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PREDICTION OF THE EFFECTS OF RESUSPENSION OF SEDIMENT DURING THE CONSTRUCTION PHASE OF A HYPOTHETICAL OFFSHORE POWER PLANT, WEST OF MAYAGUEZ, PUERTO RICO

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by

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FOREWORD

The marine environment is flexible and capable of withstanding many natural stresses. Man-made stresses are usually destructive, and ultimately return to affect man. The near shore marine environment is constantly existing on the fragile balance between a healthy state and an unhealthy state. For this case, this is the area of the marine environment most strongly and frequently affected by man.

The Marine Ecology Division of the Puerto Rico Center for Energy and Environment Research has as its dedicated goal the observation, prediction, and management alternatives of man-made stresses on the near shore marine environment.

This report serves to supply the observations and predictions of the effects of the construction phase of a power plant that would be constructed in the near shore marine environment.

Juan G. González
Head
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ABSTRACT

The purpose of this study was to evaluate those potential effects that would result from resuspended sediment during the construction phase, if an offshore nuclear power plant would be built west of Mayaguez, Puerto Rico, in the Cabo Rojo Platform.

During the study we developed water current predictions. We also evaluated sediment for grain-size, trace heavy metals, settling velocity, and sedimentation rate. The water was analyzed for trace heavy metals as well. The results of the above are a potential particle trajectory model, suggesting potential redeposition locations.

The conclusion reached from this study was that, except for sessile benthos near the actual construction site, and the seagrass, rocks and reef habitats to the north and south of the area, little negative effects would be felt during the construction of such a plant.

This report was submitted in fulfillment of contract No. D5-E681 by the Center for Energy and Environment Research under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from September 1975 to December 31, 1976, and was completed as of May 30, 1977.

CONTENTS

LIST OF TABLES

Tables (cont.)

LIST OF FIGURES

SECTION 1

INTRODUCTION

In recent times we, the world scientific and environmental community, have become aware of the importance and practicability of studying an environmental situation before a possible environmental insult could occur. Therefore, should the results of the analysis deem it necessary, the community could be prepared to take the necessary preventative or corrective action, take moderate precautions, or just be more aware of the potential problems, if the symptoms were to develop.

The subject of this report is a pre-environmental-insult study. There have been discussions as to the possibility of constructing, and subsequently operating, a nuclear power plant off the western coast of Puerto Rico. The area under discussion is called the Cabo Rojo Platform. Many questions arose during the Offshore Nuclear Power Siting Workshop (U.S. AEC, 1973) regarding just such a potential situation.

This report has, as its primary purpose, the assessment of possible environmental effects that would result from the resuspension of the sediment in the area during the construction phase of such a power plant, should it be built. In the report the physical area is described, with special emphasis given to those features to be used during the subsequent analysis. The study is divided into ten sections; the subject matter of each is used in the overall analysis.

The sediment is studied in detail, specifically with respect to the grain-size and possible contaminants. Also, the sediment settling properties are evaluated for salt water.

The study is concerned with the water as well. The emphasis is on the physio-chemical properties, as well as the current patterns in the area. Using these results, predictions become possible as to potential particle trajectories, indicating where the material may resettle.

Finally, the biota is considered and some conclusions are reached as to the possible effects on this biota from this potential environmental insult.

SECTION 2

CONCLUSIONS

The major conclusions of this study are that if the construction of a nuclear power plant should take place offshore, west of Mayaguez, Puerto Rico, in the northern basin of the Cabo Rojo Platform, the following would occur:

1. The bio-available trace heavy metals would show little change throughout the basin in the sediment or in the water. This is primarily due to the present low contamination levels in the area.

2. There would be little effect due to the sediment relocating in areas remote from the basin. This is because only a small amount of the material has been projected as having a reasonable probability of leaving the basin. Of this material that may leave, most, if not all, is less contaminated than the areas it may move into.

3. There may be a considerable build-up in fine sediment over the northern and southern boundaries of the basin. Some fine material would remain in suspension long enough to deposit onto the reefs, rocks, and into the seagrass beds, which form these boundaries.

These major conclusions suggest that there are two environmental problems which must be considered. The first problem is that of the biota of the rocks, reefs, and seagrass beds, and these habitats, themselves. These areas could be covered with a significant amount of sediment, as they lie across the northern and southern boundaries of the basin. These are the boundaries over which all the water must pass. The second problem is the direct effect on any of the sessile benthic organisms that may be buried by the large amounts of material that could settle rapidly to the sea bottom, especially near the construction area.

SECTION 3

RECOMMENDATIONS

There are three recommendations based on the work completed in this study.

A specific location for a power plant is necessary to determine the effects sought in this study. This work did more of a methodology study than a specific site study. The recommendation is to choose the exact location to determine the potential effects.

Little work has been done to determine the effects of excessive sedimentation onto specific benthic habitats. As increased resuspension of bottom material is becoming a larger by-product of man's exploitation of the sea, more work must be carried out to study this effect. The recommendation is to actually examine the direct effect of different size sediment loads on different benthic habitats.

Finally, no work was done in this study to determine the effects of increased suspended load to the primary productivity. This is a large and complex subject. The recommendation is to study the direct relationship between suspended inorganic solids and primary productivity. This should again be site specific, considering the specific sediment grain-size and the specific biota involved.

SECTION 4

DISCUSSION

In order to study the potential environmental effects of resuspending the sediment in the Cabo Rojo Platform, many items must be investigated independently, then integrated to determine how the potential environmental insult might affect the area. Those subjects studied were:

1. Physical description of the area.
2. Water masses.
3. Water currents.
4. Sediment origin and grain-size distribution.
5. Sediment variation below the sediment/water interface.
6. Particle settling velocity in sea water.
7. Sediment grain particle trajectory.
8. Analysis for trace heavy metals.
9. Foraminifers.
10. Benthos.

Physical Description of the Area

The Commonwealth of Puerto Rico, associated with the United States by bilateral agreement, consists of a main island and several smaller islands. These islands are all located along the Antilles Chain of islands, extending almost from Florida, U.S.A. to Venezuela, South America (see Fig. 1). Puerto Rico is approximately half way along the Chain, about 1700 km from Miami, Florida. The nearest large land mass to Puerto Rico

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Physical Description of the Area

The Commonwealth of Puerto Rico, associated with the United States by bilateral agreement, consists of a main island and several smaller islands. These islands are all located along the Antilles Chain of islands, extending almost from Florida, U.S.A. to Venezuela, South America (see Fig. 1). Puerto Rico is approximately half way along the Chain, about 1700 km from Miami, Florida. The nearest large land mass to Puerto Rico is the island of Hispañola, about 130 km to the west. The Chain can be considered the separation between the Atlantic Ocean and the Caribbean Sea. As Puerto Rico is situated along an east-west axis, the Atlantic washes its north coast, and the Caribbean, its south coast. At the latitude of about 18°N, Puerto Rico is in the trade wind belt, with both the winds and oceanic currents generally moving east to west past the island.

The main island of Puerto Rico is roughly rectangular in shape, about 180 km east to west, and about 60 km north to south. The island is a mixture of mountains, rolling hills, and broad flat plains. Where the plains meet the sea, the climate is typically tropical marine (except along the desert-like south-western coast). The sea surface temperature changes little from day to day, day to night, and even throughout the year. Each morning the sun rises over a warm sea and a cooler land mass. The land quickly heats up causing a convection cell to form bringing humid sea air landward. By late afternoon the land is cooling rapidly, causing the reversal of the cell, with the wind now moving seaward. Frequently during these landward excursions, the moisture rich sea air becomes saturated, and rain is the result.

The area of concern in this report-the Cabo Rojo Platform-lies off the western coast of the main island of Puerto Rico (Fig. 2). The Cabo Rojo Platform has a somewhat right-triangular shape (U.S. NOS, 1975). The "base of the triangle" extends almost due west from about the mid-point of the western coast. (This is the location of the coastal city of Mayaguez-the island's third largest population center.) This westward trend continues for about 25 km, and to a depth of about 35 m. During the next 1 km the depth drops quickly to 150 m, and the Mona Channel has been entered. The Mona Channel lies between Puerto Rico and the island of Hispañiola. The "hypotenuse of the triangle" travels from this furthest west point in a southeasterly direction to the southern shelf of the island. This occurs near Cabo Rojo, a point extending southward from the southwestern corner of the island. The third side of the "triangle" is the island's western coastline.

Along the eastern area of the platform are numerous *Thalassia* beds and runoff deposits of a terrestrial origin, extending from Mayaguez (the Yaguez and Guanajibo Rivers) to about half the distance to the above-mentioned drop-off. These shallows then change in character, becoming mainly coral reefs, and proceed more westerly and southerly. There are two other east-west shallow areas in the platform, south of this large northern rise. One serves to almost close off a northern basin. This occurs west of Punta Ostiones, and there is but a small channel through the reef and rock that is buoy marked. Tidal currents are given for this channel (U.S. NOS. 1976a). The more southerly east-west shallow area is not nearly as intensive, nor as obvious. It has numerous channels and large openings, but does serve to identify a southern basin.

The western area of the platform has a gradual seaward slope, with few shallows and obstructions. Near the southern edge of the platform the drop is from 25 m to 350 m in less than 1 km distance.

Both the north and south basins were under consideration as possible study areas, either separately or together. However, we chose to study the northern basin because:

(a) the time and effort required limiting the scope and area of the study,

(b) this basin appears to us to be a more probable power plant site,

(c) this basin is virtually enclosed, allowing a clearer evaluation of the potential problems.

The northern basin, seen in detail in Figure 3, is approximately square, with a portion of its northwestern corner removed. The basin is about 7 km north-south, and about 6 km east-west. Along the north it is bounded by Thalassia beds, and across the northwest corner lies Escollo Negro, a reef of only 1-3 m depth. The western boundary is made of reef and rocky outcroppings with depths of 1-3 m. The southern boundary is the aforementioned reef and rocky area west of Punta Ostiones. The depth here varies from 1-4 m. The eastern boundary is much less defined, as there is a gradual slope from the land. But, an arbitrary line can be drawn at the 10 m contour that runs almost exactly north-south. This material is primarily land runoff.

Water Masses

To better understand the oceanography of the platform, the water masses of the northern basin must be studied. The description of these waters, with their normal ranges of physicochemical parameters is always useful to describe the overall situation.

A cruise was conducted on 20 April 1976 aboard the University of Puerto Rico's R/V MEDUSSA. The purpose of the cruise was to collect hydrographic data in the northern basin of the Cabo Rojo Platform. Bottom grabs were also taken on this cruise, and will be discussed later. The stations visited are those shown in Figure 3. (Note-the station's name serves as both the abstract reference name-E for example-as well as the location within the basin-East for example.)

Water samples were taken from the surface (actually 1 meter below the surface), mid-depth, and bottom (actually 1 meter above the sediment/water interface). Two reversing thermometers (Watanabe Keiki protected type) measured temperature at each depth. These were attached to the Niskin type water sampling bottles. The accuracy of the thermometers is ± .02°C, after calibration. In some cases, only one thermometer was readable, due to malfunction.

The salinity was measured by using a Plessy Portable Laboratory Salinometer, Model 6220. The accuracy of this instrument is quoted at ± .002°/°°. The water samples were brought back to the laboratory to measure the salinity.

The results of this hydrographic cruise are presented in Table 1. The hour on-station is also shown in the table. The tidal current tables (U.S. NOS. 1976a) indicate that the tidal currents in the basin are moving to the north in the early morning (when the ship was in the northern sector), slack during mid-day (the ship was in the middle of the basin during this time), and moving southward during the afternoon (ship in the southern sector). Therefore, there is a good chance that the same water was being measured throughout the day.

Some observations from the cruise indicate that on this day there was but one total water mass moving in and through the basin. The range of temperature at the surface was 25.88-26.16°C or 0.38 C°. The range for the mid-depth was 26.81-26.16°C or 0.35 C°. The range for the bottom water temperature was 25.40-26.12°C or 0.72 C°. The total range throughout the water in the basin that day was 25.40-26.26°C or 0.86 C°.

The salinity range for the surface water was 36.010-36.092°/°°, or .082°/°°. The range for the mid-depth water was 36.036-36.127°/°°, or .091°/°°. The range for the bottom water was 36.032-36.093°/°°, or .061°/°°. The salinity range throughout the basin on that day was 36.010-36.127°/°°, or .117°/°°.

The density of the water can be described by values of sigma-t (σ_t) units. This measure takes into account the temperature and the salinity. The average sigma-t value for the cruise was 23.88. The values of the sigma-t varied by no more than 0.2 for any depth, and only 0.3 throughout the entire basin.

The minimum salinity and minimum density occurred in the surface waters at station NE. This is the water most influenced by the outfall of the Guanajibo River.

With all this evidence, it appears that during this time of the year, the water is moving in the basin as single water mass, with the only possible exception being that water from the Guanajibo River.

Table 2 contains data taken from past cruises into the area. This information was reported previously (Wood, et al., 1975). These data span an entire year (September 1973-November, 1974). During any one cruise, sometimes lasting up to two days, the magnitude of variation was similar to that of our April, 1976 cruise. This is an indication that there is always a single water mass moving through the basins regardless of the time of the year. There is some indication of a slightly greater stratification during the fall cruises, than the others. This slight stratification is not enough to consider a two layer situation.

Water Currents

In order to evaluate the trajectory of potentially resuspended sediment, it is necessary to know the current patterns in the area. Of what influence are the wind, tides, or other non-local effects, such as steady currents in the area? How large is the influence of nearby global-ranging currents? Are the currents seasonal? Do the currents vary with depth? These and other questions demand answers to properly evaluate a study such as this.

