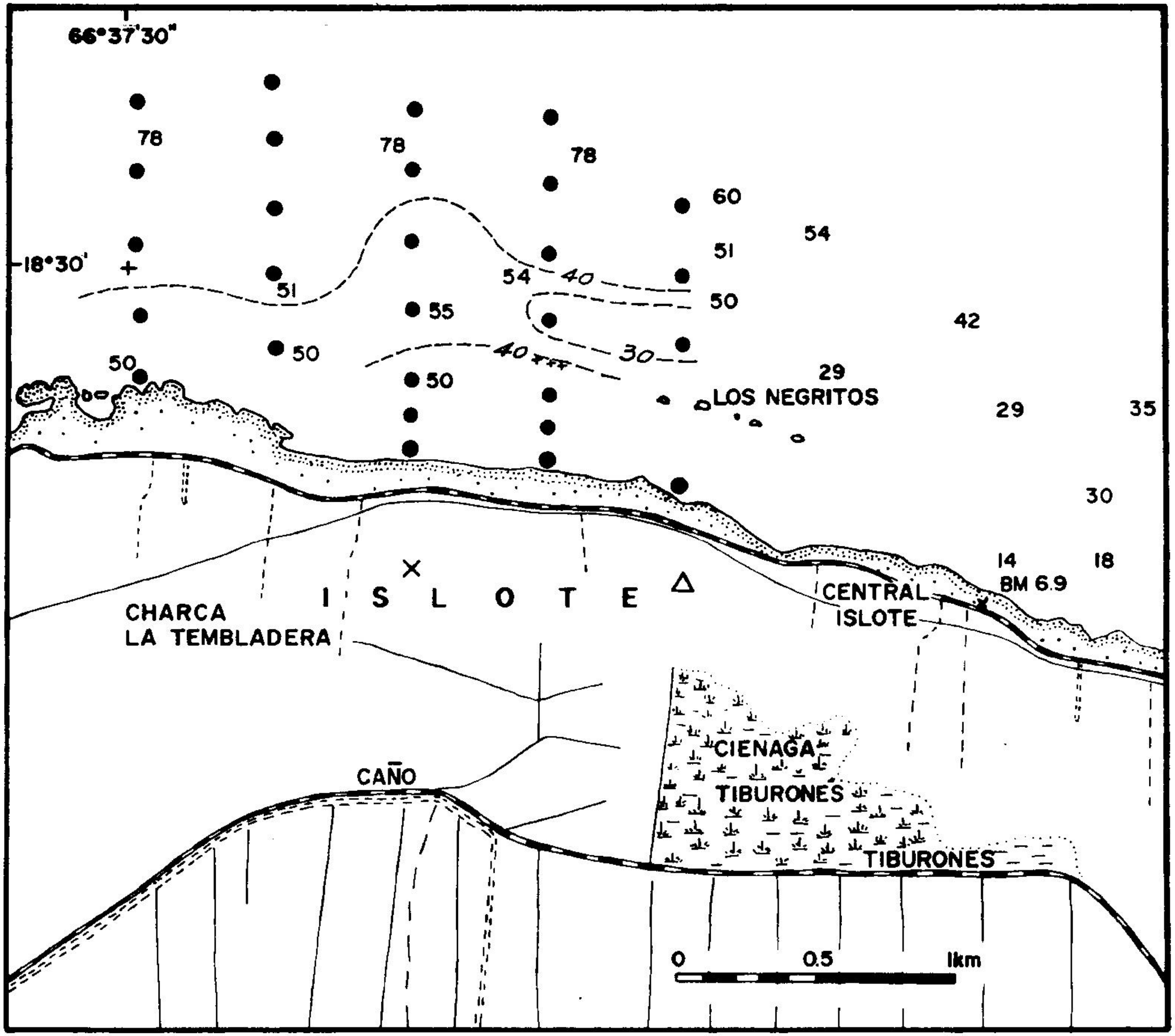


Figure 4. Distribution of polished foraminifers. Percentages in relation to the total number of foraminifers.

TABLE 4. Percentages of polished and unpolished foraminifers in the sediments of Islote area

	IA-1		IA-2		IA-3		IA-3R		IA-4		IA-5		IB-1b		IB-2		IB-3	
	U	P	U	P	U	P	U	P	U	P	U	P	U	P	U	P	U	P
Amphistegina gibbosa	0.7	14.3	3.1	13.3		8.1	10.3	28.1	4.9	31.0	13.3	42.2	3.2	11.3	5.8	18.9	1.5	17.7
Archaias angulatus	0.7	1.1		6.7			1.3	5.2	1.2	13.2	6.7	16.3		4.2	1.0	1.9	1.5	5.4
Articulina? mexicana						2.7				3.2		0.6				0.9	1.5	2.7
Asterigerina carinata	0.7		4.6	6.7	1.2				1.2	0.4					4.9	1.0	7.6	2.7
Miliolidae	2.8	10.8	15.4	3.3	6.2	8.1	7.6	7.3	3.7	5.2	6.7	10.9	8.0	5.6	3.8	5.7	4.5	10.2
Neoconorbina cf. orbicularis	1.1				1.2	2.7												
Rosalina cf. florida					1.2													
Rotorbinella rosea	78.6	54.8	46.1	36.7	79.3	62.1	67.9	47.4	61.0	32.4	20.0	21.1	69.8	54.9	71.8	54.7	71.2	50.3
Other foraminifers	15.4	19.0	30.8	33.3	10.9	16.3	12.9	12.0	28.0	14.6	53.3	8.9	19.0	24.0	12.3	16.9	12.2	11.0

	IB-4		IB-5		IC-01R		IC-1		IC-2		IC-3R		IC-4		IC-5	
	U	P	U	P	U	P	U	P	U	P	U	P	U	P	U	P
Amphistegina gibbosa	2.6	21.2	5.7	21.6	2.9	17.3	6.1	28.7		20.0	2.8	20.6	4.9	6.1	5.2	18.5
Archaias angulatus	1.3	0.7	1.4	0.6		4.4	4.1	13.0			1.4	2.9	1.0		2.1	1.5
Articulina? mexicana						0.9							2.0			0.7
Asterigerina carinata	19.5	2.2	5.7	1.4	0.7						1.4		0.9		3.1	0.7
Miliolidae	5.2	8.7	2.8	11.5	0.7	4.9		5.6	8.5	2.5	5.7	11.7	11.9	5.8	1.0	14.0
Neoconorbina cf. orbicularis															1.0	
Rosalina cf. floridana									2.9		1.4				1.0	
Rotorbinella rosea	68.8	57.7	78.6	53.4	90.7	53.1	71.4	41.7	70.0	47.5	65.7	44.1	63.7	59.2	73.2	50.4
Other foraminifers	2.6	9.5	5.8	11.5	0.7	19.4	18.4	11.0	18.6	30.0	21.6	20.7	15.6	28.9	13.4	14.2

