

2CC-BCC-7

GOVERNMENT OF BELIZE
DEPARTMENT OF FISHERIES

COASTAL ZONE MANAGEMENT

AN INVESTIGATION OF THE IMPACT ON THE BELIZE BARRIER REEF OF
CHANGING MAINLAND FINE SEDIMENT DISCHARGE REGIMES
PHASE 1: REEF FINE SEDIMENT DYNAMICS

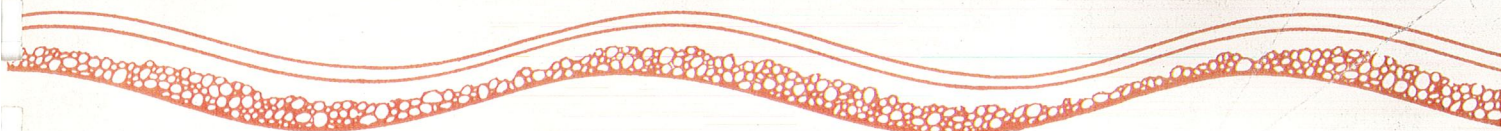
HUNTING CAY APRIL 1993
FIELD SURVEY REPORT



CORAL CAY CONSERVATION LTD
BELIZE 90-95

sea
sediments

Court Mill, Wadeford, Chard, Somerset. TA 20 3AY.
Telephone Chard (04606) 2981



SUMMARY

A field investigation has been completed as part of a programme to identify the impact of changing mainland freshwater sediment discharge regimes upon the Belize barrier reef. In its present phase the study is concerned with the physical processes of fine sediment accumulation along the landward margins of the barrier reef; this particular field survey was undertaken in the Sapodilla Cays area at the southern extremity of the reef.

A variety of techniques were used to examine the environment of sediment accumulation, including current metering, wave and wind observations, echo-sounding and sampling and mapping of the seabed using divers.

The survey results show that in water depths of 15-30m along the landward margin of the reef the seabed is principally composed of corals and exhibits a very irregular bathymetry. In the three areas examined the coral seabed contains localised basins of sediment, varying from a few metres to a few tens of metres in diameter. Cores taken from the sediment reveal the surface ~0.3m of the sediment to be of a very uniform nature, showing no evidence of episodes of sediment erosion. The sediments are muddy sands, containing 10-40% silt and clay.

The basins are interpreted as zones of undisturbed accumulation of far-travelled suspended sediments, containing also coarser coral and algal carbonate debris generated along the immediate coral margins. It is hypothesised that the area of the seafloor covered by these basins, the form of the basins and the rates of accumulation within them will reflect spatial and temporal variability in the balance between fine sediment influx and local energies for sediment reworking. They may be the manifestation of a natural regulatory system which enables the clear-water reef environment to co-exist with the turbid waters of the adjacent channel area.

These findings are consistent with the requirements of the overall study, and various recommendations are made regarding the development of future surveys, leading ultimately to the instatement of a monitoring programme involving sediment coring, dating, and contaminant analysis.

1. INTRODUCTION

1.1 BACKGROUND TO THE PROJECT

The Belize Barrier Reef is some 250 km in length and in most areas lies within 30 km of the mainland coast (figure 1). The swathe containing the shallowest coral areas (<5m depth) is normally less than 10 km wide. Between this swathe and the mainland is a channel where depths reach about 40m and which is floored mainly by mud deposits. Chetumal Bay and the Gulf of Honduras (at the northern and southern extremities of the reef respectively) are also essentially mud-floored areas. Seaward of the reef depths rapidly descend to 500m and greater. The seafloor at these depths also comprises muddy sediments.

Coral growth is very sensitive to water turbidity. The juxtaposition of the Belize reef system and extensive zones of mud deposit invokes the existence of a dynamic interface separating the two. The position of this interface will be sensitive to changes in the supply of fine sediment to the region.

It is possible that the principal source of fine sediment to the areas inside the reef is freshwater discharge. The largest catchments (Rivers Hondo, New, Belize and Sibun) drain into the sea along the northern sector of the coast (figure 1) and may be responsible for the highest solids inputs.

Concern is being expressed that developments in Belize may be significantly affecting the fine sediment regime. The system may be undergoing change in three ways:

- 1) The amount of material entering the sea via the rivers may be increasing as a result of altered land use. Deforestation and intensive agriculture can increase soil erosion and hence the input of sediments to rivers.

- 2) Many long-lived pollutants associated with developing agriculture (eg pesticides), industrialization (eg trace metals) and urbanization (eg pathogens) become associated with the particulate phase of discharges entering coastal waters.

- 3) Development projects on the reefs themselves may be affecting local conditions, for example the growth of tourist populations may increase contamination by sewage particles.

1.2 APPROACH

A useful way of discovering the degree of change that has occurred to date on the reef, and of monitoring impacts into

the future, may be to examine the rate of deposition and contaminant content of fine sediments which have been accumulating in an undisrupted manner at sites within the reef. Historical data may be determined by carefully collecting cores of mud, dating and analysing the properties of the sequentially accumulated sediment layers. A record of change may be preserved in the sediments if;

- 1) there has been a steady accumulation of fine material. If the site is subject to occasional periods of intense energy (eg waves or surges under hurricane conditions) the body of mud may become totally resuspended into the water, mixed up, and then resettled, thus destroying any original layered sequence of sediments.

- 2) bioturbation is not too intense. Animals living within the sediment stir the sediment around with their actions ("bioturbation"). If this process is intense and 'burrowing' occurs to deep levels in the sediment then again any sediment layering will be destroyed.

In reality a small amount of bed disturbance by physical or biological means always occurs, and 'blurs' rather than destroys the layered sedimentary record.

Before going down the expensive path of collecting samples and undertaking complex dating and chemical measurements it is therefore important to ascertain whether suitable fine sediment 'sinks' occur along the reef. Phase 1 of this study is concerned with investigating physical conditions at potential coring sites in order to assess their suitability.

1.3 SELECTION OF STUDY ENVIRONMENT

From published data and an exploratory diving survey three potential types of sampling environment have been identified:

- 1) Channel deposits immediately landward of the reef (Admiralty chart information)
- 2) Mangrove deposits (Zisman 1992)
- 3) Localised mud areas within the coral in depths of 20-30m along the leeward side of the reef (Nunny 1992)

The channel deposits are less than ideal as they do not actually reflect conditions on the reef.