After evaluating many methods of current measurements, the current drogues appeared to be the best choice, when used in combination with the tide tables (U.S. NOS., 1976b) and the tidal current tables (U.S. NOS., 1976a). The primary hypothesis for this combination is that the water in the basin does move as one single mass, and that the bottom layer does move in coincidence with the top layer. Evaluation of the single layer model involved looking at the hydrographic data as well as using current drogues at various depths. If the water did, in fact, move as a single water mass, then the drogue measurements could be compared with the tidal currents and wind-driven currents. A positive confirmation from these two data sources would indicate that the tidal current predictions, with the superposition of wind drift, could be used to predict the water movement in the basin. It was hoped that this method would yield sufficient accuracy to apply to the particle trajectory concept for the resuspended sediment.

Drogue measurements of the currents in the northern basin of the Cabo Rojo Platform occurred on 14 and 16 July 1976. A schematic drawing of our drogue design is seen in Figure 4. The water sensitive surfaces are ballasted wooden panels set at right angles to each other. Each panel is .91 m by .91 m, giving a water sensitive area of from .83 m^2 to .64 m^2, depending on the panel's orientation to the actual current. These panels can be set to any reasonable depth, depending on the length of the connecting line. In our case, the depths used were near surface, 5 m and 10 m. A float and flag assembly sit at the water surface. In this case, the float was a standard inflated automobile tire inner tube. The total cross-sectional area, exposed to either wind or water at the surface, is about .08 m^2. This type of surface float is designed so that the wind sensitive area can be minimized by adjusting the inflation pressure of the inner tube. The single major disadvantage with the tube is its susceptibility to puncture. This never occurred. The flag is connected by netting arrangement to the tube, as is also the connecting line.

During the first of the measurement periods, we used three drogues. One drogue was set at (or nearly at) surface, one at 5 m and one at 10 m. Figure 5 shows the trajectories for the three drogues. As these trajectories indicate, the surface drogue did not behave as did the others. The water sensitive panel broke loose from this float, and the float was influenced primarily by the wind. The 5 m and 10 m drogues did follow the water pattern, to the best of our knowledge. The best possible time for analyzing the speed of the drogues is between 1230-1400. The drogues were moving in a southerly direction, and using the distances and times shown in the figure, the speed was 50 cm/sec at the 5 m depth and 59 cm/sec at the 10 m depth.

According to the tidal current tables, the tidal driven currents past Punta Ostiones should be as shown in Table 3. The days of concern are 14 and 15 July 1976. The table shows the speed, direction, and time of the currents past the Punta Ostiones buoy.

Except for a brief wind driven westward excursion during the time of slack tide, the two remaining drogues did follow a parallel path. Recalling that the two were set at 5 meters and 10 meters in depth, this does supply evidence that at least the water from 5-10 m moved as a single entity through the basin that day.

The next experimental period, 16 July 1976, had both of the two remaining drogues set at 5 m depth. The distance between the two drogues was 30 m upon starting. This distance varied from 15 m to 40 m throughout the day. Therefore, the two are shown as a single trajectory line in the Figure 6. In this case, from 1001-1046 the water was moving at 13 cm/sec, northerly.

To determine if the tidal current tables can adequately describe the water motion in the northern basin, cross-sections were taken at Buoy, Southern, and Central in Figure 7. The average depth and cross-sectional area at each line is shown on the figure. The tidal current tables give the current past the buoy on line Buoy. The total volume flow past this cross-section can be calculated. A factor of 0.87 converts the current past the buoy as listed in the tables, to that of the average current past the Buoy cross-section.

To compare the tables with the drogues, the volume flow rate is calculated past Buoy line at any time. This volume flow is corrected for the Southern line or the Central line by using the cross-sectional area ratio. Then the new velocity at the Southern or Central lines can be calculated, based on the tables for Punta Ostiones. These results are then compared to the calculated drogue speeds past that line at that time.

For the case of the 14 July measurements, the drogues' trajectories passed the Southern cross-section. The estimated average speed of the water (average of the two drogues) while passing this line is 54 cm/sec, at 1315. According to the tidal current tables the water velocity past the buoy at Punta Ostiones at that time was 60 cm/sec, southward. The average speed across the Buoy cross-section is 52 cm/sec (0.87 x 60 cm/sec). The average speed past the Southern cross-section is 36 cm/sec (63,000 m^2/90,000 m^2 x 52 cm/sec). The percent difference between these two determinations is 40%.

In the case of the 16 July data, the drogues passed the Central cross-section at 1045. According to the tidal current tables, the speed past the buoy at Punta Ostiones at that time was 22 cm/sec (50 cm/sec x 0.45 time correction). The speed past the Buoy cross-section was 20 cm/sec (22 cm/sec x 0.87). And the speed past the Central cross-section was calculated to be 15 cm/sec (63,000 m^2/84,000 m^2 x 20 cm/sec). The drogues were moving past this line at 13 cm/sec, which yields a percent difference of 14%.

The average percent difference for these two cases of comparisons is 27%. If this error is acceptable, a north-south component of the water current can be predicted in the northern basin. The prediction will be of direction, speed, and time, as well. This can all be done without the use of long-term expensive measurements. This procedure is highly recommended wherever conditions such as these prevail.

There is, at frequent times, an east-west component to the current. This component is wind-induced. The wind-induced currents have little effects on the overall water motion, and are most noticeable at periods of slack tide currents. (This is seen in the Cabo Rojo Environment Report (Wood, et al., 1975), where recording current meters were placed in the water for periods of a couple of days.) By assuming the trade winds are blowing westward with an average speed of 5 m/sec (U.S. NHO, 1958), and a typical 1% factor for the conversion of wind to water currents, the result is a possible steady 5 cm/sec westward component due to the wind. This value shall be used for the particle trajectory calculations.

It is very difficult to predict the effects of the predominant westerly currents moving past the island, in both the Atlantic and the Caribbean. On occasion these currents do affect our study area, but these situations are not too frequent, and are relatively unpredictable. This information will not be used for the particle trajectory prediction.

Sediment Origin and Grain-Size Distribution

Describing the potential effects of possible resuspension in this area necessitated a thorough study of the sediment. The sediment information is used to understand the source material, as well as its potential and redistribution effects.

During the aforementioned cruise of 20 April 1976, sediment grab samples were also collected at each station (Fig. 3). The samples were obtained using a Shipek Grab sampler. The sampler has an opening of 20 cm by 20 cm, and a total collection volume of about 3000 cm^3. One grab sample supplied many samples. Each station supplied at least one subsample (100 ml or 200-300 gm) for grain-size analyses. Also, during a cruise of 25 March 1976, aboard the R/V PALUMBO (PRNC/CEER), core samples were taken at the approximate location of our station C. The piston coring device contained a 6.3 m inside diameter tube. The maximum length core that we collected with this corer was about 1.5 m long. From one of the successful cores, subsamples were taken at 0.0, 0.3, 0.6, and 0.9 m below the sediment/water interface for analysis of grain-size distribution and many other measurements.

The grain-size analysis involved using the wet sieve technique first to separate the coarse fraction from the finer material. Pipetting further separated the finer fractions.

The wet sieve method (Griffiths, 1967; Folk, 1968) consists of washing a small sample of material with fresh water while sieving the material through screens of mesh size phi = -1, 0, 1, 2, 3, and 4. The wet sieving technique serves to wash the salt from the sample, to separate the small particles that have been consolidated into larger lumps, and to lubricate the grains during the sieving to prevent their being abraded against the mesh and each other. (The size unit, phi (Φ) = $-\log_2$ (diam. in mm). Table 4 contains the conversions from the phi size used in this study to millimeters and inches.)

The material remaining in each of the sieves is carefully removed and dried at about 80°C. The material that remains in the final pan, after passing through the phi = 4 sieve, is allowed to sit for an extended time while the sediment settles. The excess water is carefully decanted, and this very fine material is air-dried, with a subsample of about 20 gm being set aside for further analysis.

This fine material was separated into fine fractions using the pipette method (Griffiths, 1967; Folk, 1968; Carver, 1971; Shepard, 1963). The material used for this report was divided into sizes of phi = 4, 5, 6, 7, 8 and greater than 8. The results of the sediment grain-size analysis can be seen in Table 5. The table has listings for all eight stations, their average, and the four core subsamples. The stations are broken down by phi-size (columns) from $\Phi = -1$ to $\Phi = 8$. The finest material is shown as $\Phi > 8$. The information on the table is given in percent by-weight of the total sample. The upper-level number for each entry is the percent by-weight for the given phi-value for that station. The lower-level number for the entry is the accumulated percent, from $\Phi = -1$ toward the finer material (from left to right on the table). The final as cumulative value is shown at the right. The value for the phi-arithmetic-mean (M-Φ) for each station is shown in the extreme right column. Figure 8 depicts a graphical representation of the grain-size distribution for each of the eight stations in the northern basin. The graphs of phi-size versus percent within the given phi range are displayed on the figure. The relative location of the graphs in the figure is similar to the layout of the stations within the basin.

Figure 8 is useful in helping to interpret possible drift, movement, and sources of sediment in the northern basin. Moving southward along the eastern line (NE to E to SE) shifts the material from the mid-size grains toward finer material. The fine material is much more abundant at stations E and SE than any of the others. This can be seen in Table 5 where the M-Φ (phi-arithmetic-mean) shifts from 4.5 at station NE to 7.2 and 7.0 at stations E and SE, respectively.

The material at station W is definitely of a different composition (M-Φ =2.3). This station lies adjacent to an area of reef and rock, and the sediment is composed of larger shell fragments not found in the same abundance at other stations. Station SW has more coarse material than the eastern stations, but not nearly as much as station W. Station W has more fine material than the western stations, but more coarse material than the eastern stations. Station C is possibly a mixture of the material source to N and the material source to W. The material at station S seems to be very poorly sorted, and very evenly distributed with respect to grain-size, with contributions from probably the north, east, and west. This station is situated near the southern entrance to the basin, with only a small opening in the reef, and the water moves at a higher speed near here than elsewhere in the basin. This is probably the source of the excellent mixing of sediment material.

In summary, it appears that the finer material may be entering the basin from the eastern side, from either land run-off, small creeks in the area, or from the Guanajibo River. From this eastern edge, the material moves usually southward, and then is swept along the southern boundary of the basin. From here, it is either evenly distributed on a northward tide or carried out of the northern basin to the south. The coarse material is probably entering the basin from the western edge, and moving north and east into the central area. The central area appears to be a mixing zone for the two main sources.

There appears to be no difference in the vertical distribution of material. The results of the analysis for the four core samples are shown in Table 5. The surface core sample (C-0) does have a tendency to peak more toward the midsizes than toward the coarse or fine material, but not to any important degree.

During this analysis, there were many possible sources of error. We were on alert for the obvious ones, the not-so-obvious ones could have caused some problems. Some possible sources of error in this grain-size analysis are:

1. Non-representative sample.
2. Failure to eliminate clumps of small grains.
3. Loss of material while removing from sieves.
4. Loss of material while decanting off the water.
5. Insufficient removal of salt (poor washing).
6. Errors in mass measurements.
7. Incorrect penetration distance for the pipette.
8. Incorrect timing for the pipette action.
9. Unequal weight gain during temperature equilibration after drying.

Analysis for calcium carbonate helps show the origin of the sediment. It may also help predict the influence the material might have when it is redeposited in a new area. We analyzed samples from each of the eight stations and the four core subsamples (Fig. 3). We followed the procedure described by Carver (1971), and each sample had a comparison replicate.

We measured the weight loss after washing, dissolving with hot acid, heating, decanting, and drying the material. Our hypothesis was that this weight loss was due entirely to the calcium carbonate dissolving in the acid (Carver, 1971). Figure 9 shows the results of this work, as does Table 6. The table contains the values for the percent by weight of calcium carbonate in each of the replicate pairs. These average values appear in Figure 9, showing the calcium carbonate tending toward a minimum along the eastern and southeastern sectors of the basin. The values rise to the west, reaching maximums at stations W and C.

Within this basin, it can probably be assumed that the source of the calcium carbonate in the sediment is biologically- and marine-formed. This material was probably produced by Molluscs, algae, corals, Foraminifera, silica spicules, etc., (Shepard, 1963; Twenhofel, 1932). The material is probably being formed along the western edge in the reefs and rocks and is then deposited. The larger materials are found at station W, and the smaller are found at station C. This is due to the drift of the water when reaching the cut-off northwestern corner. The water at this corner is probably diverted somewhat to the east toward stations C and N. Also, the heavy, larger material descends through the water column faster than the smaller material, hence it is found at station W and the smaller at station C, "downstream" from station W.

The terrestrially derived material containing little calcium carbonate is probably entering the eastern edge and moving basically south and west. There is some mixing with the calcium carbonate material in the central areas.

The lower portion of Table 6 shows the calcium carbonate content of the sediment below the sediment/water interface. These are the values from the four core samples. The average value for the surface sample, Core-0, is 77.6%. The average value then decreases to Core-90, where it is only 60.2%. At first impression it appears that there is a real decrease in the calcium carbonate deposition with time. Bathurst (1971) has found similar results occurring off Florida and the Grand Bahama Banks. A possible explanation is that the sediment settles, and is then covering already existing sediment. This new material now removes the old material from direct contact with its major source of oxygen, the water. As the benthic organisms respire, and oxidation of organic matter continues, the available oxygen is slowly consumed. Therefore, an excess of carbon dioxide remains. The environment becomes more acidic, and the calcium carbonate appears as a constituent of the buried sediment. Using this model, the evidence does not show that the rate of calcium carbonate deposited in previous times is any different from now. The actual amount may have been somewhat less, but the evidence is inconclusive.

As can be seen in Table 6, some of the replicates at a particular station show considerable differences. An example of this is station SW. One replicate has 52.5% calcium carbonate, the other has 64.4%. The most accepted reason for such a large variation from the same sample is the occurrence of one or two large shell fragments in the replicate which registered the higher value. This would certainly produce such a result.