	ID-01R		ID-1		ID-2		ID-3		ID-4R		ID-5		IE-3		IE-4		IE-5	
	U	P	U	P	U	P	U	P	U	P	U	P	U	P	U	P	U	P
Amphistegina gibbosa	5.7	16.8	25.0	28.9	3.6	12.2	5.3	18.3	25.0	35.4	2.0	28.0		9.7	17.3	37.0	25.3	34.3
Archaias angulatus		3.2	2.5	7.9	0.6			2.3	3.8	9.8		5.3	5.3	1.6	8.7	10.0	2.2	8.2
Articulina? mexicana								0.8		5.5		2.7	1.6	3.2		3.3		2.2
Asterigerina carinata					3.0		2.7	0.8			4.0	1.3	2.0		0.9	2.8	3.3	0.7
Miliolidae		4.3		9.5	24.2	12.2	4.1	10.0	7.5	9.7	6.0	13.3	2.8	9.6	1.0	14.7	3.3	18.6
Neoconorbina cf. orbicularis					0.6		1.3						0.8		2.9			
Rosalina cf.floridana					3.7						4.0							
Rotorbinella rosea	83.0	62.1	57.5	37.9	36.0	56.1	68.0	53.4	52.5	29.3	60.0	33.3	66.1	51.7	56.7	14.2	44.0	27.6
Other foraminifers	11.3	13.6	15.0	15.8	28.3	19.5	18.6	14.4	11.2	10.3	22.0	16.1	21.4	24.2	12.5	18.0	21.9	8.4

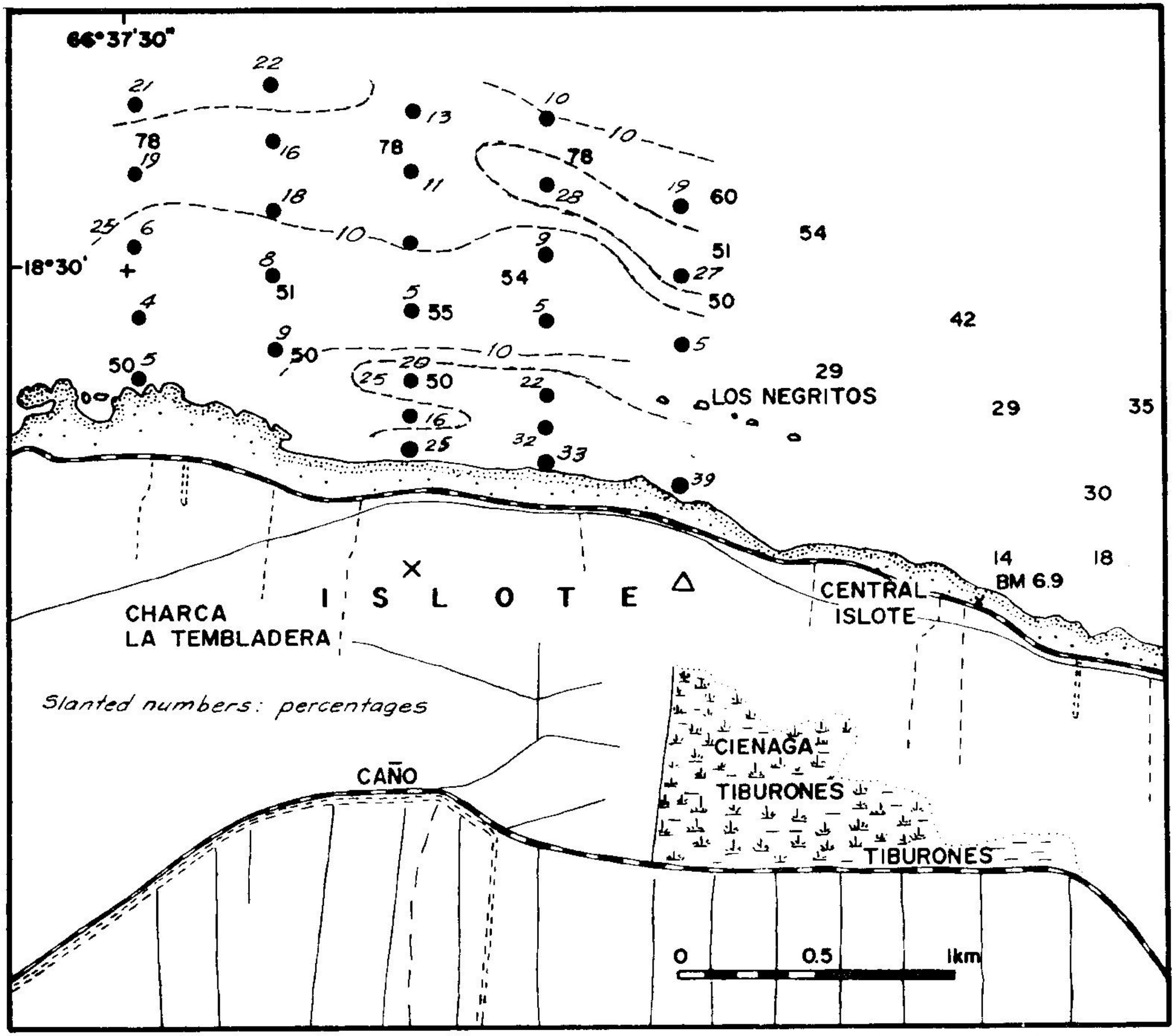


Figure 5. Distribution of polished fragments of coralline articulate algae. Percentages in relation to the total number of grains (polished and unpolished)