Mangrove deposits seem unsuitable for the following reasons:

- 1) Many of the mangrove stands on the reef are not dense, offering little shelter from wave action, and are therefore unlikely to be effective sites of mud accumulation.
- 2) Mangrove-induced deposition is essentially confined to the intertidal range, which is small. As mangroves are now thought

not normally to be 'land building' ie having seaward expanding margins, the scope for deep deposit formation through historical time is limited.

3) The stability of mangrove deposits as portrayed in the literature is conflicting. There appears to be evidence that although very dense stands can stabilize local sediments against short term storm events, mangroves are very susceptible to persistent changes in local conditions, and wax and wane accordingly. This apparent longer-term instability is not consistent with coring requirements

4) The principle accumulation beneath mangroves is peat, derived from leaf litter. Changes in the quantities and quality of terrigenous material accumulating within this peat will therefore tend to be masked by the bulk of locally derived organic matter.

5) The peats beneath mangroves are often extensively burrowed. High levels of bioturbation confuse core records.

The occurrence of localised sites of fine sediment deposition on the leeward side of the reef is therefore being investigated as the prime option. A reconnaissance survey at 20-30m water depth was conducted by Coral Cay divers in the Sapodilla Cays area in November 1992, and identified localised areas of mud/sand accumulation amongst the coral (Nunny 1992).

The survey reported here is a more detailed investigation of some of these areas.

2. METHODS

2.1 LOCATION, TIMING AND MANPOWER

The survey expedition was based at Hunting Cay in the Sapodilla Cays. Three survey sites were located at increasing depths (21m, 28m and 32m) along a transect running northwest from Hunting Cay; the outermost of these coincided approximately with Site 5 of the previous November's survey (figure 2). The sites were annotated 59, 58 and 52 respectively. A single core was also collected at a deeper site (37m) in the vicinity of site 52; this site was designated 51.

The survey took place between 1st and 20th April 1993.

The expedition was organised through Coral Cay Conservation and undertaken by members of a Marconi/GEC volunteer team of fourteen divers.

2.2 TECHNIQUE DEVELOPMENT

The volunteer divers were untrained scientifically and so the initial week was spent in developing competence. In parallel with this an important objective of the expedition was to develop and standardize optimum survey techniques so that continuity of data quality could be maintained as the study progressed using different teams of divers. The principal developmental tasks addressed were;

- 1) perfecting flotation skills so that work could progress over muddy substrates without significantly disrupting the seabed or impairing visibility
- 2) trying out a system of triangular rope markers for laying out survey sites
- 3) developing a hammered pin penetration test as a technique for assessing the nature and depth of muddy deposits with minimal disturbance of the seabed
- 4) discovering the best technique for collecting short (0.3m), undisturbed cores of the seabed.

2.3 TIDE, CURRENT AND WAVE CONDITIONS

A stage board was located in 0.5m of water on the western (leeward) side of Hunting Cay and water levels recorded at intervals to establish the tidal regime during the survey.

Wind and wave conditions (height, period and direction of approach on both the windward and leeward sides of the island) were recorded at daybreak, noon and sunset. In addition spot observations of wave conditions were made during survey trips.

The drift of the current seaward of the reef was measured by drogue tracking on one occasion.

Currents at the three survey sites were measured by deploying a Sontek S-2000 recording current meter (velocity, direction and temperature logged over four minutes every 24 minutes). The meter was mounted on a 'U' mooring and located 1m above the seabed. Deployments were for periods of up to one week (table 1).

2.4 MAPPING

Bathymetric surveys of an area approximately 300m in diameter were initially conducted using a Trimble Differential GPS and an Apelco XCD350 LCD display sounder, bottom profiles being traced onto acetate overlays at minute intervals.

Suitable fine sediment areas were subsequently identified both from the echo records and from reconnaissance dives. Local

areas were then mapped by laying out rope markers in the form of right-angle triangles (10m x 10m x 14.1m). The alignment of the triangle was observed using diver's compass, and features were then mapped by offset to the triangle sides. Local depths and angle of coral slopes were estimated from diver depth gauge readings.

2.5 CORAL IDENTIFICATION

A two day course on coral, hydroid, sponge and algae identification was provided by Coral Cay science officers. Identification was limited to the major species present, and was aided by the limited range of flora and fauna found in these deeper water, muddier areas. Divers were asked to concentrate upon the nature of coral areas fringing the sediment areas under examination (typical descriptions included % live coral cover, dominant species, size of colonies, steepness of coral slopes, conditions along sediment/coral boundaries). Photographs were taken of typical coral conditions at each site.

2.6 SEDIMENT PROPERTIES

The surface characteristics of the sediment (particle-size, bed-forms, flora or fauna, cohesiveness) were described from visual and tactile observations. Photographs were taken.

Penetration tests were conducted at preselected points in relation to the triangle marker. A 5lb lump hammer was allowed to drop under its own weight from a height of ~20cm onto a graduated 6mm diameter steel pin 0.5m in length. One of a diver pair operated the hammer, the other observed the penetration per blow. This was continued until full penetration was achieved or the pin ceased to move (sometimes curtailed by lapsed dive-time).

At points shown to be suitable by the pin-penetration tests four short cores were collected per site (table 2). The core tubes were 68mm in diameter and 0.3m in length. Cores were carefully hammered into the bed and then dug out, capped and returned upright to the field laboratory onshore. The cores contained a sponge plug, initially at the bottom, which lay on the sediment-water interface in the tube and helped prevent disturbance.

All testing/sampling points were marked by flags, thus enabling subsequent sampling at adjacent points and also avoiding working at points which had already been disturbed.

Cores were extruded into half-section sleeves and then split longitudinally into two. One half was dried in the sun for two days and then an epoxy resin 'peel' was made to reveal the texture and structures within the core. The other half was split into 5cm slices and sun-dried. Each such section was then dry-sieved to determine the particle size content. The

sieve nest had half-phi intervals in the sand fraction (1mm - 63um) plus 4mm and 2mm sieves.

Peels and sieved samples have been retained and will be returned to the UK for further examination and analysis.

A limited number of settling tests were conducted on the 4mm, 2mm and 1mm sieve fractions by timing individual particle descent through a 0.5m deep water column.

At one location (site 59) an attempt was made to investigate the angle of descent of the coral/sediment boundary. This was undertaken by boring with a simple airlift device, supplemented by hammering a 3m length of 13mm diameter reinforcing rod down the airlift bores.

2.7 INFAUNA AND FLORA

Two 80mm diameter by 250mm deep cores were collected at each site for infauna analysis. Samples were sieved through a 1mm mesh and animals picked from the retained fraction spread in a shallow tray of water.