Other possible sources of error in this procedure are:

1. Sediment loss during decanting.
2. Insufficient salt removal from sediment.
3. Insufficient dissolution of calcium carbonate.
4. Unequal shell fragments in the replicates.
5. Errors in mass measurements.

Particle Settling Velocity in Sea Water

In order to determine the trajectory of any resuspended material in the northern basin of the Cabo Rojo Platform, the settling velocity for the resuspended sediment in sea water must be known. A literature search failed to provide data for material as is in this basin, so the settling velocity had to be determined experimentally.

We proceeded in the direction of first assuming that in distilled or fresh water the settling velocity of the sediment particles follows Stokes' Law (Carver, 1971). However, in sea water, there is a tendency to build up ionic charges on the individual particles. Rather than settle as individuals, the particles tend to clump together and react as a larger single particle. This clump falls at a much different rate in sea water than the individual particles in fresh water--usually much faster.

We thought that if a representative sample of the sediment material from the Cabo Rojo Platform could be analyzed in both distilled/fresh and ambient sea water, much information could be obtained comparing the fresh water settling rates (Stokes' Law) with the settling rates in sea water--or those settling rates that would actually occur in nature.

A sample of the fine fraction ($\Phi \geq 4$) of sediment from station C was carefully washed, mixed, and divided into two portions, each containing about 20 gm. The first portion was re-washed in distilled water, mixed, and allowed to set for a few days in the distilled water. The second portion was given the same treatment in Cabo Rojo sea water. This setting allowed the sediment and water to come to chemical equilibrium.

Some of the water was decanted, and the individual portions were then poured into their respective settling tubes of fresh or sea water. The pipette technique was again used to fractionate the samples by size. Seven pipette draws were made from each of the two tubes. Table 7 gives the cumulative percent by weight in each of the seven draws for both the sea and fresh water. In the case of fresh water, the cumulative percent of material versus sediment particle size is shown in Figure 10.

Because each pipette sample was drawn at the same time from tubes, the same settling characteristics (velocity) can be said to exist for the matching pipette draws, although each may be associated with a different grain-size. The velocity characteristics of the first pipette draw in the fresh water corresponds to that of the first pipette draw in sea water, etc. However, the cumulative percent of material in the sea water tube did not follow that of the material in the fresh water tube, but increased faster. Therefore, a given percent of the same material in sea water was settling faster than the same percent of material in fresh water. (Recall that the actual material in each tube is assumed to be of the same size distribution.)

On the curve seen in Figure 10, the circled numbers indicate the pipette draws from the fresh water tube, and the squares indicate the sea water tube. Each circle (fresh water draw) gives three bits of information. Its value along the abscissa corresponds to the grain-size. This is determined by using Stokes' Law (Carver, 1971) and using a pre-set formula for deciding when and how deep to draw into the testing tube. The ordinate value is the cumulative percent of the sediment by weight, starting from the coarse material. This is determined mathematically from the actual amount remaining after the material drawn is dried and weighed. Of course, the last bit of information is the number of the pipette draw. This number is found inside the circle.

For the salt water case, there is also multi-information. The number within the square indicates the pipette draw number. The location along the ordinate indicates the cumulative percent, as in the fresh water case, and the grain-size value corresponding to the square indicates the same as for the fresh water.

A careful look at the figure uncovers that the first three pipette draws for both conditions are similar. The fourth and fifth draws are quite different. The fourth draw for sea water has the same cumulative percent as the sixth draw for fresh water. This means that the fourth draw involves material falling at a rate calculated in the fresh water (4th draw). But the material involved in sea water is of a much finer size, $\Phi = 7$. The particles are settling at a rate of .05 cm/sec, and in fresh water this corresponds to a size of $\Phi = 5.5$. Similarly for the fifth pipette draw from the sea water, and the seventh draw from the fresh water.

Following this reasoning, the estimated settling velocity of the sediment is shown in Table 8. This table shows the settling velocity in both the fresh water and in sea water versus the grain-size.

Sediment Particle Trajectory

One of the most important subjects of this report is the determination of the expected particle trajectory for the resuspended sediment. In this section, an attempt will be made to make a reasonable estimate of this trajectory, as well as predict the new location of the resuspended material, after it has again settled to the bottom.

In making this estimate, the following assumptions were made for the northern basin of the Cabo Rojo Platform, based on information learned during this study:

1. The water moves as a single mass throughout the basin. The currents are similar from top to bottom in the water column. The water current studies seem to confirm this.
2. The east/west cross-sectional area across the basin is always the same, regardless of latitude. A given north-south current near the southern

section will result in essentially the same current in the central or northern section of the basin. This may introduce a possible error of up to 25-50% in velocity for the worst cases, but it simplifies the calculations considerably.

3. The times for the maximum and slack tidal currents in the basin are those shown in the tidal current tables for the Vieques Passage, Puerto Rico, with the appropriate correction for Punta Ostiones, Puerto Rico.
4. The maximum current speeds are assumed to be always the same, the listed average is .5 m/sec, and this will be used. This is for both ebb (southward) and flow (northward) tidal periods. This is accurate for an average, but the actual values may range from .2-.9 m/sec.
5. The tidal period is semi-diurnal. This is based on the tide tables.
6. The tidal current follows a sine curve, having a maximum speed of .5 m/sec, and a period of 12 hours. The exact 12 hours is to again simplify the calculations.
7. The wind-driven currents have a magnitude of 1% that of the wind velocity. The wind is steady out of the east at 5 m/sec (10 knots) producing a continuous .05 m/sec westward water current in the basin.

8. There are no currents in the basin other than the observed north-south and wind-driven westerly currents. This is not always the case, but other currents in the area are very unpredictable as to frequency and magnitude.
9. During the proposed "construction", a mass of unconsolidated, but contiguous sediment would be raised as a single entity to the surface, then allowed to fall as individual particles.
10. The boundaries to the north, south, and west of the basin have depths of 3 meters.

Some results of the predictions are seen in Table 9. The table shows the estimated percent of the material from each of the stations that may be carried out of the basin. Also, the direction of departure and percent of time each day that such a redistribution could occur is also seen. Of all the material in the basin, only that material of a size $\Phi = 7$ or finer would remain in the water column long enough to be carried out past the basin boundaries. Also, in all cases--except station W--the northern stations appear to lose material only to the north, and the southern stations appear to lose material only to the south. By the time the water would move from the southern stations to the northern boundary, it would have lost its sediment load. The case of station W is an anomaly. This station is located directly south of a diagonal boundary cut-off. For this reason, the material from this station is lost over the northwestern corner.

It is also noteworthy to mention that, except for the material of size $\Phi = 4$ and larger, much of the finer material will be re-deposited within the basin, but not onto the boundary areas, such as the reefs, rocks, and Thalassia beds. The larger material will be more randomly distributed throughout the basin, with much falling back to the bottom near its original resting place.

The last column in Table 9 contains the percent of time of each day, or actually a probability time-function, that the indicated activity could exist. These values verify that the rest of the prediction is an upper limit, occurring only part of the time. For example, if the currents are moving northward, and the material is resuspended from station N, some may be carried out of the basin. However, if the currents are slack or moving southward, no material will leave the basin. The last column shows the maximum percent of the time that the material could be swept out of the basin.

It is also important to see that based on these assumptions, no material would be lost out of the basin if the construction took place near either stations C or E, or actually almost anywhere along this line, except south of the northwestern corner.

Analysis for Trace Heavy Metals

During the hypothetical construction and resuspension, the sediment will be lifted and moved from its original position. The sediment may be associated with various contaminants, specifically heavy metals. Some of these metals occur in trace amounts in nature and are necessary for the survival of aquatic organisms. However, if the amount of the heavy metals exceeds certain limits (different for each organism), adverse effects can result. In order to assess their potential environmental significance arising from resuspension and resiltation, an analysis was made of the trace metals in the sediments and water of the northern basin of the Cabo Rojo Platform.

The resiltation of the sediment and/or the mixing of the sediment with the water column could cause changes in the amounts of these trace heavy metals throughout the water column and sediment layer. In this connection, the amounts of various heavy metals were determined for samples of surface sediment (see Fig. 3 for stations), for sediment as a function of depth below the sediment/water interface (from a core at station C), and from the water column (water sample from mid-depth at station C). The surface sediment was part of the material collected during the cruise of 20 April 1976, as was the water. The core material was abstracted from a one-meter-long core collected on 25 March 1976.

The original surface and core sediment samples were oven-dried (95°C) and triplicate subsamples of 3 grams each were acid-digested to obtain total metals. The samples were subjected to a successive treatment with inverse aqua regia (3 HNO_3; 1HCl), hydrogen peroxide and 2N HCl to accomplish total dissolution of the material. Finally, they were centrifuged and the supernatant was saved for analysis. Determinations were performed on a Perkin-Elmer Atomic Absorption Spectrophotometer, Model 303 on an air-acetylene flame. The instrument featured deuterium arc background correction. Blank samples were carried through the procedure for systematic corrections. Chromium, zinc, nickel, copper, lead, and cadmium were the unknown metals sought in the sediment.

The water analysis determined the concentration for zinc, copper, lead, nickel, cadmium, iron, manganese, and cobalt. These metals were chelated with ammonium pyrrolidine dithiocarbamate (APDC) and concentrated by extraction into a small volume of methyl isobutyl ketone (MIBK) using a method adapted by López (1973) from that suggested by Standard Methods (APHA et al., 1971). We placed triplicate 150 ml sample portions in 250 ml volumetric flasks and adjusted the pH to 2.5 ± .01 using a 0.2°/°° bromophenol blue indicator in alcoholic solution. The color was adjusted to blue by dropwise addition of NH_4OH (30%). The samples were backtitrated with HCl (2.5%) until the blue color just disappeared. At this point, addition of 1.01 ml of 2.5% HCl brought the pH to the desired value. A freshly prepared solution of APDC (2%) was twice extracted with appropriate portions of MIBK, and the organic phase discarded. A 5.0 ml portion of the APDC solution was added to each flask and mixed. This was followed by a 10.0 ml of MIBK and vigorous shaking on a wrist-action shaker for 5 minutes. The phases were allowed to separate. We then added deionized water to bring the organic phase up to the neck of the flask for direct aspiration into the atomic absorption flame. A blank and standard addition made on water of the appropriate matrix were carried through the procedure.

Table 10 shows the results of the analysis for trace heavy metals in sediment. The mean concentration (N=3) for the selected metals is given in mg/kg. The standard deviations show the precision of the analysis. The table also shows the measurement detection limits for each of the metals. In addition, the U.S. EPA Region VI (Dallas, Texas) proposed guidelines for determining the acceptability of dredged sediment (cited in López, 1976) is given in the table for comparison. These criteria, although not directly applicable, provide a useful guideline as to the expected potential significance of sediment resuspension in a water column.

The values presented represent total metals present in the sediment. These values do not necessarily bear any simple relationship to the potential contamination of the water by the sediment, should resuspension occur. In general, the results indicate the sediment is relatively uncontaminated with heavy metals, since similar levels of these same metals are found in areas known to have little or no pollution influence (López, 1976).

The quantites of lead and cadmium are close to naturally-occurring levels, and are distributed uniformly throughout the basin and with depth. This implies there is little, if any, foreign or un-natural inputs of Cd into the area in the far or recent past.

The other metals, chromium, zinc, nickel, and copper indicate an apparently significant enrichment along the eastern edge of the basin and to the south (Stations NE, E, SE and S). This appears to follow closely the probable path of water coming from the land-based sources (Guanajibo River and rain runoff). Kattman (1972) and Giullou and Jewell (1957) confirm that there is a high concentration of these heavy metals in the watershed of the Guanajibo River and near shore in the hills where direct runoff is possible.

Examination of heavy metals concentration in the core samples (C-0 to C-90) shows little or no change with depth for most of the metals. These data (Table 10) show no change in chromium, copper, lead, or cadmium. There is an apparent increase in zinc and nickel concentration as a function of depth from the surface of the sediment. This may be attributable to the increased land usage for agriculture or housing, causing an increase in the metal content of the runoff because of lack of normal vegetation. One other likely source is the increased use of tin roofing material in the area over the past century.

Generally, it can be said that the sediment in the area is not contaminated with excessive amounts of heavy metals. Comparing the results from this study with the proposed guidelines for determining the acceptability of dredged sediment for disposal into the ocean (EPA-cited in López, 1976), show that only copper and nickel exceed the suggested EPA limit (Table 10). It must be noted that these criteria represent sediment concentration limits beyond which the resuspension of sediments may be expected to result in a water quality problem from the point of view of aquatic life. However, this type of criteria is also questionable as the implication that a greater metal concentration will result in a greater metal release to the water column may be a geochemical oversimplification. Based on the above information, it can be said that little or no direct effect can be expected in the water column due to the resuspension of these sediments, as far as the trace heavy metals is concerned.

The results of the analysis for trace heavy metals in the water are shown in Table 11. This table shows the total metal concentration for the selected metals as the water was not filtered to exclude the non-dissolved fraction. The second column of the table shows the average value of the concentration of the metal considering the three replicates. The third column is the standard deviation of the three replicates. The fourth column is the value of the concentration for these metals for typical sea water (Horne, 1969). The fifth column is the proposed maximum acceptable limits of the concentration of each of the metals (U.S. EPA, 1975). This last column has units of either μg/ℓ or fractions of the concentration. In some cases, the criterion is a fraction of the 96 hr LC_{50} Standard Methods for the most sensitive important animal of the locality.

The trace heavy metal concentration found in the northern basin of the Cabo Rojo Platform is higher than typical sea water values. However, the nearness of the metal-rich coast is a great influence on this enrichment. Also, in all cases, (using similar water and temperature) the concentrations we found were lower than the EPA proposed limits, and in many cases as much as ten times lower.