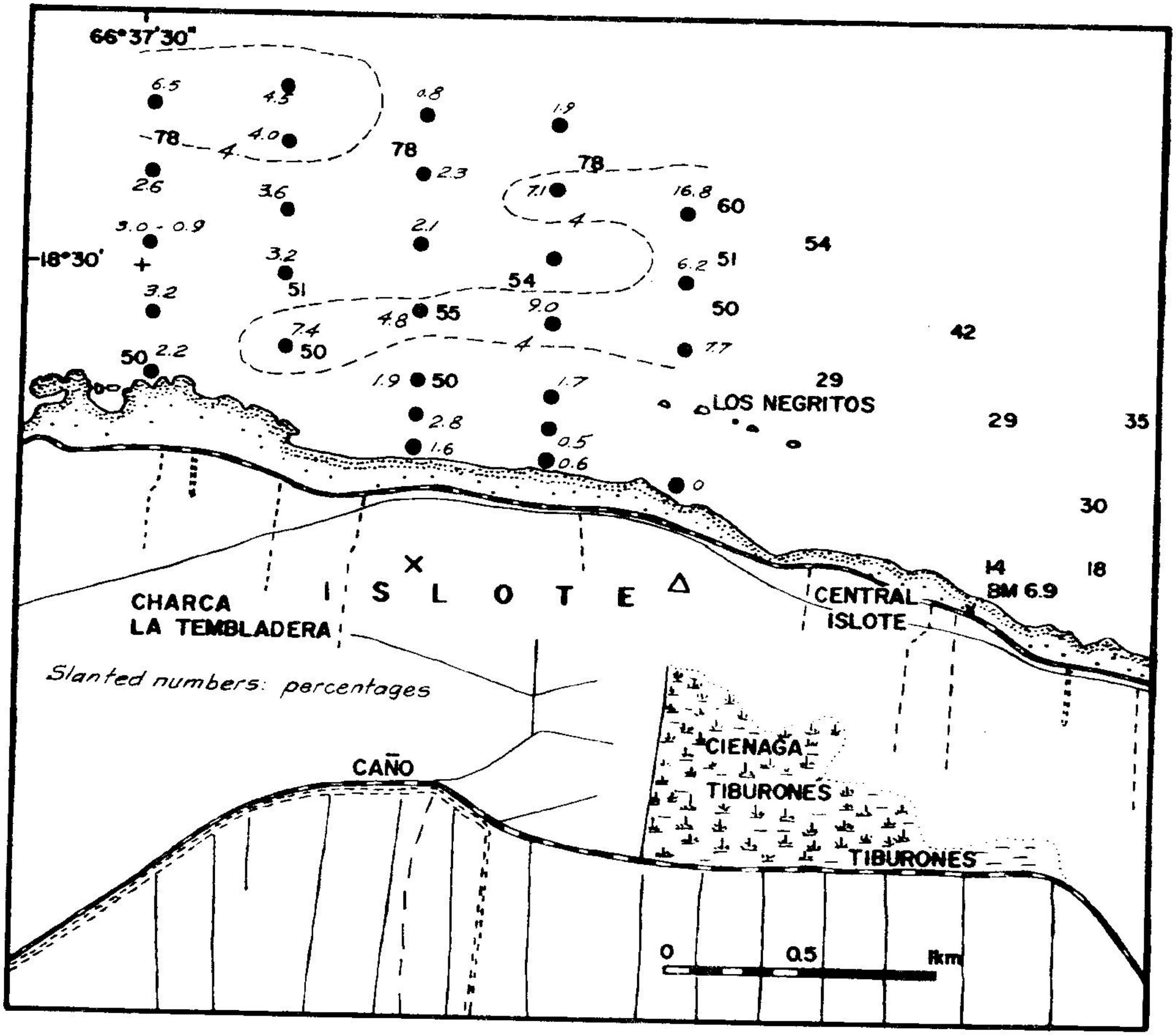


Figure 6. Distribution of unpolished fragments of coralline articulate algae. Percentages in relation to the total number of grains (polished and unpolished)