Burrows/holes were present in the sediment at all three sites; the above samples were collected from over burrows. The density of burrows on the seabed was measured by counting within quadrats, four spaced-apart square metres being examined per site.

Samples of algae growing on the sediment surface were collected.

3. RESULTS

3.1 TIDES, CURRENTS AND WAVES

Tidal stage records are shown in figure 3. There is a semi-diurnal tide which varies in amplitude over the spring/neap cycle. However other factors, such as barometric effects or wave set-up effects modify this pattern. The peak amplitude observed was about 0.3m.

The current set outside the reef was measured as 26 cm s^{-1} to the 215° , which is in agreement with the predicted drift for the southern reef (Hydrographic Dept. 1970). The currents measured at the survey sites to the leeward of the reef are plotted in figure 4 A-C. The strongest flows ($10\text{--}15 \text{ cm s}^{-1}$) were observed at site 59, closest to the open sea. Flow appeared to be randomly intermittent, but at times of strongest flow was moving to the sector $150^\circ - 270^\circ$, consistent with being a response to the current outside the reef. Wind directions during this period were quite variable (table 3); no attempt has yet been made to investigate whether the recorded flows can be resolved into offshore current and wind-

driven components. Semi-diurnal variability due to tidal effects appears to be absent.

At locations 58 and 52 flows were more intermittent and slower than at 59 (usually $<10 \text{ cm s}^{-1}$). Wind conditions were more stable during these deployments (table 3); at site 51 (2-6 April) winds were from the sector around 60° , and at site 58 (15-19 April) from the sector $240-270^\circ$. The prevailing flow directions recorded at each of these sites ($\sim 270^\circ$ and $\sim 70^\circ$ respectively) are broadly consistent with wind generation of these currents.

A range of wave conditions were observed during the survey (table 3). Outside the reef a 7-9 second period sea dominated. Often this was not related to local wind conditions; this swell reached about 1.5m height on occasions, with run-up just reaching the top of the beach. Local onshore winds reached force 4 sometimes for short durations, but failed to generate seas as high as the longer-travelled swells. Inside the reef conditions were always calmer. Traces of the 7-9 second swell could often be identified, but periods of 3-4 seconds were the norm. Force 4 winds from the north generated 4 second seas with maximum wave heights of the order of 1m at the survey locations. Divers working at depths of $>20\text{m}$ during these episodes did not notice significant oscillatory flows.

3.2 BATHYMETRY

The bathymetry of the three survey sites is shown in figures 5A-C. At all sites the bathymetry was very irregular, both at the scale of the survey (100+m, figure 5) and at the mezo-scale (10+m, echo trace, figure 6). Site 52 varied in depth between 26m and 35m, Site 58 between 22m and 30m and Site 59 between 7m and 27m.

Diver reconnaissance surveys showed a coral seabed, with the low areas on the mezo-scale being sediment-filled depressions in the coral bed. The smallest of these depressions, perhaps only a few metres in diameter, are very shallow features. With increasing size the angle of the coral slope surrounding the sediment area can become quite steep, creating amphitheatre-like formations. The sediment floor of these depressions is very flat, but with a local upward-turning meniscus at the coral boundary.

The shape, size and form of the basins surveyed are shown in figure 7. A single dive and collection of a core sample was made in a deeper, larger basin in the vicinity of site 52; no detailed data are available for the form of this basin (site 51).

3.3 CORAL SUBSTRATES

Mountainous Star and Scroll/Leaf/Saucer corals predominate at all three sites. However Mountainous Star is the dominant species at the shallowest site (59), whereas Scroll/Leaf and Saucer corals are the most common at sites 58 and 59. The variety of coral species present is greatest at site 59, and includes Brain, Ribbon, Pillar and Rod corals, as well as Gorgonians.

The size of individual coral colonies decreases with increasing depth. At site 59 colonies attain dimensions of the order of 1.5m height and diameter. These dimensions decrease to an average value of 0.5m at site 58 and 0.3m at site 52.

Similarly the percentage live coral cover decreases with depth. At site 59 the estimated cover is about 75%; at the other sites 20-50% is the norm. In many instances coral growth is taking place immediately adjacent to the sediment margin.

The areas between live coral, more noticeable at the deeper sites 58 and 59, comprise coral rock and coral fragments/sand. There is also a dense coverage of algae, noticeably the encrusting fan-leaf coral *Lobophora sp.* and the calcified-leaved *Halimeda sp.*

The coral slopes surrounding the sediment-filled depressions vary considerably in angle (figure 7), but are occasionally near-vertical for several metres height, and commonly of stepped appearance at angles of 45° or steeper, thus providing a 'walled' margin to the basins.

A profile of the coral surface descending beneath the sediment was measured at one location at site 59 (figure 8). At this point the coral sediment interface steepens below the seabed to an angle >45°.

3.4 SEDIMENT CHARACTERISTICS

Particle-size.

The percentage 'gravel' (>2mm) and 'silt/clay' (<63µm) in each of the core slices, and also core and site mean values are presented in table 4. The analyses show the sediments to be very similar in size composition. The percentage >2mm is normally <5% (extreme value 19%) and the percentage <63µm normally lies between 10-30% (extreme values 2 & 42%). There is a significant difference in the silt/clay content between the sites, with sites 58 and 51 containing 22 and 26% respectively, site 59 16% and site 52 10%. There does not appear to be any obvious correlation between silt/clay content and the depth, size or form of the sedimentary hollows.

The particle-size distributions of the sand fractions of the cores are plotted in figures 9 A-D. The distributions are very uniform, showing that the material has undergone little sorting by transport processes. The distributions are also very similar between samples, cores and sites; if anything a slight tendency for the preferential accumulation of fine as opposed to medium and coarse sands can be identified at the deeper sites.

Sediment materials.

The >2mm fraction of the sediment consists primarily of *Halimeda* fragments, small shells and shell fragments. Where samples contained >5% of this size fraction it was usually due to the presence of isolated but quite large (several centimetre) coral fragments.

Inspection of the sand fractions under a hand lens showed the grains to be very angular carbonate material.

The <63µm fraction has yet to be analysed for organic matter and carbonate content.

Sediment structure.

Peels made of the exposed core faces confirmed the particle-size results on the uniformity of sediment texture through the surface 20-30cm of the sediment. In no core was there any suggestion of laminae due to changing conditions of accumulation, nor of 'shell' layers formed by winnowing episodes. This information is indicative of very uniform and stable conditions of accumulation.