The true environmental significance of the trace heavy metals is their bio-availability to aquatic life. Once the material becomes available within the water column, the next significant feature is the relative toxicity of each existing chemical species. For instance, it is generally felt that the particulate forms of the elements are less available for uptake by floating and swimming organisms. These particulate forms are often strongly bound to materials like clay-minerals and other inorganic precipitates that are not assimilable by these organisms. Likewise, by being bound in this fashion, the potential toxicity of these elements is effectively reduced as they are removed from the water column by sedimentation and their chemistry also changes. Jenne (1968) and Lee (1975) have treated this subject in detail with particular reference to the role of ubiquitous hydrous oxides of iron, manganese, and aluminum in controlling the concentration of trace heavy metals in natural water systems.

In general, the free ionic form of a metal is usually its most toxic form. This is followed in toxicity by other dissolved forms, which may be variously complexed by either organic or inorganic ligands. These chemical forms are usually readily bio-available.

Conclusions regarding the trace heavy metal results are that if the construction of an offshore power plant would occur in this area, there is little or no significant addition of bio-available trace heavy metals. The sediment is below the "proposed" limits of heavy metal concentration (except for copper

Of the eight stations observed, only three showed any living foraminifers. They were stations W, E, and SE. Normally, this kind of result would give rise to the suggestion of severe pollution at the other stations. However, the most probable cause of this lack of live fauna was that the grab sampler may have penetrated too deeply into the sediment, thereby passing the upper few centimeters of sediment where the living foraminifers are found. A second strong possibility as to the lack of the living animals is that the sediment/water interface may have been washed out of the sampler while being brought up through the water column and onto the vessel.

The results of the observations for the living foraminifers can be seen in Table 12. Table 13 is shown here for comparison, and is taken from Seiglie (1970) showing his results for the stations near our own in the Cabo Rojo Platform. Our station E corresponds to Seiglie's CR-13, and our station W corresponds to Seiglie's CRT-15. Both similarities and differences can be seen between the two tables.

The investigation of the core produced only one living foraminifer at the surface. This also was probably due to the collecting technique. The dead animals within the core seemed to be uniformly distributed with respect to type from the top to the bottom (0-90 cm).

They consisted of:

Foraminifers:

Quinqueloculina cf. *tricarinata*

Q. cf. *bicostata*

Q. cf. *lamarckiana*

Q. cf. *candeiana*

Pyrgo comatula

Others:

Tagelus divisus (bivalve)

Dentalium antillarum (scaphopod)

Turrilella exoleta (gastropod)

Bulla sp.

Caucum sp.

Cirripeda

Table 14 shows an accounting for all the animals at the three aforementioned stations, E, W, and SW.

A summary of the results of the foraminifer study indicates:

a) Little actual pollution is currently influencing the basin, except possibly near station SE, where a large number of *Florilus grateloupii* was found. According to Seiglie (1974), this species may be a pollution indicator, if the count continues to increase. Station W experienced few of these animals at this time (3%), but in 1970 (Seiglie) there were almost 7%. Furthermore, *Fursenkoina pontoni*, which was found at the 1-2% level in 1970 is not found at all now. Increasing abundance of these has also been related to pollution.

b) As seen in Seiglie (1974), there may be a relationship between the total number of animals found in a sample and the ambient pollution. The general trend being that the lower number of animals, the more the area is influenced by pollution, all other things being equal. From Tables 12 and 14, it can only be said that if there is any influence at all, it is only slightly indicated and again at station SE.

c) From Table 14, the number of nematodes can be compared to the number of foraminifers. For all given cases, the nematodes far outnumber the foraminifers. This is usually a strong indicator that the area is virtually free from any significant man-made pollution, or its influence.

d) The examination of the 90 cm of the core failed to reveal any difference between the origins and mechanisms of sedimentation from the time necessary to deposit 90 cm of sediment and now. The animals found in the core appeared to be uniformly distributed throughout its length.

Sediment Variation Below the Sediment/Water Interface

Studying the properties of the sediment and the variation of these properties with depth below the sediment/water interface involves studying samples from the grab and core data, as well as looking far beneath the sediment surface.

Coring attempts yielded only a maximum 1-1.5 m cores. Four subsamples from a 1 meter core have been analyzed for grain-size, calcium carbonate, foraminifers, and trace heavy metals. The results of each of these analyses are discussed in their respective sections of this report. Only a summary of each will be given in this section.

The sediment grain-size analysis (Table 5) shows no variation with depth that cannot be explained by sampling technique. Calcium carbonate content in the sediment appears invariant with depth (Table 6), if the pH and available oxygen are taken into account. The variation in trace heavy metals with depth (Table 10) appears negligible, with the exception of the zinc and nickel concentration. This was discussed in the trace metal section. The Foraminifera analysis showed change in neither fauna nor number of fauna with depth along the core.

Therefore, from this evidence--although it is only from about one meter depth--there is no reason to believe that there has been any change in the sources, mechanisms, or rates of deposition in the recent history of the northern basin of the Cabo Rojo Platform.

The second method to evaluate the sediment's characteristics with depth considered the history of the basin. Historical dating as well as sub-bottom profiling were put together to give a first approximation as to the estimated "life" of the basin.

Carbon-14 dating on a sample of sediment taken from the one meter depth indicates that the sediment at that depth is 2110 $\pm$ 80 years old. From this information, it is estimated that the deposition rate in recent history has been .047 $\pm$ .002 cm/yr, or about 0.5 m/1000 yr.

Communication with Mr. James V.B. Trumbull of the San Juan Puerto Rico Office of the U.S. Hydrographic Survey, produced a sub-bottom profile along the line indicated by dots in Figure 2. No attempt will be made to reproduce the profile in this report, as the loss in quality and readability would be too great. The depth of the bottom of the unconsolidated sediment can be calculated from these seismic profiles. The velocity of the sound in the sea water is taken to be 1700 m/sec (Shepard, 1963). The depths of unconsolidated sediment are shown in Table 15 for values every 350 m along a north-south line through our study area. The values of the depth of this sediment ranged from 153-424 meters with an average depth of 274 meters.

Using the information obtained by the carbon-14 dating, and the estimated settling rates, the age of the sediment sitting directly on the bedrock in the northern basin of the Cabo Rojo Basin is estimated to be about half million years old, assuming that the same mechanisms, sources, and rates apply from the 1 meter depth down to the sediment/bedrock interface.

Possible sources of error in this analysis are:

1. Speed of sound in sea water.
2. Readability of thickness of sediment in the seismic profile.
3. Location of distance and position in the seismic profile.
4. Measurement of length of the core sample.
5. Carbon-14 counting.
6. Assumption of "no variation in sediment" between 1 m and bedrock.

Benthos

The resuspension and recirculation of the marine sediment that could and would occur during an offshore construction job would affect the relatively slow moving or stationary organisms living on the ocean bottom. These benthic organisms, or benthos could be affected by the siltation causing smothering and/or reduced light penetration. The siltation could smother such sessile organisms as corals, gorgonians, sponges, and algae. The reduced light penetration could affect the photosynthetic capabilities of algae associated with the coral and gorgonians. Furthermore, the resuspended sediment could completely cover otherwise available and usable substrate, needed for the settling of larvae of sessile organisms. Also, the removed or destroyed food sources could then affect the plant and invertebrate population, and ultimately the higher food chain organisms such as fish or even man. These reasons called for at least a preliminary examination of the benthos in the northern basin of the Cabo Rojo Platform.

During the sediment/hydrographic cruise of 20 April 1976, bottom grabs were also taken for analysis of the benthos in the area. The sampler was the same Shipek grab, with an area of .04 m^2. Three replicate grab samples were taken at each of the eight stations indicated in Figure 3. Each of the grab samples was washed through a screen of 1.5 mm mesh and the residue was preserved in 70% ethanol solution. Laboratory analysis separated the living organisms and classified them to the lowest reasonable taxon.

The results of the analysis and identification are shown in Tables 16 and 17. Table 16 has the identification for each of the three replicate samples at the eight stations. Table 17 intercompares the occurrence of the different species with the stations.

Thirty-six different species representing seven animal phyla and one plant phylum were collected in the sampling area. The most common species were represented by the Pelecypods (9 species), polychaetes (8 species), and ascidians (7 species). The polychaetes were present at all stations, and a total of 19 specimens were collected. Station W had the largest diversity with 10 species, while the lowest was at station S with only three species. Of the 36 species collected, 10 were sessile organisms. These can be directly affected by the siltation. In the specific case of _Halophila baillonis_, a seagrass, and the only representative of the plant kingdom collected, the reduced light penetration can also be detrimental.

Since _H. baillonis_, as well as coral reefs and _Thalassia testudinum_ beds are found on the bottom, their photosynthesis (in the case of corals, the zooxantella associated with it) and growth would be limited by the available light, all other things being equal. Turbidity and siltation reduce the light penetration to the bottom, and would reduce the primary productivity of the seagrass beds and reefs.

Furthermore, corals are able to survive for short periods when covered with sand and sediment (Edmondson, 1921; Vaughan, 1916; Marshall and Orr, 1931). This survival is accomplished by removing the sediment from their surfaces. However, data is not available as to how much sediment an organic reef can remove when experiencing high rates of siltation.

It has been shown, also, that sponges and ascidians could be adversely affected by sedimentation, especially due to the clogging of their canals and chambers, along with their total burial (Bakus, 1968).

The most obvious sources of error in this benthos study are the sampling methods. Using a grab sampler of only 20 cm by 20 cm will cause the data to be highly insensitive to naturally occurring patchiness, as well as more mobile ones.

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TABLE 1. Hydrographic data from the cruise of 2[illegible] April 1976 into the northern basin of the Cabo Rojo Platform.

Station	Depth (m)	Salinity ($^{o}/_{oo}$)	Temperature (°C)	Density (σ_t)	Time on Station
C (20m)	1	36.073	26.09	23.84	1225
	10	36.069	25.86	23.92	
	19	36.067	---	---	
N (13m)	1	36.036	25.88	23.89	0930
	5	36.049	---	---	
	12	36.032	25.40	24.03	
NE (14.5m)	1	36.010	26.24	23.74	1020
	7	36.036	25.81	23.90	
	13	36.035	25.48	24.01	
E (13m)	1	36.081	26.02	23.87	1120
	6	36.076	25.96	23.89	
	12	36.076	25.92	23.90	
SE (12m)	1	36.061	26.19	23.80	1615
	6	36.127	26.16	23.86	
	11	36.076	26.12	23.84	
S (17.5m)	1	36.092	26.26	23.81	1530
	7	36.084	26.08	23.85	
	16	36.093	26.04	23.86	
SW (22m)	1	36.077	26.07	23.86	1440
	11	36.081	25.92	23.90	
	21	36.052	25.80	23.92	
W (22.5m)	1	36.059	26.06	23.84	1350
	10	36.041	25.87	23.89	
	21	36.048	25.63	23.97	

TABLE 2. Hydrographic data from previous cruises (Wood *et al*., 1975) into the northern basin of the Cabo Rojo Platform.

Station (PRNC)/Current)	Depth (m)	Temperature (°C)	Salinity (°/₀₀)	Density (σ_t)
-September 1973-				
CRP-9B/N	0	29.21	35.167	22.14
	10	29.12	35.223	22.21
CRP-8B/C	0	29.26	35.128	22.10
	10	29.13	35.148	22.15
CRP-7B/S	0	29.25	35.066	22.05
	10	29.03	35.085	22.14
-January 1974-				
CRP-9B/N	0	25.47	35.138	23.32
	10	25.46	35.188	23.36
CRP-8B/C	0	25.43	35.141	23.34
	10	25.43	35.134	23.33
CRP-7B/S	0	25.47	35.173	23.35
	10	25.42	35.160	23.35
-April 1974-				
CRP-9B/N	0	26.58	35.796	23.47
	10	26.26	35.763	23.55
CRP-8B/C	0	26.48	35.797	23.50
	10	26.37	35.792	23.53
CRP-7B/S	0	26.48	35.817	23.52
	10	26.32	35.812	23.57
-November 1974-				
CRP-9B/N	0	27.05	34.033	22.00
	10	26.95	34.029	22.03
CRP-8B/C	0	27.17	33.744	21.74
	10	26.99	34.072	22.05
CRP-7B/S	0	27.12	33.810	21.81
	10	26.92	33.885	21.93

TABLE 3. Tidal currents past Punta Ostiones during the period of our current measurements (from Tidal Current Tables, U.S. NOS, 1976a).

Slack Time	Maximum Current Time	Velocity Speed-Direction (cm/sec-deg)
----------14 July 1976----------		
----	0616	60-000
1017	1245	60-189
1640	1844	30-000
----------16 July 1976----------		
----	0738	50-000
1127	1407	60-180
1813	----	

TABLE 4. Conversion of phi (ϕ) units to metric and English units.

Phi (Φ)	Metric (mm)	English (inches)
-1	2	.07874
0	1	.03937
1	.5	.01968
2	.25	.00984
3	.125	.00492
4	.0625	.00246
5	.0312	.00123
6	.0156	.00062
7	.0078	.00031
8	.0039	.00015

TABLE 5. Results of grain-size analysis for sediment in the northern basin of the Cabo Rojo Platform. (Upper value is percent, lower value is cumulative percent.)