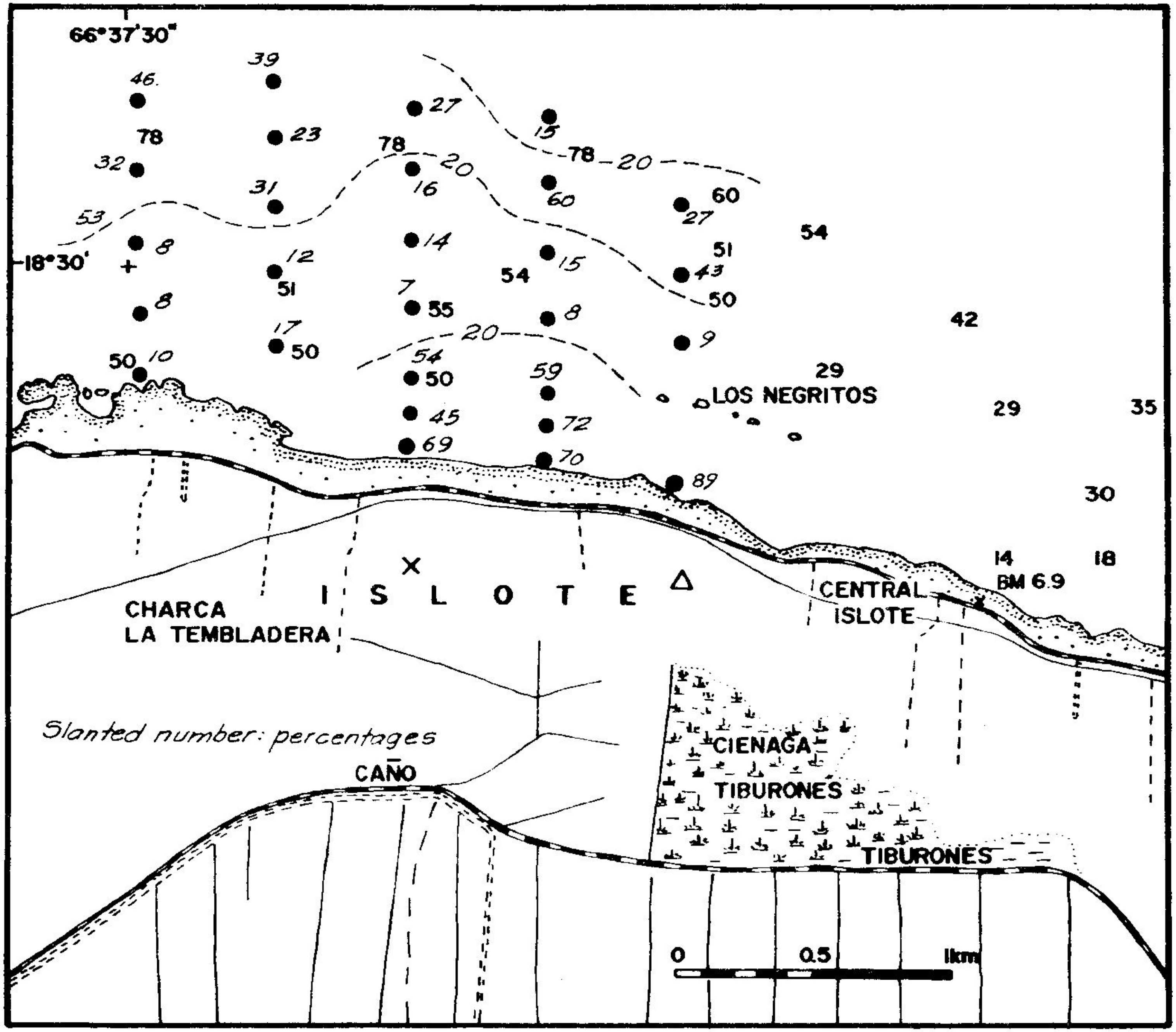


Figure 7. Distribution of polished grains. Percentages in relation to total number of grains.

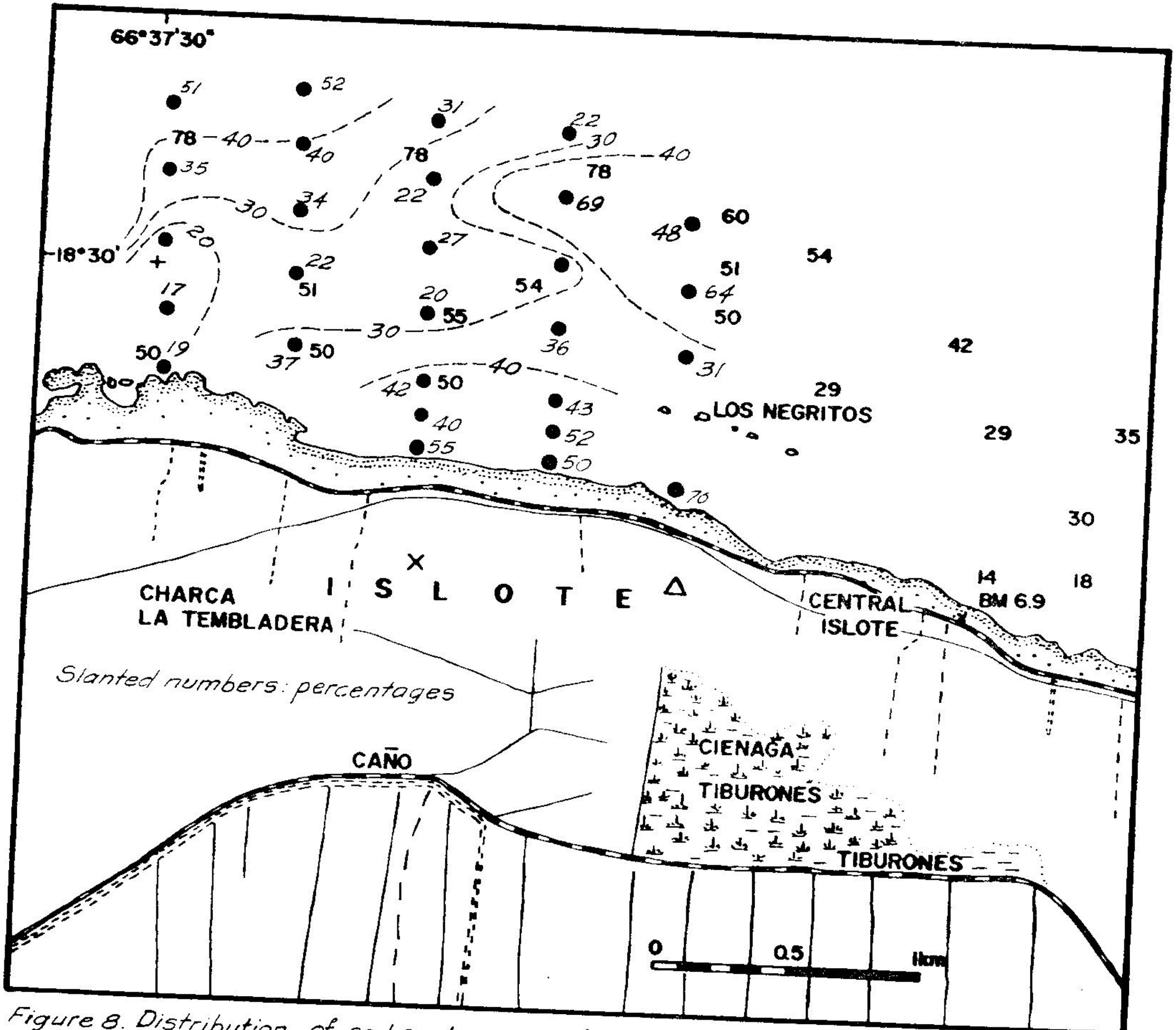


Figure 8. Distribution of carbonate grains (polished and unpolished). Percentages in relation to the total number of grains.