The pin penetration tests were designed to a) probe the sediment depth and b) reveal whether sediment properties varied with depth (layering was present). The results of the tests are plotted in figures 10 A-C. Bearing in mind the crude nature of these tests the data reveal that:

- 1) at most sites occupied the sediment depth is >0.5m
- 2) the properties of the sediment are very consistent with depth, confirming the core data on lack of layering
- 3) isolated coral fragments are occasionally present in the sediments
- 4) the difference in the mean rate of penetration was probably largely due to operator differences. A simple check was run to see if there was any correlation with sediment particle-size. The slope of the best-fit straight-line regression was determined for each of the pin tests and plotted against the mean particle-size values for the cores collected at the same point. Little correlation with silt or sand content was evident. There was a slight suggestion,

however, that penetration was easier with increased >2mm fraction (figure 11).

Coarse sediment settling velocities.

The mean settling velocities of coarse sediment particles from core 51 were:

Retained on 4mm sieve (20 tests) - 6.9 cm s^{-1}
 Retained on 2mm sieve (100 tests) - 8.0 cm s^{-1}
 Retained on 1mm sieve (100 tests) - 8.7 cm s^{-1}

3.5 INFAUNA AND FLORA

Sieving of core samples revealed the presence of a small number of species of worms which have yet to be identified. The level of bioturbation is thought to be limited.

The density of burrows visible at the sediment surface did not vary between sites, and lay between 3 and 30 per square metre. In small areas ($\sim 0.1\text{m}^2$) densities attained $100/\text{m}^2$.

The sediment surfaces are essentially free of algal growth. Several small areas of growth were found, containing *Rhipocephalus sp.* and *Kallymenia sp.*

4. DISCUSSION

4.1 THE AVAILABILITY OF ENERGY FOR SEDIMENT TRANSPORT

The best interpretation of the current data that have been recorded is that inside the hook of the Sapodilla Reef flows are very weak and predominantly wind driven. Close to the eastern reef margin the southgoing gyre from the Caribbean current may penetrate into the shallow waters and influence flows, introducing a prevailing southeasterly flow. Currents are generally less than 10 cms^{-1} at 1m above the bed and hence unable to initiate sediment motion (Komar 1976); they are, however, capable of dispersing materials placed in suspension by other means.

Wave data from the area are sparse. Meteorological Office wind data (Hydrographic Department 1970) could be used to predict worst storm wave conditions expected in an average year inside the Sapodilla reef. From this information the maximum depth at which significant sediment disturbance would be expected to occur can be calculated (Soulisby and Smallman, 1986). By this method it should be possible to define a depth below which sediment disturbance by locally generated waves will normally not occur. The impact of swells penetrating the reef and of storms with a recurrence interval of greater than about ten years can not be assessed theoretically.

The marked uniformity of the sediments accumulating in basins within the leeward reef, and the apparent absence in cores of depositional features relating to periods of sediment disturbance both suggest that wave energies rarely if ever are competent to erode cohesive muddy sands below 20m depth. However, the presence of sand and *Halimeda* sp. fragments throughout the sediments of the basin indicate that wave induced currents commonly waft these non-cohesive particles from the shallower coral margins of the basins. The settling velocity data of the coarse particles are consistent with this conclusion.

The extreme angularity of the sand grains and the total lack of particle-size sorting in the sand fraction confirm that this material has not travelled far but has gravitated to the basins from the surrounding reef area where it was generated.

4.2 A THEORY OF FINE SEDIMENT DYNAMICS IN A LEEWARD REEF AREA

Corals feed on planktonic organisms. For example, measurement of depletion in oceanic water masses passing over a Caribbean reef have demonstrated a 91% reduction in the diatom crop (Barnes and Hughes 1982).

Feeding from suspension involves a mucociliary mechanism. Any drifting particle can become enmeshed in the mucus and transported by ciliary currents, either to the mouth if food or along rejection tracts if sediment. Thus the reef is a huge filtering mechanism, constantly abstracting fine particles from the base of the water mass and rejecting them as faeces and psuedo-faeces.

In terms of sediment dynamics this process is important as the mucus system radically alters the effective size of suspended particles. Very fine, readily suspended oceanic particles are transformed into quite large agglomerations of tiny particles bound together with mucus, with significantly higher settling velocities.

On the outer reef the near-constant wave energy efficiently keeps this material in motion. Passing into deeper waters on the leeward side of the reef, however, these energies die out, and the coral communities must increasingly waste their energies in playing 'pass the parcel' in an attempt to keep their surfaces free of particles. If the sediment loading (controlled by sediment influx and availability of suspending currents) becomes too great then the least efficient corals will succumb to smothering, and the seabed in this area will become a site of accumulation for the suspended materials ie. 'dustbin' areas. This development has a positive effect for the remaining colonies in that the suspended load is reduced.

This system will only be required to operate at times of peak sediment loadings, for example during storms when attrition

and abrasion are actively generating suspended solids along the outer reef, or at times of high river runoff or strong offshore winds when terrigenous material may reach the reef.

The density of occurrence of these 'dustbin' areas within the reef should reflect the balance between the vigorousness of coral growth and the severity of the occasional sediment influxes. It is likely that the number of these basins per unit area increases away from the reef towards the mud-floored channel areas.

It is suggested that this system of formation of small localised sinks, and their constant readjustment with time in response to sediment loadings, may be the mechanism of the dynamic interface which separates the reef from the deeper inshore mud-floored channel.

4.3 THE SIGNIFICANCE OF BASIN FORM

The cross-sectional characteristics of these sediment-filled basins may offer some clues as to the relative dominance of sediment accumulation as opposed to coral growth. In areas where sediment deposition is occurring at a faster rate than coral growth then the normal coral growing surfaces will simply be being swamped by sediment, and there should be no marked changes in the slope of the coral surface where it meets the sediment (figure 12A). In the balanced situation where coral and sediment levels are building up simultaneously there should be a marked break of slope at the sediment-coral boundary, with the sub-sediment coral wall descending very steeply (a 'pipe', figure 12B). Finally, where coral growth dominates the coral should stand in walls above the sediment surface, perhaps even developing overhangs (figure 12C). At the locations examined a balanced or coral-growth dominated model appears to prevail.

It was suggested in the previous section that the area of seafloor occupied by sediment basins should increase towards the primary sources of sediment influx. By the same argument the form of the basins should change similarly, passing from type C to type A as the sediment source is approached. It would be a very instructive exercise to map the variability in density of occurrence and form of sediment basins across swathes of the inner reef/channel margins. This may be practical using sonar techniques.