STATION	Φ=-1	Φ=0	Φ=1	Φ=2	Φ=3	Φ=4	Φ=5	Φ=6	Φ=7	Φ=8	Φ=8	MΦ
C	9.8	2.6	3.8	3.9	8.4	32.5	18.3	4.9	5.8	4.4	5.4	4.5
	9.8	12.4	16.2	20.1	28.5	61.0	79.3	84.2	90.0	94.4	99.9	
N	3.8	5.9	11.6	12.1	17.2	26.0	11.3	3.0	3.6	2.2	3.1	3.8
	3.8	9.7	21.3	33.4	50.6	76.6	87.9	90.9	94.5	96.7	99.8	
NE	2.4	2.2	3.6	7.4	30.1	27.6	9.8	0.6	7.6	3.5	5.0	4.5
	2.4	4.6	8.2	15.6	45.7	73.3	83.0	83.6	91.2	94.7	99.7	
E	0.0	0.0	0.1	0.1	0.9	16.8	20.1	7.1	13.0	11.0	31.0	7.2
	0.0	0.0	0.1	0.2	1.1	17.9	38.0	45.1	58.1	69.1	100.1	
SE	0.6	0.1	0.1	0.3	1.1	13.3	23.0	10.2	16.8	12.6	21.5	7.0
	0.6	0.7	0.8	1.1	2.2	15.5	38.5	48.7	65.5	78.1	99.6	
S	6.2	5.7	8.1	11.6	7.2	14.1	16.0	6.5	7.9	6.5	9.9	4.7
	6.2	11.9	20.0	31.6	38.8	52.9	68.9	75.4	83.3	89.9	99.7	
SW	10.6	6.2	8.1	6.1	9.3	30.0	15.8	3.6	5.0	2.6	2.6	3.9
	10.6	16.8	24.9	31.0	40.3	70.3	86.1	89.7	94.7	97.3	99.9	
W	36.9	8.4	6.3	4.8	9.7	16.0	10.3	1.9	2.6	1.1	1.8	2.3
	36.9	45.3	51.6	56.4	66.1	82.1	92.4	94.3	96.9	98.0	99.8	
Ave.	8.8	3.9	5.2	5.8	10.5	22.0	15.6	4.7	7.8	5.5	10.0	4.7
	8.8	12.7	17.9	23.7	34.2	56.2	71.8	76.5	84.3	89.8	99.8	
Core-0	7.5	3.4	5.1	4.7	10.1	33.6	28.9	1.4	1.1	0.6	3.3	4.1
	7.5	10.9	16.0	20.7	30.8	64.4	93.3	94.7	95.8	96.4	99.7	
Core-30	7.4	2.7	2.7	3.3	7.1	33.6	21.7	6.0	6.6	3.4	5.3	
	7.4	10.1	12.8	16.1	23.2	56.8	78.5	84.5	91.1	94.5	100.0	
Core-60	15.6	2.8	2.5	2.9	6.6	32.3	17.5	6.2	5.7	3.5	4.2	
	15.6	18.4	20.9	23.8	30.4	62.7	80.2	86.4	92.1	95.6	99.8	
Core-90	10.7	2.5	3.0	3.9	6.5	33.2	17.4	5.7	5.7	3.8	8.5	3.9
	10.7	13.2	16.2	20.1	26.6	58.8	76.2	81.9	87.6	91.4	99.9	

TABLE 6. Results of the analysis for calcium carbonate in the sediment and core of the northern basin of the Cabo Rojo Platform. (Two replicates at each station.)

Station	Calcium Carbonate (%)	Average $CaCO_3$ (%)
C	79.6 69.8	74.7
N	64.1 60.5	62.3
NE	55.8 67.3	61.6
E	40.8 38.2	39.5
SE	40.9 40.2	40.6
S	54.5 56.2	55.3
SW	64.4 52.2	58.3
W	70.1 72.6	71.4
Core-0	83.1 72.1	77.6
Core-30	75.0 75.3	75.1
Core-60	67.4 72.8	70.1
Core-90	60.2 60.2	60.2

TABLE 7. Cumulative percent of the extracted sediment material with successive pipette draws during the determination of the sea water settling rate for the sediment of the Cabo Rojo Platform.

Pipette Draw (#)	Φ for Fresh Water	Cumulative Percent for Fresh Water(%)	Cumulative % for Sea Water
1	4	18.6	16.3
2	4.5	39.4	32.6
3	5	50.2	48.6
4	5.5	59.4	79.7
5	6	70.6	101.3
6	7	80.0	---
7	8	100.2	---

TABLE 8. Settling velocity for sediment grains of a given phi size in fresh water (Carver, 1971) and Cabo Rojo Platform sea water-determined experimentally at 28°C.

Phi Size	Settling Velocity for Sediment in: Fresh Water (cm/sec)	Sea Water (cm/sec)
4	.4	.4
4.5	.2	.2
5	.1	.1
5.5	.05	
6	.03	
7	.006	.05
8	.002	.03

TABLE 9. Results of the particle trajectory calculations for the northern basin of the Cabo Rojo Platform.

Station	Description and location of material leaving basin: Material Leaving (%)	Direction Leaving (deg)	Time possible (% day)
C	0	---	---
N	9.1	000	21
NE	16.4	000	21
E	0	---	---
SE	51.3	180	21
S	24.6	180	25
SW	10.3	180	8
W	5.7	000	8

TABLE 10. Results of the analysis for trace heavy metals in the sediment and core of the northern basin of the Cabo Rojo Platform, April 1976. Values of the average ($\bar{X}$) of the three replicates and their standard deviation (σ) are given in units of mg/l

Station	Cr		Zn		Ni		Cu		Pb		Cd	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
C	44.8	1.3	13.0	1.0	49.7	4.7	85.1	0.1	12.6	0.6	0.37	.06
N	9.4	0.1	8.9	0.7	39.1	1.2	25.1	0.9	13.6	0.5	0.4	0
NE	41.4	0.3	10.3	0.8	50.2	0.4	35.3	2.3	12.0	0.1	0.4	0
E	87.7*	0	26.8	2.8	122.	7.9	90.4	3.9	10.0	0	0.4	0
SE	66.4*	4.4	19.7	2.4	53.0*	1.4	85.6	7.2	8.8	1.1	0.33	.06
S	65.3	4.4	16.2	2.9	59.5	12.9	50.9	7.2	10.7	0.7	0.33	.06
SW	8.5	0.3	7.1	0.4	25.0	0.2	22.4	0.7	13.6	0.6	0.4	0
W	7.2	1.5	7.4	0.8	30.9	1.0	23.4	0.6	14.6	0.5	0.4	0
C-0	34.0	1.4	15.1	1.0	59.8	0.2	85.0	0.7	13.3	0.6	0.33	.06
C-30	30.2	3.7	7.1	1.3	36.1	6.0	85.1	0.5	12.5	0.6	0.4	0
C-60	34.9	2.2	8.3	0.1	42.4	2.5	85.9	0.4	12.5	0.4	0.4	0
C-90	32.7	4.4	7.4	0.1	36.8	3.9	86.0	0.2	11.5	0.5	0.4	0
Detection Limits	0.03		0.01		0.03		0.02		0.07		0.01	
EPA** Guideline	100		75		50		50		50		2	

* Only 2 replicates useable.

** (Cited in Lopez, 1976)for U.S. EPA Region VI Dallas, Texas.

TABLE 11. Results of the analysis for total trace heavy metals in the water of the northern basin of the Cabo Rojo Platform.

Metal	Cabo Rojo Concentration (μg/ℓ) $\bar{X}$	σ	"Normal" Sea Water Concentration (μg/ℓ) (Horne, 1969)	EPA Proposed Limits(U.S. EPA,1975)	Detection Limits (μg/ℓ)
Zinc	38.2	8.9	10	0.1x96 hr LC_{50}	1
Copper	4.9	0.8	3	0.1x96 hr LC_{50}	1
Iron	90.0	39.0	10	1.0 mg/ℓ	3
Lead	<1.0	--	.03		1
Manganese	<10	--	2	100 μg/ℓ	10
Nickel	10.8	0.5	2	100 μg/ℓ	2
Cadmium	2.5	0.2	0.1	5.0 μg/ℓ	0.5
Cobalt	3.4	0	0.5	--	2

$\bar{X}$ is the average of three replicates.

σ is the standard deviation of the three replicates.

TABLE 12. Living foraminifers at three stations in the northern basin of the Cabo Rojo Platform, April 1976.

Foraminifers	STATIONS SE	E	W
Ammonia catesbyana	1	3	
Angulogerina angulosa			1
Articulina mayori		1	
Baggina philippinensis	1		
Bigenerina textularioidea	1	1	3
Brizalina cf. variabilus		2	1
Buliminella elegantissima	2		
Cancris sagra		1	1
Cribroelphidium poeyanum	5	56	4
Cymbaloporetta squammosa			1
Discorbinella floridensis			2
Discorbis bulbosa			3
Florilus grateloupii	5	2	1
Fursenkoina punctata	1	1	1
Miliolinella subrotunda	2		
Neoconorbina terquemi			1
Nonionella cf. turgida			1
Nouria polymorphinoides		2	
Planorbulina larvata			1
Protelphidium sp.			1
Quinqueloculina bosciana	1	2	
Q. candeiana		1	1
Q. cf. seminulum		1	1
Q. sp. 1	1		
Sagrina pulchella			1

TABLE 12 (continued)

Foraminifers	STATIONS SE	E	W
Siphogenerina duartei			1
Spirillina densepunctata			1
Triloculina trigonula	1		
Textularia conica			1
Trochammina cf. *challengeri*			3
Unidentified forams.			1
TOTAL	21	73	32

TABLE 13. Living foraminifers at two stations in the northern basin of the Cabo Rojo Platform (Seiglie, 1970). Station CR-13 corresponds to our station E, station CRT-15 corresponds to our station W. The values assigned to each species are the percent of the total number at that station.

Foraminifers	STATIONS CR-13 (E)	CRT-15 (W)
Ammonia spp.	2.6	8.2
Amphistegina gibbosa	.5	.6
Angulogerina cf. *bella* Phl. and Park	1.0	---
Archaias angulatus	.5	---
Asterigerina carinata	.5	---
Bigenerina textularoidea	2.6	---
Cornuspira involvens Reuss	.5	5.7
Discorbis (?) *bulbosa*	1.0	3.2
Elphidium discoidale	19.1	.6
E. poeyanum	3.1	10.1
E. sagra	1.0	---
E. spp	4.6	4.4
Florilus grateloupii	.5	6.9
Fursenkoina pontoni	1.0	1.9
Miliolidae (smooth walled and small)	19.1	30.8
Neoconorbina orbincularis	1.0	---
Pytro subsphaerica	1.5	---
Quinqueloculina agglutinans	1.0	---
Q. biscostata	7.7	---
Q. candeiana	3.6	1.3
Q. lamarckiana	6.2	1.3
Q. spp.	2.0	---
Rosalina sp. A	.5	---
Reussella atlantica	.5	.6
Spiroloculina arenata	1.6	2.5
Triloculina trigonula	---	3.8
Others	16.8	18.1
Totals	100.0	100.0

TABLE 14. Meiofauna at three stations in the northern basin of the Cabo Rojo Platform, April, 1976.

Meiofauna	STATIONS SE	E	W
Foraminifers	21	73	32
Nematodes	110	120	114
Polychaeta		14	
Other worms	14	26	36
Bivalves			
Ostracodes	2	20	
Amphipodes	2	122	2
Bivalves	5		
Bryozoans (colonies)			2
Totals	154	375	206

TABLE 15. Calculated depth of the unconsolidated sediment in the northern basin of the Cabo Rojo Platform.

Point (#)	Depth (m)
1	357
2	357
3	213
4	424
5	373
6	306
7	255
8	186
9	186
10	340
11	306
12	237
13	220
14	153
15	169
16	306
17	306
18	306
19	204
Average	274

TABLE 16. Quantitative benthos results from the April, 1976 cruise in the northern basin of the Cabo Rojo Platform.

STA. NE-I	Number
Halophila baillonis	
Carbula caribaca	1
Microcosmus exasperatus	1
Unident. Polychaetes	3
STA. NE-II	
Halophila baillonis	
STA. NE-III	
Halophila baillonis	
Trigoniocardia antillarum	2
Anygadalum dendriticum	1
Microcosmus sp.	1
fam. Orbiniidae (Polych)	1
fam. Callianassidae	1
STA. E-I	
Phacoides muricatus	1
STA. E-II	
Chione sp.	1
Unident. Polychaete piece	
Unident. Sipunculids	2
STA. E-III	
Unident. Sipunculid	1
STA. SE-I	
Halophila baillonis	
Ascidia syndneiensis	1
Tellina sp.	1
STA. SE-II	
Pitar aresta	1
fam. Didemnidae	
STA. E-III	
Halophila baillonis	
fam. Polyonidae	1
fam. Acoetidae	1

STA. N-I	Number
Eulima auricincta	1
Unident. Polychaete	1
STA. N-II	
fam. Maldanidae	1
fam. Aphroditidae	1
Unident. Polychaete	1
STA. N-III	
Unident. Polychaete piece	
STA. C-I	
fam. Maldanidae	1
Unident. Sipunculids	4
STA. C-II	
Unident. Sipunculids	4
Unident. Polychaete	1
STA. C-III	
Eulima auricincta	1
fam. Aphroditidae	1
fam. Callianassidae	1
Unident. Sipunculids	4
Unident. Pelecypod (broken)	1
STA. S-I	
Halophila baillonis	
STA. S-II	
Halophila baillonis	
STA. S-III	
Molgula occidentalis	1 small
Nereis sp.	1
STA. W-I	
Polycarpa spongiabilis	1
Chama florida	1
Cyamon vickersi	
fam. Xanthidae	1
Haliclona sp.	