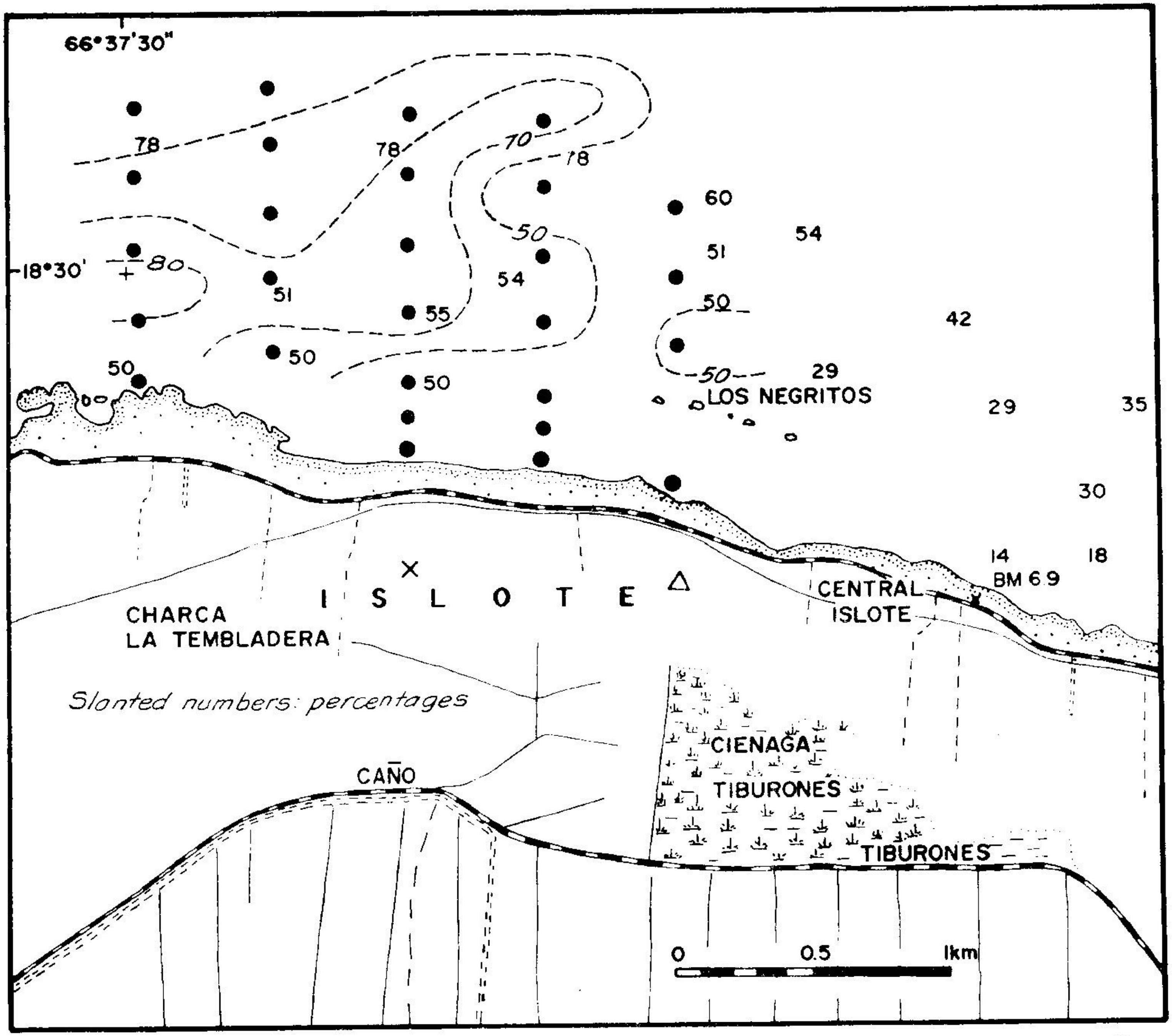


Figure 9. Distribution of unpolished inorganic grains. Percentages in relation to the total number of grain (polished and unpolished).

ORIGIN OF THE POLISHED GRAINS*

The highest percentages of polished grains occur in two belts off the Islote study area, one close to the coast and the other in the outer shelf (see Figures 3 and 4).

A scanning electron microscope was used to determine how the polished surfaces originated. Polished grains were observed under the sea, in beaches, and in dunes. For comparison, samples were taken in shallow waters off San Juan, off Islote, and off Mona Island, from the beach rocks of Boqueron beach, and from dunes at the Isabela and Islote beaches.

It was observed that the highly polished foraminifers do not present pores or pits on the surface or filling the inner structure. (Compare Figure 1 with Figure 2, Plate 2, and Figures 5 and 6, Plate 3, with Figure 1, Plate 4, and Figures 5 and 6, Plate 2). Highly polished fragments or articulate coralline algae were observed also, (Figures 2 and 3, Plate 3) but some fragments were partly broken showing the algal structure. (Figures 3 and 4, Plate 3). Some grains are not highly polished, but are coated with poorly polished calcite, such as Articulina mexicana (Figures 5 and 6, Plate 1). The highly polished surface of an Archaias angulatus (Figure 5, Plate 4) has been worn and it shows the "pores" or "pits" on its original surface (Figure 6, Plate 5. See, also, Figure 1, Plate 1).

The calcite cover of foraminifers is originated in two different environments -- dunes and beach rocks. The crystals of calcite growing on the surface of grains in dunes and beach rocks are shown in Figures 3 and 4, Plate 2, and Figures 3 and 4, Plate 4. The crystals of calcite are sharper in beach rock than in dunes. These crystals, closely interlocked, cement the grains in beach rocks and dunes. The crystals probably start growing by bacterial activity, but it is probable that most crystals grow because of alternating periods of wetness, and dryness caused by evaporation. Most cementing materials in shallow water are constituted of organisms, mainly encrusting coralline algae, Homotrema rubrum, worm tubes, bryozoans and other marine organisms (see Figure 1, Plate 3).

Calcite grains in shallow waters surrounding Puerto Rico are perforated by boring algae (see Figures 2 to 5, Plate 1; Figure 1, Plate 3; Figures 1 and 3, Plate 3; and Figure 2, Plate 4). The specimens from the outer border of the Cabo Rojo Platform (Figure 4, Plate 1) and from off Mona Island (Figures 2 and 3, Plate 1, and Figure 2, Plate 4) are the most deeply bored.

These polished grains have a calcite coat that was formed in dunes or beach rock. Grains from a beach off Mona Island are also highly polished. This indicates that high polishing may be made by waves, and also, as stated above, by wind, as in the dunes of the Islote area.

* This section was made in collaboration with Dr. Giorgio Pannela, Department of Geology, University of Puerto Rico Mayaguez Campus.

PLATE 1

Fig. 1. Amphistegina gibbosa (d'Orbigny) detail of highly polished surface with calcite coat covering surface pores. Sta. JPR-76, off San Juan, x400.

Fig. 2. A. gibbosa (d'Orbigny) deeply bored specimen off Mona Island. Sta. MI-8, x129.

Fig. 3. Detail of deeply bored surface of A. gibbosa. Sta. MI-8, x600.

Fig. 4. Articulina? mexicana Cushman, deeply bored specimen of Cabo Rojo Platform, western Puerto Rico. Sta. CRS-33 (see Seiglie, 1971), x60.

Fig. 5. A.? mexicana Cushman, poorly polished black specimen with calcite coat, bored, shelf west of Caja de Muerto Island. Sta. 054, x120.

Fig. 6. A.? mexicana Cjshman, partly coated. Sta. 054, x86.