5. CONCLUSIONS AND RECOMMENDATIONS

The expedition has demonstrated that a team of enthusiastic but scientifically untrained volunteer divers can generate useful environmental data.

The survey has discovered that in the Sapodilla area the coral seafloor on the lee of the reef contains numerous sediment

filled depressions of varying sizes and forms. The sediments in these basins contain about 5% coarse algal/shell debris and 10-30% silt/clay, the balance being an unsorted sand of angular carbonate grains. Sediment cores and penetration tests show uniformity of deposit type and the absence of layering. Low levels of bioturbation are thought to be present.

These data indicate a stable environment of accumulation. This conclusion is consistent with slow currents measured in the areas and predictions of low potential for disturbance by wave currents under normal conditions.

These findings are favourable from the point of view of defining suitable sites for coring in order to monitor historical changes in contaminant accumulation in the area.

It is postulated that the development of small sediment basins within the coral is a manifestation of the sedimentary processes active along the interface separating the clear-water reef and turbid-water channel environments. It is possible that the proportion of the seabed covered by these basins and the form of the basins respond to spatial and temporal changes in the suspended sediment regime in this marginal zone.

It is recommended that:

- 1) Diving surveys of this type continue in this area to discover whether similar conditions prevail around the inner perimeter of the Sapodilla 'hook'.
- 2) Tasks required of the dive team continue to be refined in order to home in on the issues raised by this survey.
- 3) The deployment of suspended sediment traps at a suitable location over a one year period be considered in order to estimate present accumulation rates.
- 4) The possibility of using a side scan sonar be investigated with the aim of mapping the form of and area occupied by sediment-filled depressions over a wide zone of the reef/channel interface.
- 5) A search is initiated for suitable laboratories who might be willing to undertake dating and contaminant analyses for the ultimate monitoring programme.

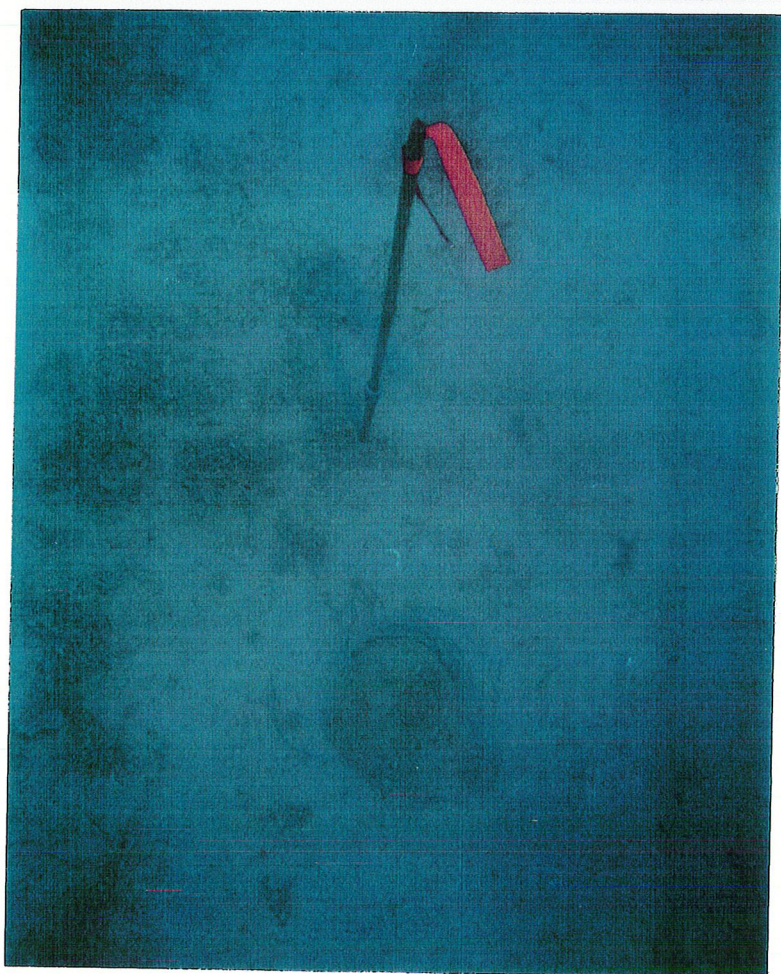
REFERENCES

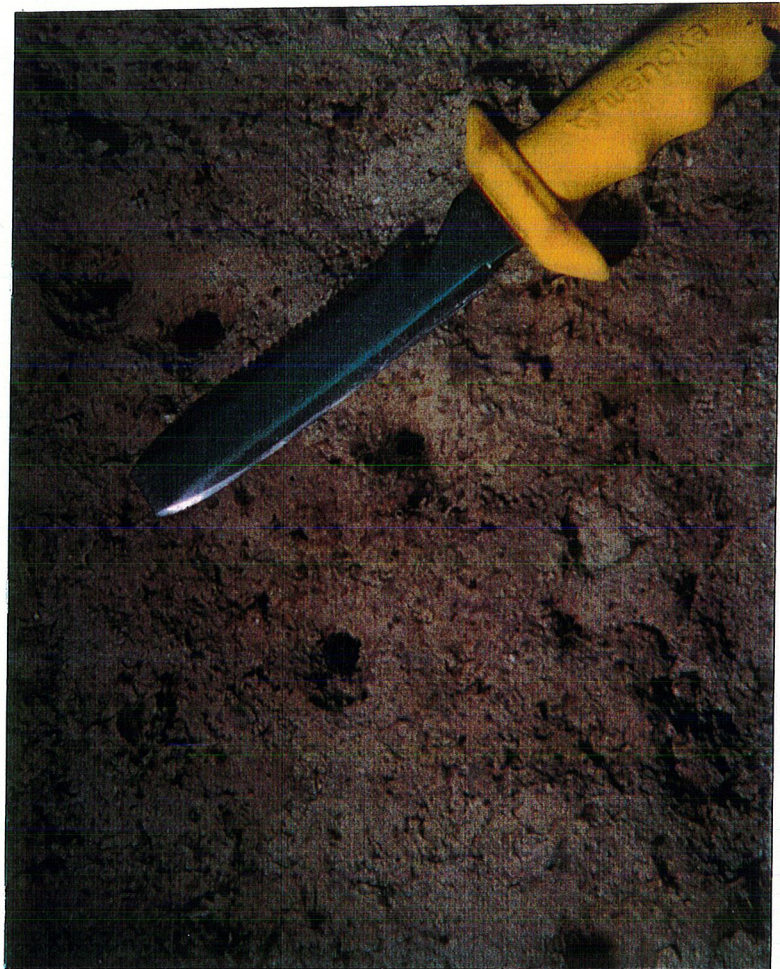
- Barnes R.S.K and Hughes R.N. 1982. An introduction to marine ecology. Blackwell Scientific Publications. Oxford, UK.
- Hydrographic Department. 1970. East Coasts of Central America and Gulf of Mexico pilot. Ministry of Defence, Taunton, UK.
- Komar P.D. 1976. The transport of cohesionless sediments on continental shelves. Chapter in Marine Sediment Transport and Environmental Management. eds Stanley D.J. and Swift D.J.P. Wiley Interscience, New York.
- Soulsby R. and Smallman J. 1986. A direct method of calculating bottom orbital velocity under waves. Hydraulics Research Report SR 70. HRL. UK.
- Zisman S. 1992. Mangroves in Belize: Their characteristics, use and conservation. Forest Planning and Management Project.
- Nunny R.S. 1992. Report of field survey, Hunting Cay, Belize. November 1992. Coral Cay Conservation.