TABLE 16. (continued)

STA. W-II	Number
Haliclona sp.	
Marphysa sp.	1
STA. W-III	
Chasmocarcinus cylindricus	1
Haliclona sp.	
Alpheus sp.	1
Cirolana sp.	1
Unident. Polychaete	1
STA. SW-I	
Tellina sp.	1
STA. SW-II	
Halophila baillonis	
Chasmocarcinus cylindricus	1
fam. Amphiuridae	1
STA. SW-III	
Unident. Sipunculid	1
Unident. Polychaete	1
Unident. Natantian (no key available)	1

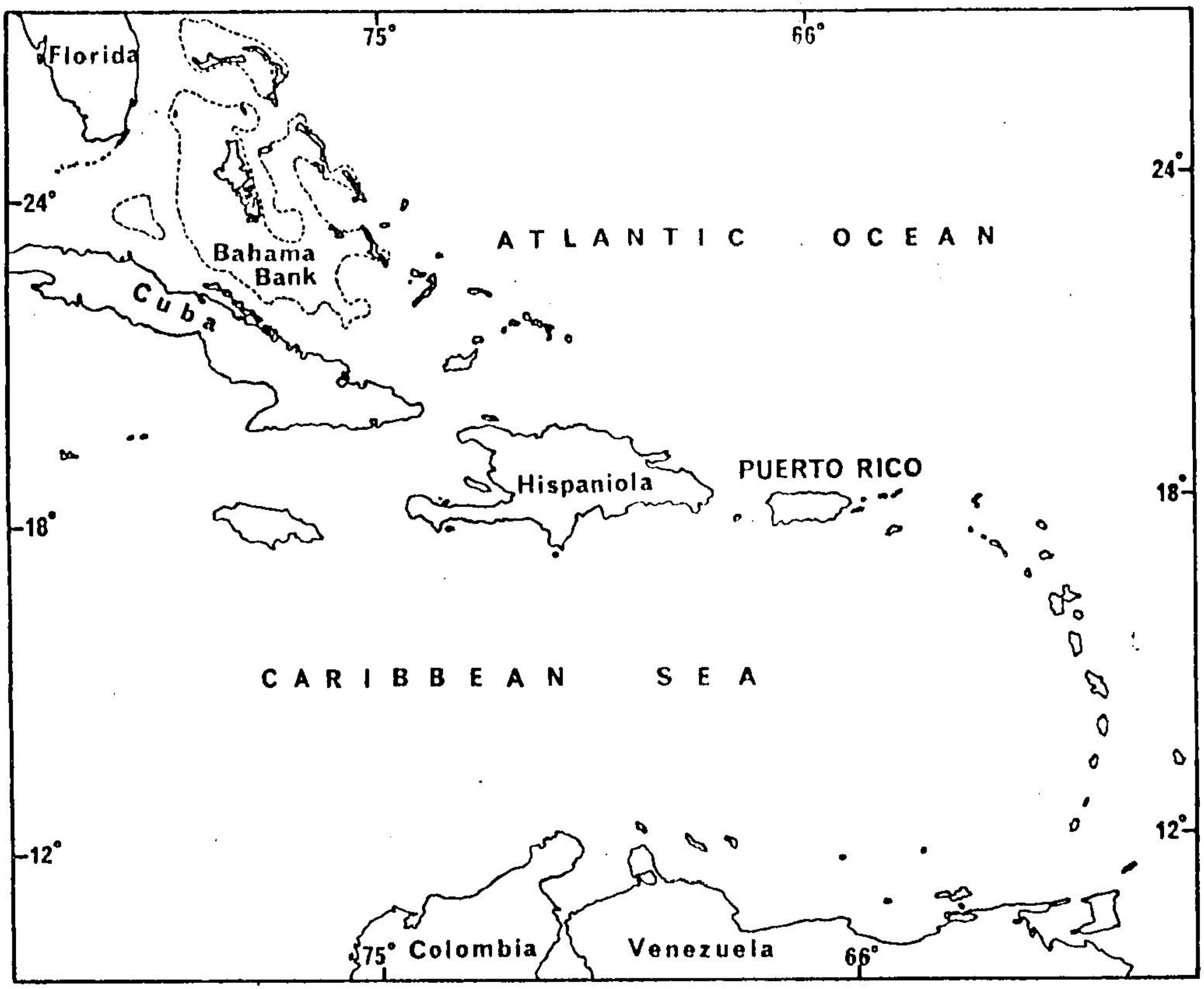
TABLE 17. Spatial distribution of benthos collected during the April, 1976 cruise in the northern basin of the Cabo Rojo Platform.

SPECIES	STATIONS							
	NE	E	SE	N	C	S	W	SW
Spermatophyta								
Hydrocharitaceae								
Halophyla baillonis	X		X			X		X
Porifera								
Haliclona sp.							X	
Cyamon vickersi							X	
Sipunculida								
Unident. Sipunculids		X			X			X
Annelida								
Polychaeta								
Nereis sp.						X		
Marphysa sp.							X	
fam. Polyonidae			X					
fam. Acaetidae			X					
fam. Maldanidae				X	X			
fam. Aphroditidae				X	X			
fam. Orbiniidae	X							
Unident. Polychaetes	X	X		X	X		X	X
Arthrapoda								
Crustacea								
Isopoda								
Cirolana sp.							X	
Decapoda								
Alpheus sp.							X	
Unident. Natantian								X
fam. Callianassidae	X				X			
Chasmocarcinus cylindricus							X	X
Unident. Xanthid							X	
Mullusca								
Gastropoda								
Eulima auricuncta				X	X			
Pelecypoda								
Tellina sp.			X					X
Chama florida sp.							X	

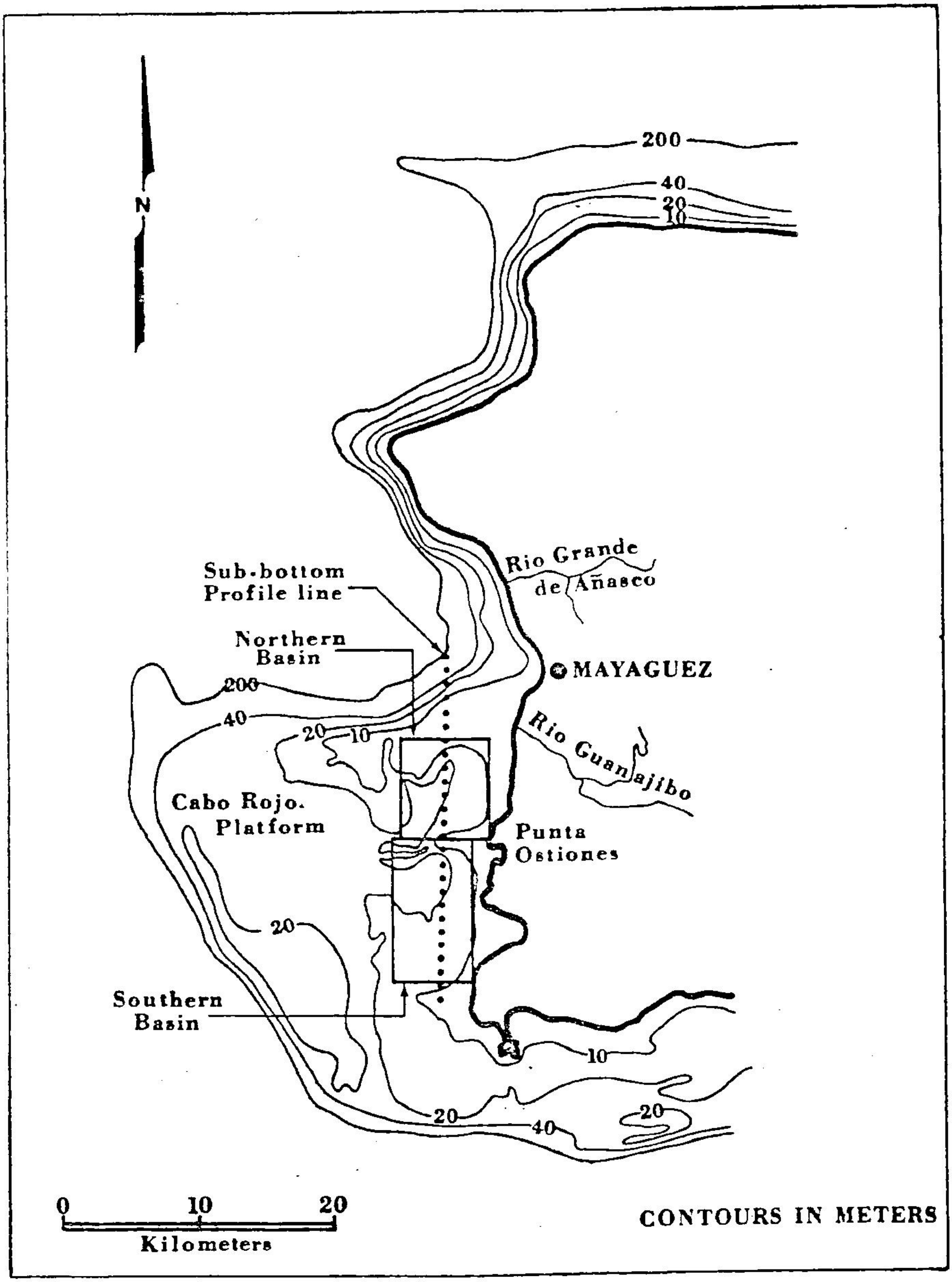
TABLE 17 (continued)

SPECIES	NE	E	SE	N	C	S	W	SW
				STATIONS				
Pelecypods (cont.)								
<u>Trigonocardia antillarum</u>	X							
<u>Amygdalum dendriticum</u>	X							
<u>Chione</u> sp.		X						
<u>Corbula caribaea</u>	X							
<u>Phacoides muricatus</u>		X						
<u>Pitar aresta</u>			X					
Unident. Pelecypod					X			
Echinodermata								
Ophiuroidea								
fam. Amphiuridae								X
Chordata								
Ascidiacea								
<u>Polycarpa spongiabilis</u>							X	
<u>Ascidia sydneiensis</u>			X					
<u>Microcosmus exasperatus</u>	X							
<u>Microcosmus</u> sp.	X							
<u>Molgula</u> sp.								
fam. Didemnidae			X					
<u>Molgula occidentalis</u>						X		
# Species	9	4	7	4	7	3	10	7

FIG.1

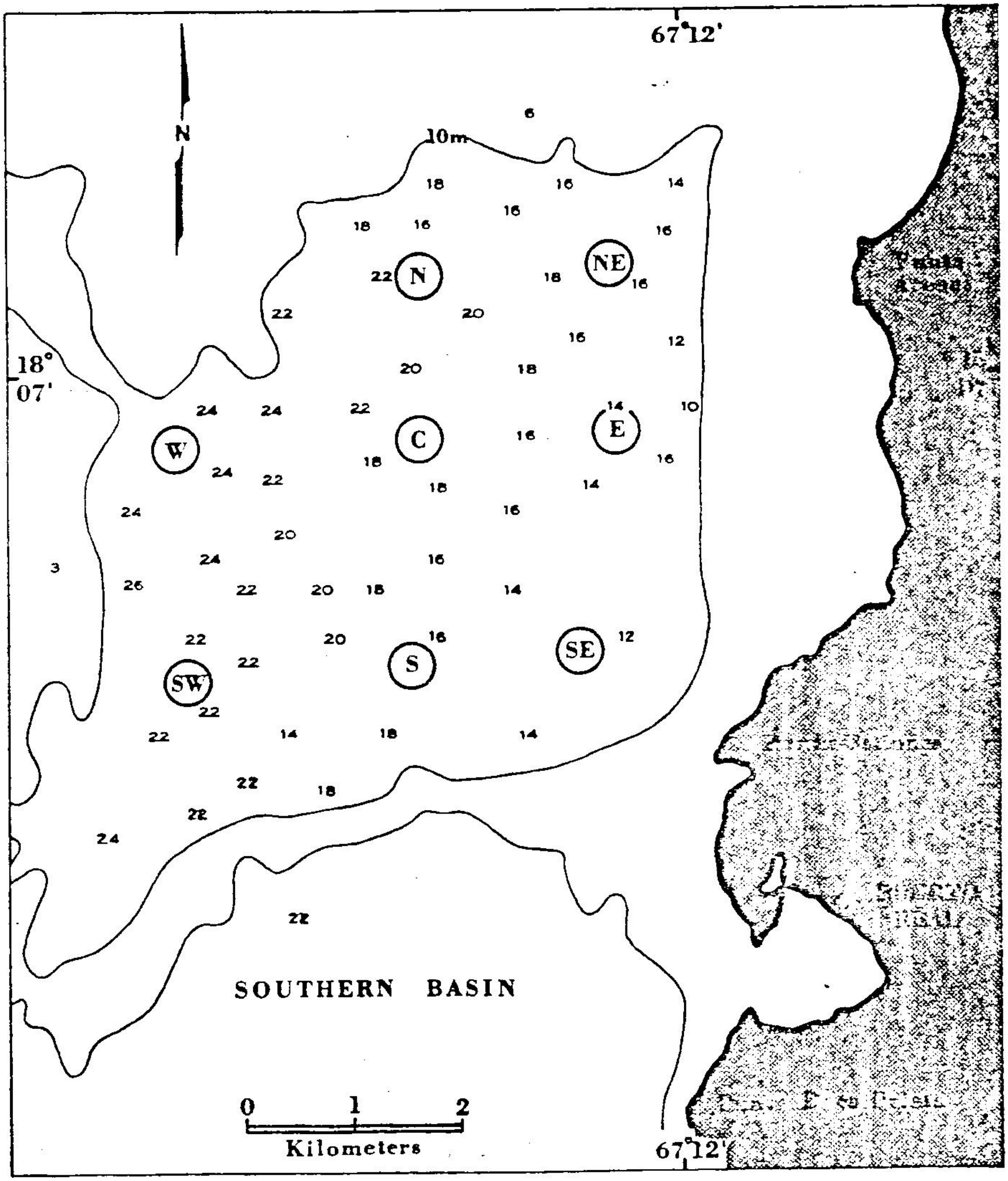


Location of Puerto Rico within the Caribbean.