PLATE I

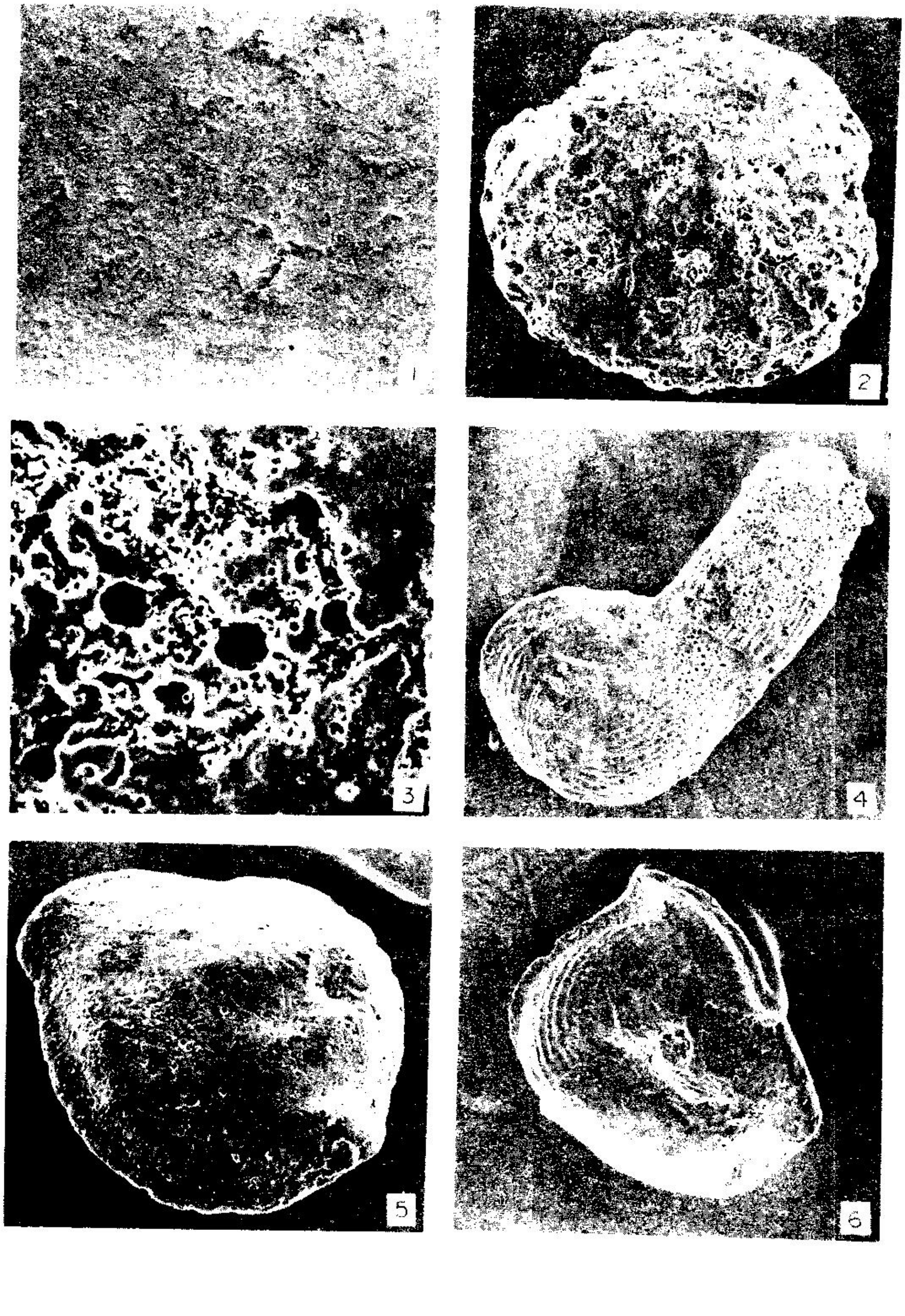


PLATE 2

Fig. 1. Rotorbinella rosea (d'Orbigny), well-preserved specimen, Islote area, northern Puerto Rico. Sta. 1B-3, x220.

Fig. 2. R. rosea (d'Orbigny), original surface coated with secondary calcite and then highly polished specimen. Sta. 1B-3, x220.

Fig. 3. R. Rosea (d'Orbigny), with crystals of calcite growing on its surface, cemented dune at Isabela beach, northwestern Puerto Rico. Sta. S-396-A, x150.

Fig. 4. Detail of the crystals of calcite growing on the surface of R. rosea. Sta. S-396-A, x4000.

Fig. 5. Homotrema rubrum (Lamarck), broken piece of a well-preserved specimen, Mona Island beach. X200.

Fig. 6. H. rubrum (Lamarck), piece, coated and filled with secondary calcite and then polished, Islote area. Sta. 1B-3, x200.