PLATES

FIRST PAGE: -Current meter deployed at site 59.
 -Seabed site showing flag marking pin-penetration
 site and hole left by core removal.
 -Core section showing uniform texture and
structure of sediment.

SECOND PAGE: -Various views of coral margins to sediment-filled
 basins.
 -Close-up of sediment surface showing in-fauna
 burrows.





SITE	DEPTH	START	FINISH	LAT	LONG
52	30m	08.53 2/4/93	17.00 6/4/93	16 08.50	88 17.80
58	25m	07.43 15/4/93	11.30 19/4/93	16 07.92	88 17.38
59	11m	13.14 7/4/93	16.05 14/4/93	16 07.08	88 16.86

TABLE 1. CURRENT METER OBSERVATION LOG

CORE NO.	DATE	LOC	LAT DEG	MIN	LONG DEG	MIN	WATER DEPTH m	CORE LENGTH mm	SECTION LENGTH mm
51.1	03/04/93		16	8.50	88	17.80	37	290	50
51.2	03/04/93		16	8.50	88	17.80	37	120	
59.1	07/04/93	N	16	7.06	88	16.86	21	260	50
59.2	07/04/93	NE	16	7.06	88	16.86	21	210	50
59.3	07/04/93	S	16	7.06	88	16.86	21	250	50
59.4	07/04/93	C	16	7.06	88	16.86	21	250	50
52.1	13/04/93	N	16	8.38	88	17.76	31	220	50
52.2	13/04/93	E	16	8.38	88	17.76	31	295	50
52.3	13/04/93	W	16	8.38	88	17.76	31	225	50
52.4	13/04/93	C	16	8.38	88	17.76	31	160	50
58.1	15/04/93	SE	16	7.91	88	17.38	28	210	50
58.2	14/04/93	C	16	7.91	88	17.38	28	270	50
58.3	15/04/93	NE	16	7.91	88	17.38	28	250	50
58.4	15/04/93	NW	16	7.91	88	17.38	28	260	50

TABLE 2. LOG OF CORES COLLECTED

Heights in cm; periods in seconds

DATE	TIME	WIND		OCEAN WAVES			LAGOON WAVES		
		BFORT	DIR	H(max)	Tz	DIR	H(max)	Tz	DIR
31/03/93	10.06	1	155	150	9	135	12	9	315
31/03/93	12.06	1	155	100	9	115	10	9	315
31/03/93	13.56	1	100	100	9	115	10	9	315
31/03/93	17.05	1	100	75	9	115	6	8	315
31/03/93	18.25	3	100	75	5	115	6	7	315
01/04/93	7.00	1	66	75	7	90	11	9	320
01/04/93	9.05	2	66	75	7	90	5	8	320
01/04/93	11.00	2	320	150	8	90	7	8	315
01/04/93	13.00	1	330	100	8	80	4	7	320
01/04/93	15.10	2	60	50	90	90	7	7	350
01/04/93	18.15	2	40	40	6	90	7	7	350
02/04/93	6.30	1	60	50	6	90	7	4	330
02/04/93	8.45	3	45	60	7	90	5	4	350
02/04/93	9.30	3	350				7	3	350
02/04/93	10.30	4	45	50	8	60	9	3	350
02/04/93	13.30	3	45	50	7	60	7	4	350
02/04/93	15.00	4	30	75	6	60	8	3	360
02/04/93	18.00	4	30	50	5	60	8	4	360
03/04/93	6.30	4	60	60	6	75	5	3	350
03/04/93	7.30	2	50	55	6	70	4	3	350
03/04/93	9.30	1	60	50	6	60	3	3	360
03/04/93	11.30	2	60	50	6	60	5	3	350
03/04/93	15.00	2	60	50	6	60	5	3	360
03/04/93	17.00	1	55	60	8	60	7	3	360
05/04/93	6.55	1	30	50	8	100	13	2	320
05/04/93	8.15						14	3	320
05/04/93	9.15	1	40	40	6	75	12	3	320
05/04/93	11.15	1	40	50	7	60	10	5	350
05/04/93	13.00	1	40	60	8	65	9	4	350
05/04/93	18.00	1	35	50	6	70	9	5	360
06/04/93	6.47	1	90	30	7	70	6	9	330
06/04/93	8.20	1	65	30	6	70	6	7	330
06/04/93	10.20	1	65	20	5	80	6	7	310
06/04/93	12.25	1	70	20	7	70	4	6	330
06/04/93	14.45	1	45	30	7	75	4	5	330
07/04/93	7.10	2	330	80	6	90	10	5	330
07/04/93	10.50	1	330	50	5	90	1	8	330
07/04/93	12.40	1	330	30	5	80	2	6	330
07/04/93	18.05	1	360	50	4	70	7	4	350
08/04/93	6.55	1	350	60	6	90	9	5	350
08/04/93	8.00	3	190	60	6	90	6	5	315
08/04/93	9.15	2	190	60	5	90	7	5	230
08/04/93	10.15	2	270	60	5	90	8	5	230
08/04/93	13.45	1	330	30	6	90	4	6	330
08/04/93	15.00	1	330	40	6	90	6	3	315

TABLE 3. WIND AND WAVE RECORDS, HUNTING CAY.