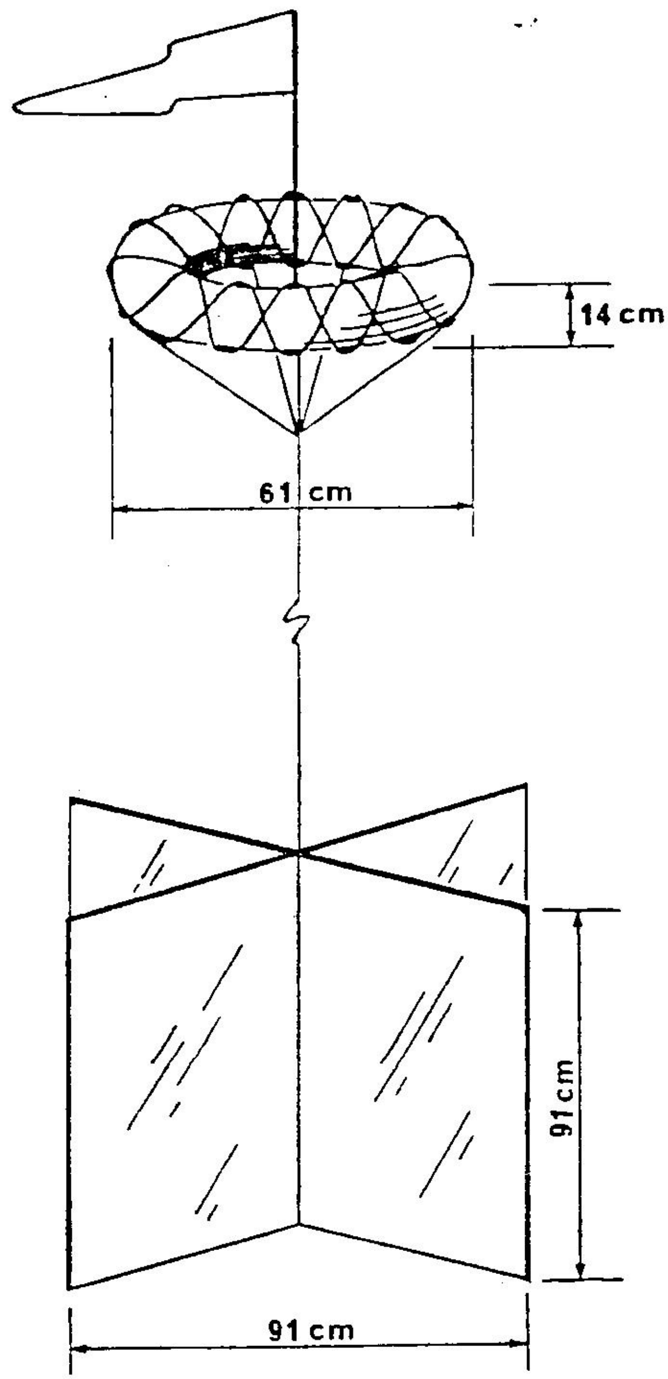
West Coast of Puerto Rico.

FIG.3



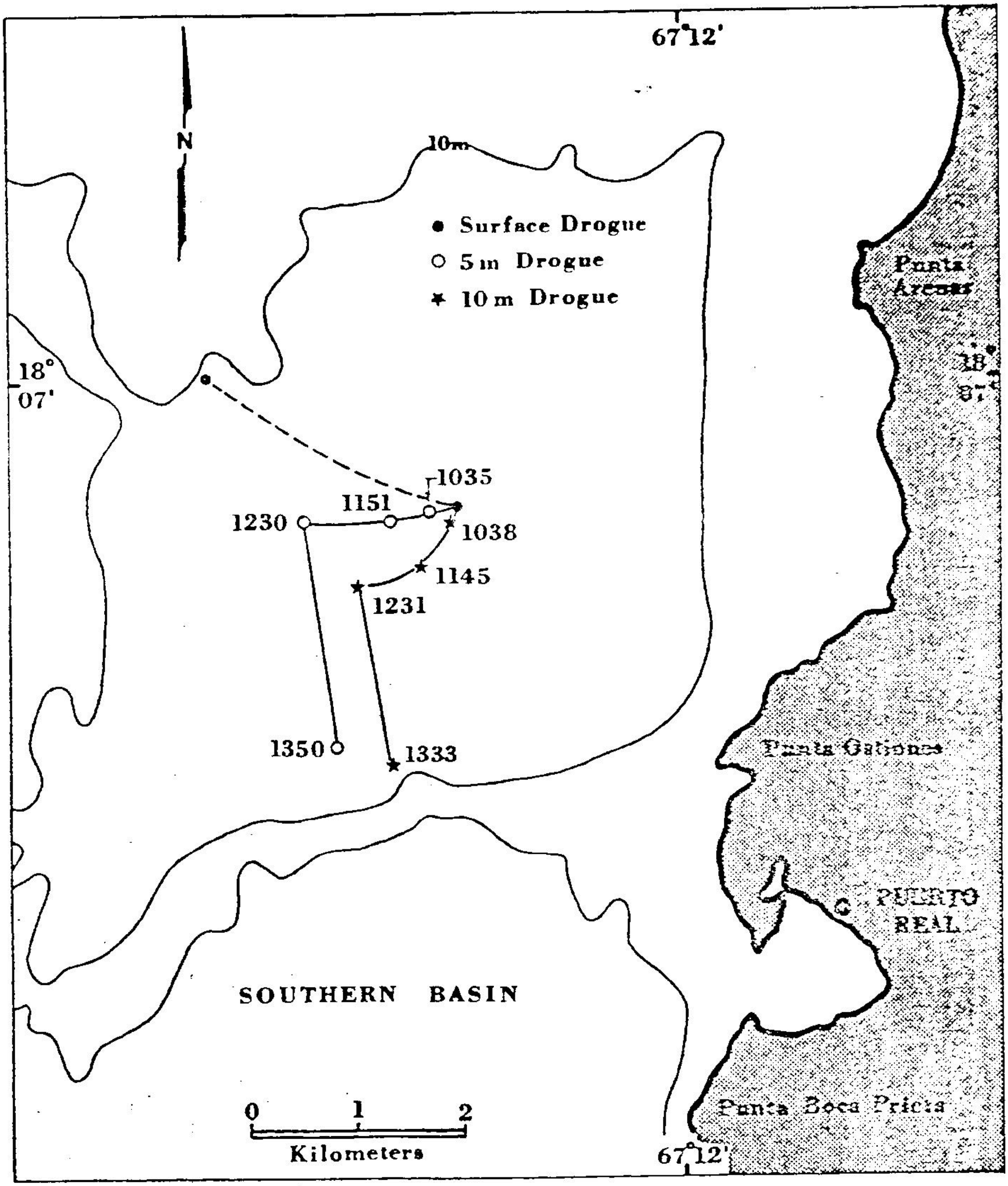
Northern basin of the Cabo Rojo Platform. Stations and depths(in meters) are also shown.

FIG.4



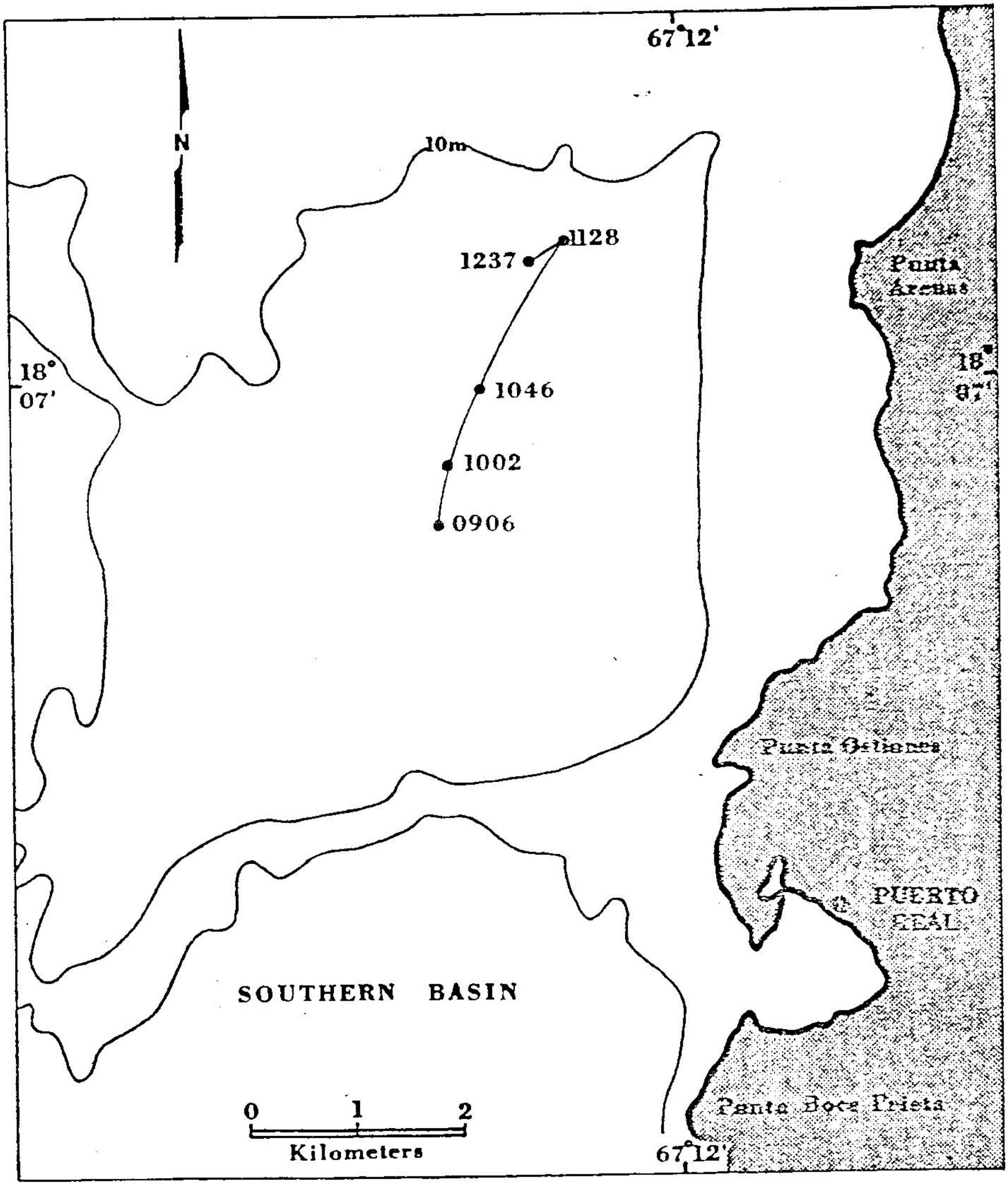
Schematic drawing of drogues used to study the currents.

FIG.5



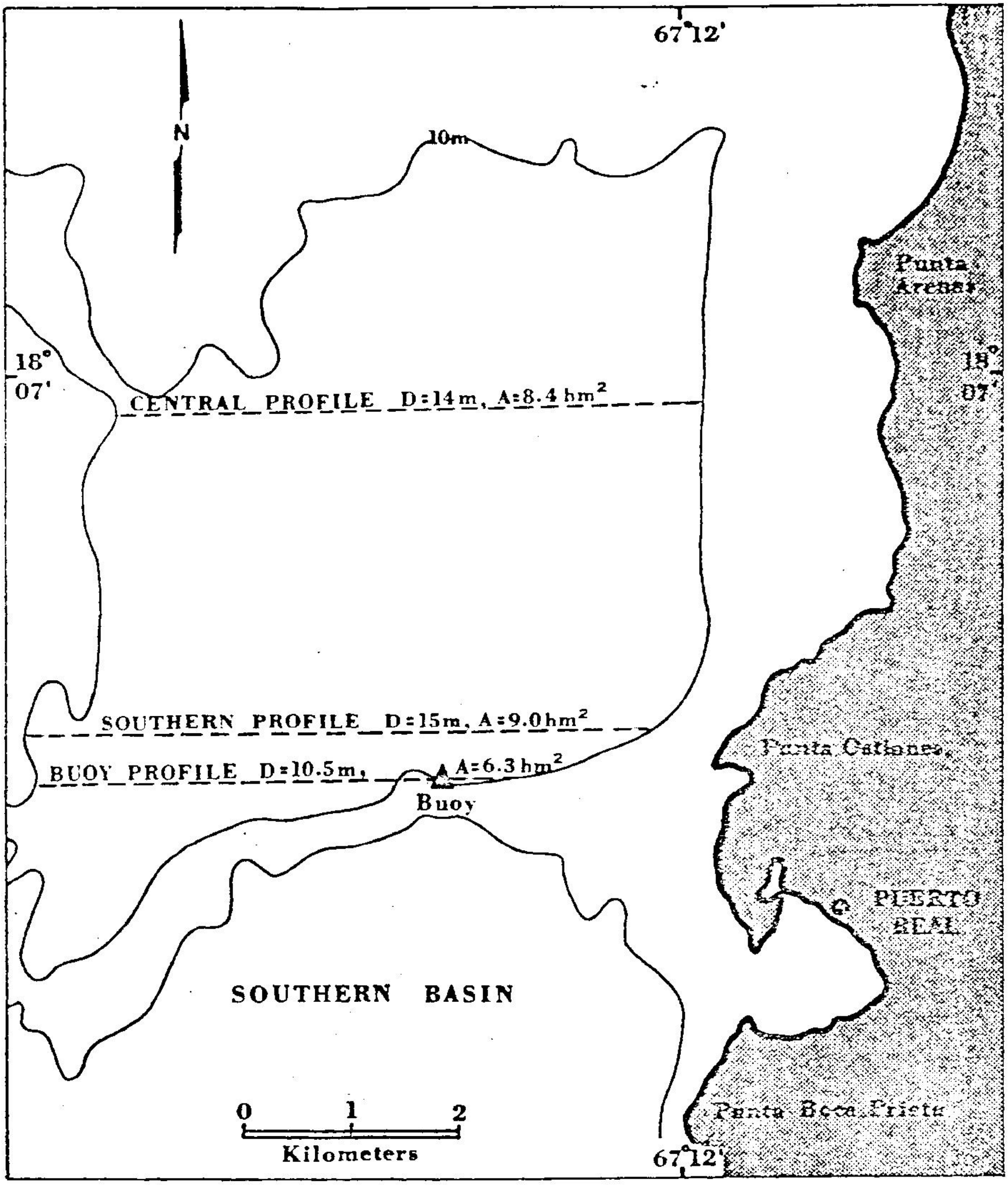
Trajectories for the current drogues in the northern basin of the Cabo Rojo Platform during 14 July 1976.