PLATE 2

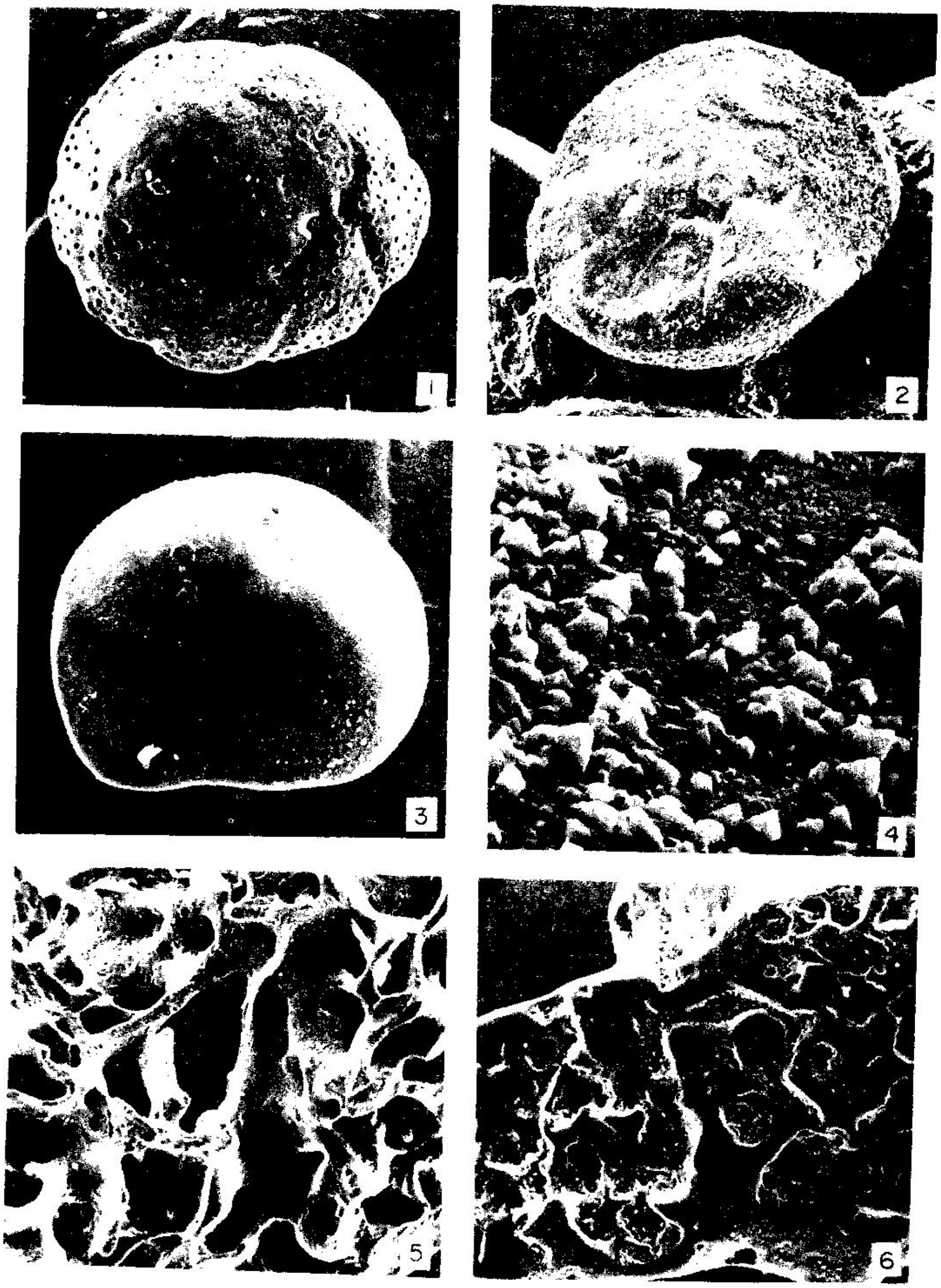


PLATE 3

Fig. 1. Coralline algae and worm tubs cementing sand grains, coralline algae bored by boring algae, off San Juan. Sta. JPR-27, x190.

Fig. 2. Articulate coralline algae, surface coated with secondary calcite and then highly polished, dune sand at Islote beach, northern Puerto Rico. Sta. IsBs-23, x150.

Fig. 3. Articulate coralline algae, surface mostly coated and highly polished, part of the coat worn showing the algal structure. Sta. IB-3, x181.

Fig. 4. Articulate coralline algae, calcite polished coat mostly worn, showing algal structure, cemented dune at Isabela beach. Sta. S-396-A, x300.

Fig. 5. Archaias angulatus (Fichtel and Moll), well-preserved specimen, off San Juan. Sta. JPR-76, x45.

Fig. 6. Detail of A. angulatus showing surface, off San Juan. Sta. JPR-76, x1000.

PLATE 3

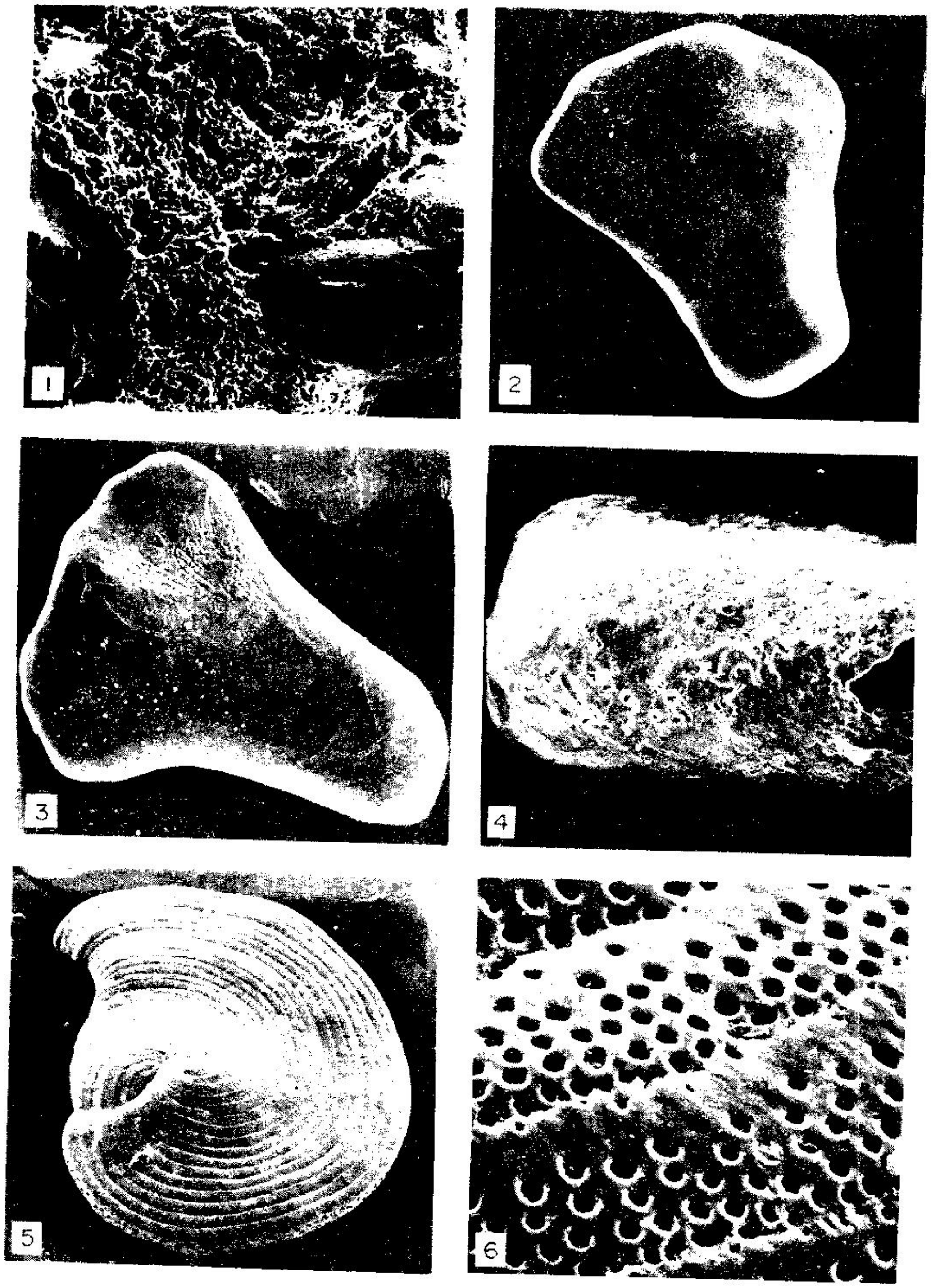


PLATE 4

Fig. 1. Archaias angulatus (Fichtel and Moll), calcite coated and highly polished, dune sand at Islote. Sta. IsBs-23, x132.