DATE	TIME	WIND		OCEAN WAVES			LAGOON WAVES		
		BFOR	DIR	H(max)	Tz	DIR	H(max)	Tz	DIR
09/04/93	7.15	2	225	100	7	90	15	2	225
09/04/93	9.55	2	245	70	9	90	20	2	245
09/04/93	11.00	3	245	100	8	90	15	2	245
09/04/93	12.50	3	245	40	8	90	12	3	245
09/04/93	16.29	2	240	30	8	90	8	4	270
09/04/93	18.25	1	340	30	7	90	6	3	280
10/04/93	7.00	2	10	15	8	80	12	4	315
10/04/93	9.10	1	10	20	7	90	8	5	310
10/04/93	11.00	1	30	20	6	110	6	5	320
10/04/93	6.00	1	50	15	5	90	2	4	330
11/04/93	12.00	1	330	15	6	45	7	5	330
11/04/93	13.00	1	340				4	4	340
11/04/93	14.00	1	340	10	6	45	4	5	340
11/04/93	16.00	1	330	10	4	45	5	2	330
11/04/93	17.00	1	330				3	3	330
12/04/93	11.10	3	80	30	4	110	5	2	360
12/04/93	13.00	3	30	25	4	60	6	2	350
12/04/93	18.00	3	255	30	4	60	8	4	340
13/04/93	6.30	0		25	4	90	2	2	340
13/04/93	8.00	1	45	25	5	90	4	2	315
13/04/93	9.30	0		25	5	90	3	2	340
13/04/93	11.10	1	360	30	6	90	5	3	340
13/04/93	14.55	2	11	30	6	90	8	3	340
13/04/93	16.35	2	90	30	6	90	8	2	340
14/04/93	9.15	0	330	30	6	90	5	2	310
14/04/93	12.30	1	330	50	6	90	7	3	310
14/04/93	14.30	1	330	60	7	90	4	3	310
15/04/93	6.10	0		70	3	90	10	4	240
15/04/93	9.20	1	270	90	8	90	10	3	240
15/04/93	13.00	1	180				8	2	300
15/04/93	15.17	1	80	100	8	90	13	9	340
16/04/93	7.00	3	270	70	8	100	15	5	270
16/04/93	8.00	3	270	70	15	90	15	5	250
16/04/93	9.00	3	250	80	10	85	15	5	280
16/04/93	10.00	3	240	100	9	90	15	4	270
16/04/93	12.00	3	240	100	9	90	10	3	260
16/04/93	13.10	1	240	100	7	90	10	3	260
16/04/93	14.05	1	240	100	7	90	10	3	260
16/04/93	15.05	1	240	150	7	90	10	5	280
16/04/93	16.00	1	240	150	7	90	10	3	280
16/04/93	17.00	0		100	9	90	10	3	280
17/04/93	7.45	1	270	20	9	90	10	2	280
17/04/93	9.15	1	270						
17/04/93	15.30	2	70	20	11	90	5	2	330
17/04/93	18.30	2	60	40	6	60	7	3	330

TABLE 3....CONTINUED

SAMPLE NO.	SLICE		PERCENTAGES		CORE MEANS		SITE MEANS	
	TOP	BOT	>2mm	<63um	>2mm	<63um	>2mm	<63um
51.1	0-5		1.2	12.2				
	5-10		1.2	27.4				
	10-15		1.4	23.2				
	15-20		1.1	41.6				
	20-25		1.2	34.1				
	25-29		1.4	18.6	1.3	26.2	1.3	26.2
59.1	0-5		1.8	22.8				
	5-10		1.4	27.0				
	10-15		1.3	23.8				
	15-20		2.9	16.2				
	20-26		1.4	25.4	1.8	23.0		
59.2	0-5		1.2	20.0				
	5-10		2.9	7.6				
	10-15		14.8	9.0				
	15-20		4.0	15.1	5.7	12.9		
59.3	0-5		3.9	10.5				
	5-10		1.4	25.4				
	10-15		5.0	13.8				
	15-20		1.3	20.0				
	20-25		1.2	12.0	2.6	16.3		
59.4	0-5		0.9	19.0				
	5-10		0.9	14.7				
	10-15		0.7	3.4				
	15-20		0.9	13.3				
	20-24		0.8	14.2	0.8	12.9	2.7	16.3
52.1	0-5		1.1	11.0				
	5-10		1.1	14.9				
	10-15		1.2	12.3				
	15-22		2.0	14.0	1.4	13.1		
52.2	0-5		2.7	5.3				
	5-10		1.2	11.8				
	10-15		1.4	5.8				
	15-20		3.1	1.5				
	20-25		0.0	6.5				
	25-29		12.1	6.9	3.4	6.9		
52.3	0-5		2.7	4.1				
	5-10		1.2	8.2				
	10-15		1.2	10.8				
	15-23		1.6	14.6	1.7	9.4		
52.4	0-5		7.5	6.3				
	5-10		12.6	6.9				
	10-16		18.9	13.1	13.0	8.6	4.9	9.5

TABLE 4. PARTICLE SIZE FRACTIONS (% BY WEIGHT) OF CORE SAMPLES

SAMPLE
NO.

	SLICE		PERCENTAGES		CORE MEANS		SITE MEANS	
	TOP	BOT	>2mm	<63um	>2mm	<63um	>2mm	<63um
58.1	0-5	SAMPLE LOST						
	5-10	1.2	24.4					
	10-15	1.1	24.4					
	15-21	1.2	27.1	1.2	25.3			
58.2	0-5	1.1	14.9					
	5-10	1.0	18.8					
	10-15	1.4	18.8					
	15-20	2.3	23.3					
	20-27	1.1	17.6	6.9	18.7			
58.3	0-5	2.6	21.1					
	5-10	3.4	24.1					
	10-15	3.7	22.0					
	15-20	12.2	14.6					
	20-25	1.7	23.7	4.7	21.1			
58.4	0-5	2.5	21.3					
	5-10	1.3	25.3					
	10-15	4.2	26.8					
	15-20	1.1	23.4					
	20-26	2.6	26.0	2.3	24.6	3.8	22.4	

TABLE 4....CONTINUED.