FIG. 6



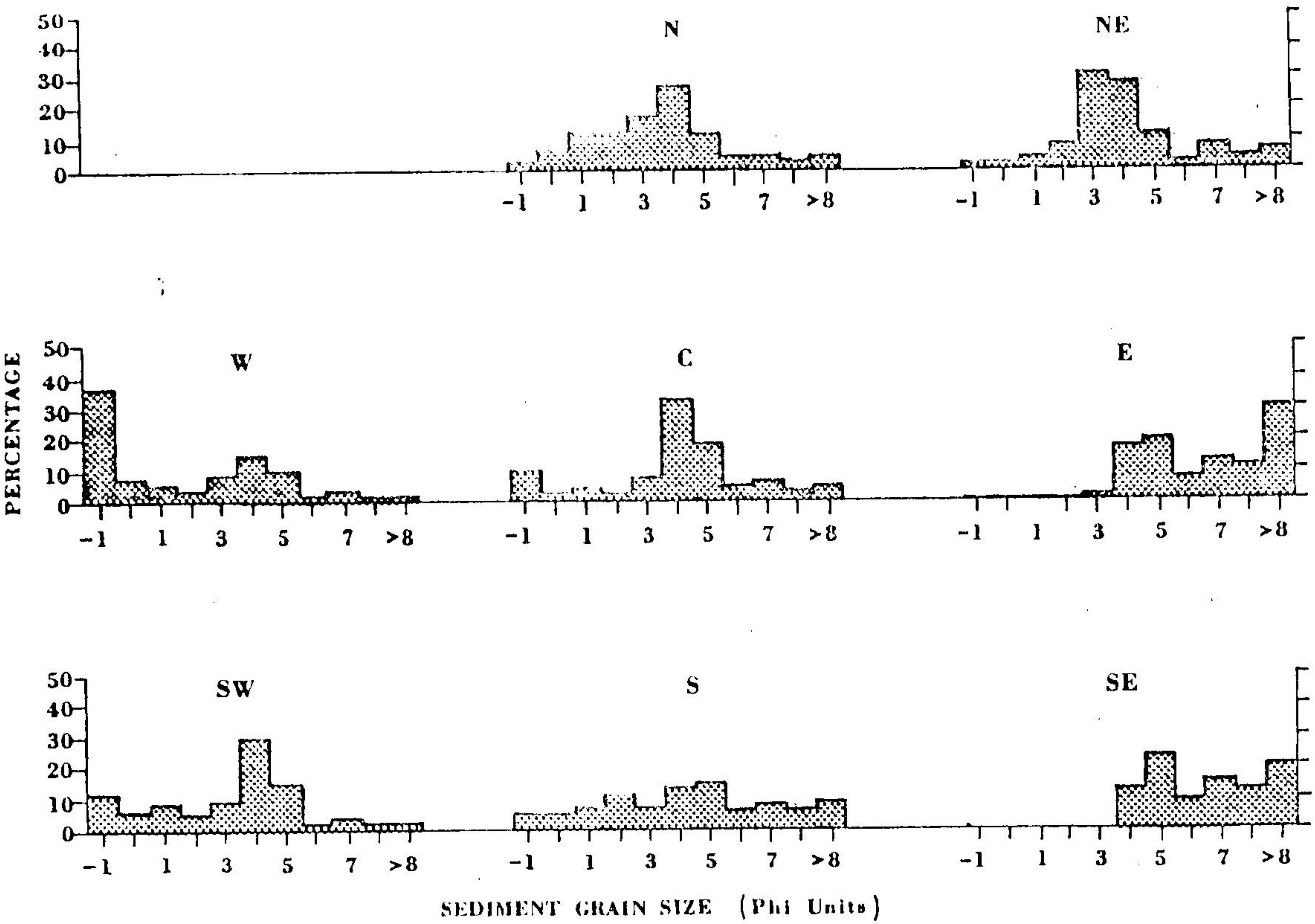
Trajectory for the current drogues in the northern basin of the Cabo Rojo Platform during 16 July 1976.

FIG. 7



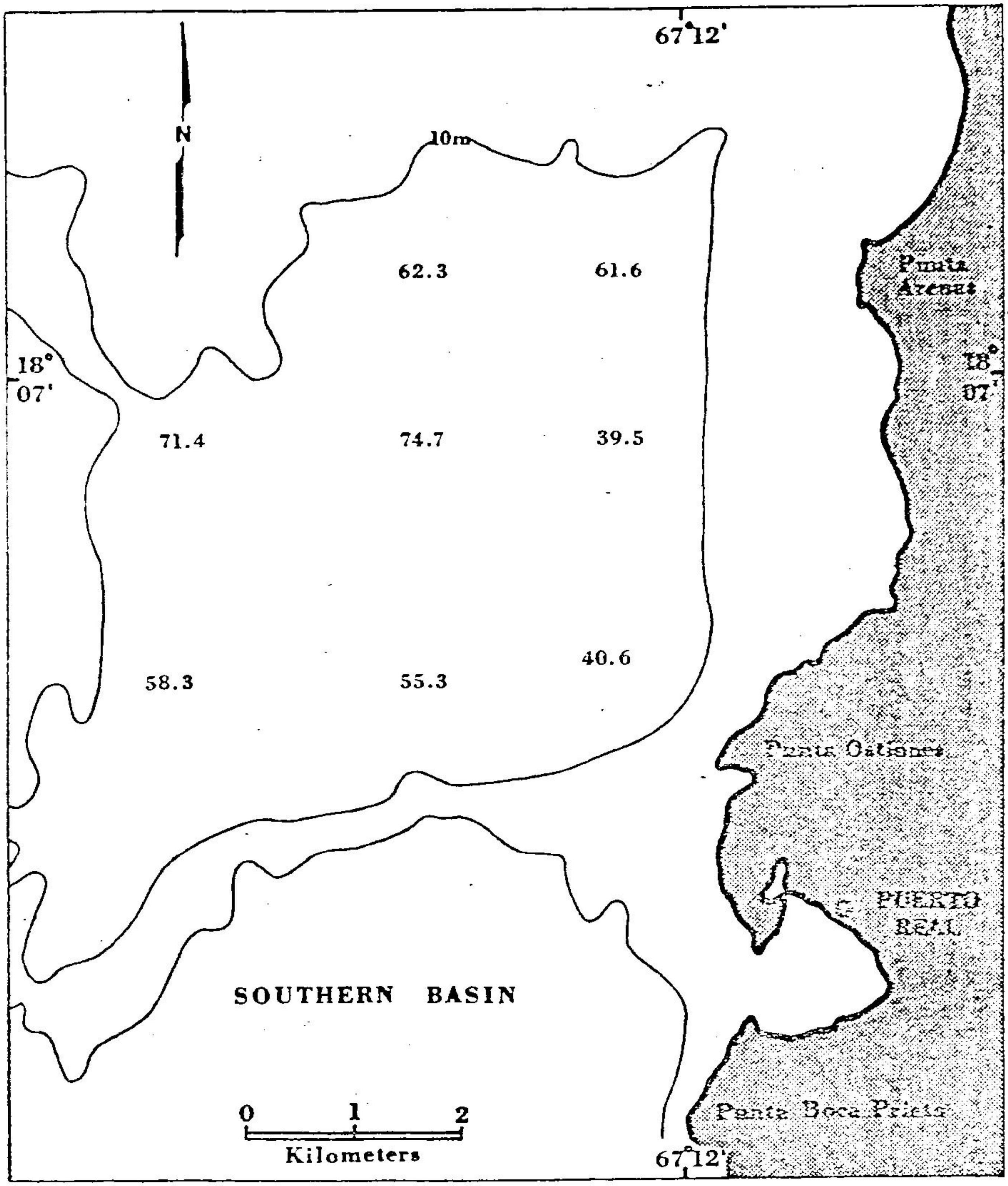
Location of the cross-sectional profiles through the northern basin of the Cabo Rojo Platform.

FIG.8



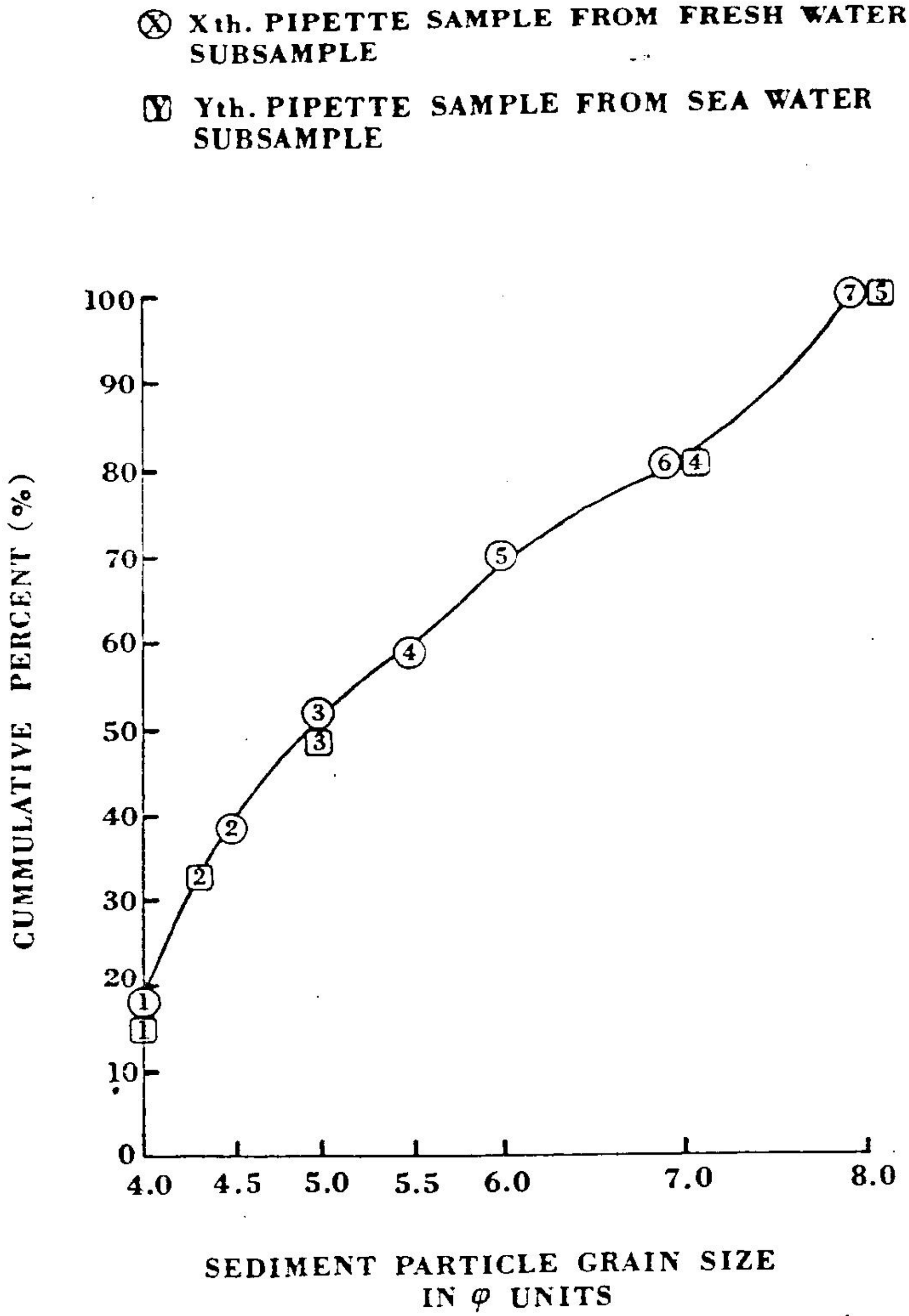
Graphical representation of the sediment grain-size distribution of material sampled in the northern basin of the Cabo Rojo Platform.

FIG.9



Average value of the percent of calcium carbonate in the sediment of the northern basin of the Cabo Rojo Platform.

FIG.10



Particle size(in phi units) versus cumulative percent for fresh water and Cabo Rojo Platform sea water samples.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The purpose of this study was to evaluate those potential effects that would result from resuspended sediment during the construction phase, if an offshore nuclear power plant would be built West of Mayaguez, Puerto Rico, in the Cabo Rojo Platform. During the study we developed water current predictions. We also evaluated sediment for grain-size, trace heavy metals, settling velocity, and sedimentation rate. The water was analyzed for trace heavy metals as well. The results of the above are a potential particle trajectory model, suggesting potential redeposition locations. The conclusion reached from this study was that, except for sessile benthos near the actual construction site, and the seagrass, rocks and reef habits to the north and south of the area, little negative effects would be felt during the construction of such a plant.

17. KEY WORDS AND DOCUMENT ANALYSIS

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