Fig. 2. A. angulatus (Fichtel and Moll), deeply bored specimens off Mona Island. MI-8, x130.

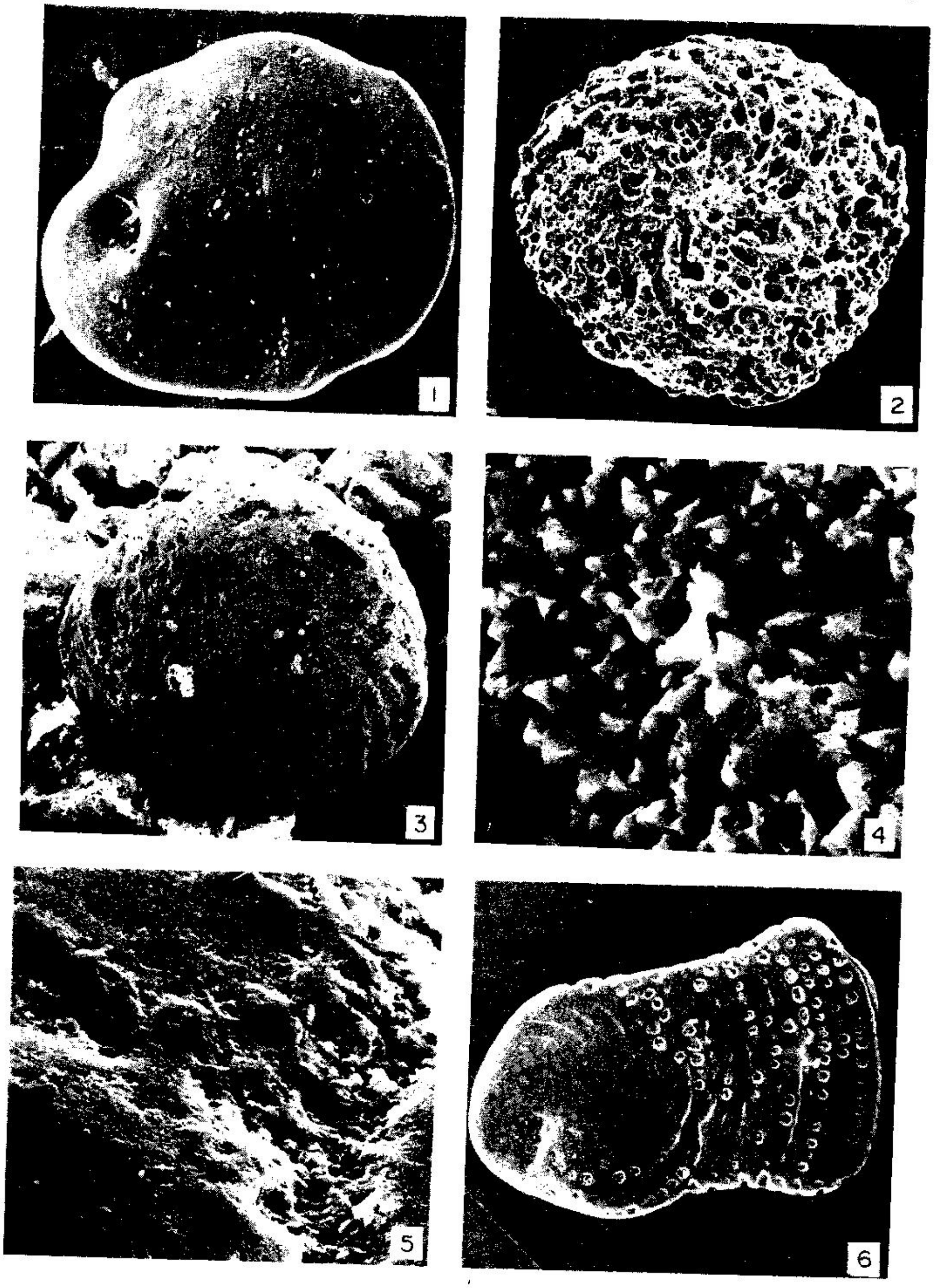
Fig. 3. A. angulatus (Fichtel and Moll), specimens with growing crystals of calcite on the surface, beach rock at Boqueron beach. x90.

Fig. 4. Detail of calcite crystal on the surface of A. angulatus in beach rock, Boqueron beach. x4000.

Fig. 5. A. angulatus (Fichtel and Moll), calcite coated and highly polished, glauconitized? It is not perforated by boring algae. Sta. JPR-76, x60.

Fig. 6. Detail on the surface of A. angulatus, showing part of the calcite coat worn showing the "pores." Sta. JPR-76, x60.

PLATE 4



CONCLUSIONS

The number of reef foraminifers (*Amphistegina* and *Archaias*) as suggested by the percentages, and the articulate coralline algae, have decreased in number from the Pleistocene to the present.

The percentages, and probably the numbers, of *Rotorbinella rosea* and *Asterigerina carinata* are higher at present than they were in the past. These foraminifers are characteristic of high energy areas. The increase in percentages of these two species in the living foraminiferal assemblages in relation to dead fauna suggests that the energy level at present is higher than it was in the past.

The distribution pattern of polished *Amphistegina*, coralline algae, total polished grains, and carbonate grains shows two belts of Pleistocene grains, one close to the coast and the other in the border of the insular shelf. The shallow belt close to the coast derives its sediments from dunes on land. The belt on the border of the insular shelf derives its sediments from older dunes whose ancient location is now below sea level and is separated from the shallow belt of polished grains.

The percentages of unpolished inorganic terrigenous fragments are higher than the percentages of polished inorganic terrigenous fragments. This indicates an increase in the rate of sedimentation of terrigenous materials from the Pleistocene to recent time. It is not possible to know if the increase has occurred slowly since the Pleistocene, or suddenly because of human activities. However, even if the increase has been caused solely by natural processes, human activities will increase land erosion. Thus, the rate of sedimentation of terrigenous materials in the study area will be increased more rapidly than by natural processes alone.

ACKNOWLEDGMENTS

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