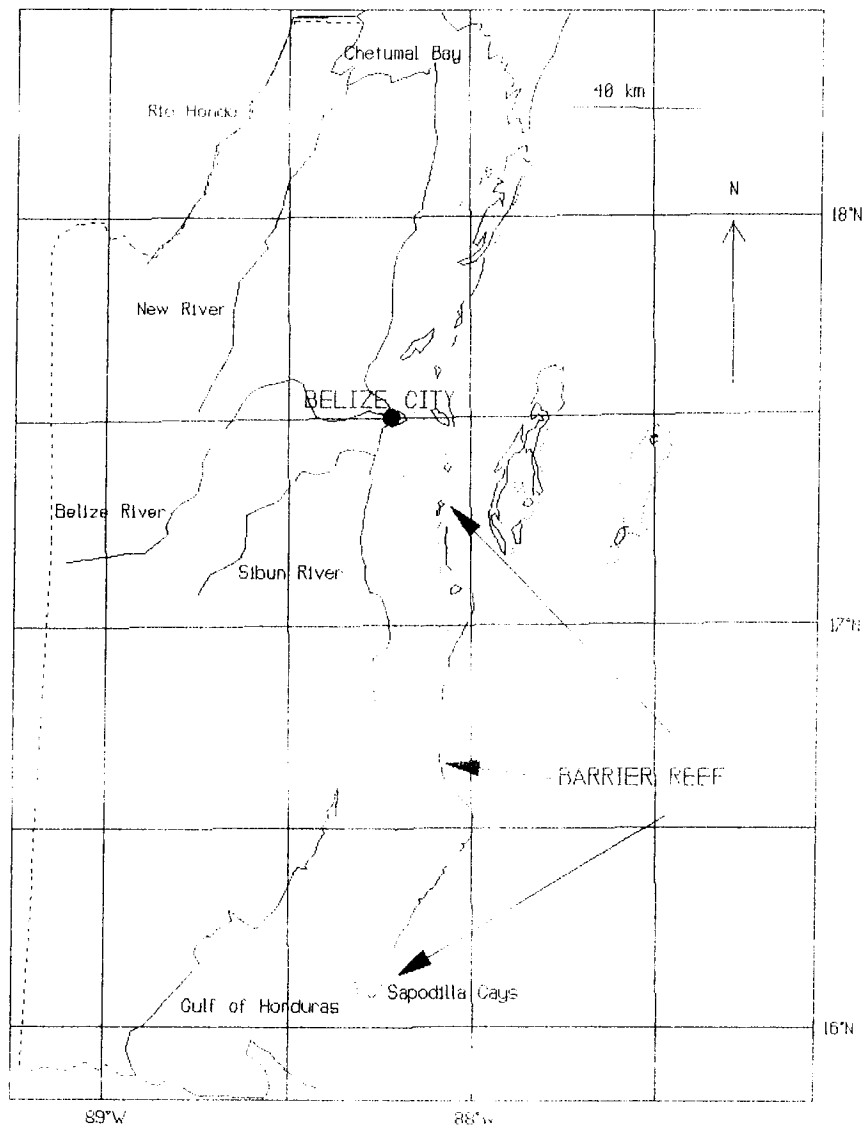


FIGURE 1. LOCATION MAP.

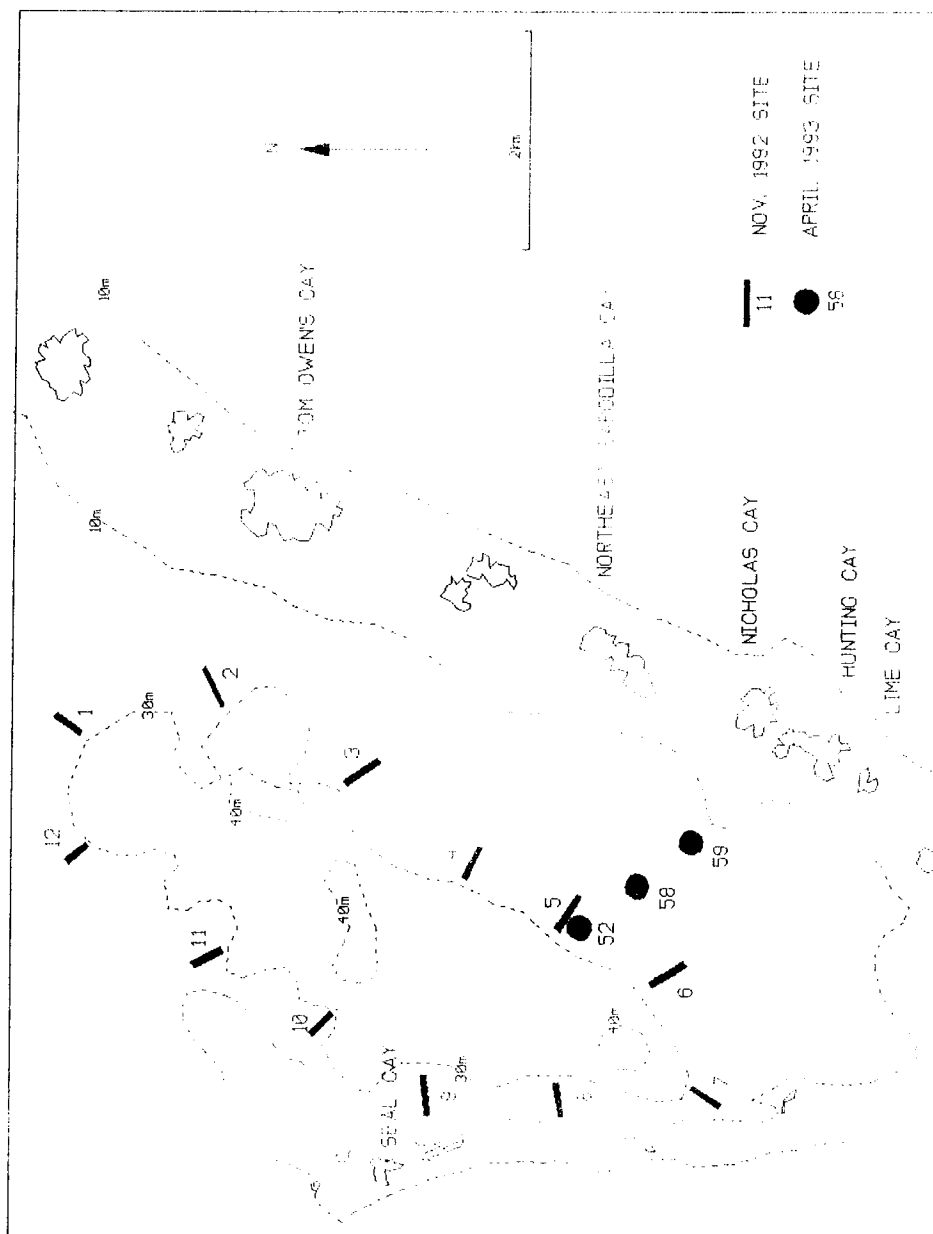


FIGURE 2. SURVEY LOCATIONS IN THE SAPODILLA CAYS

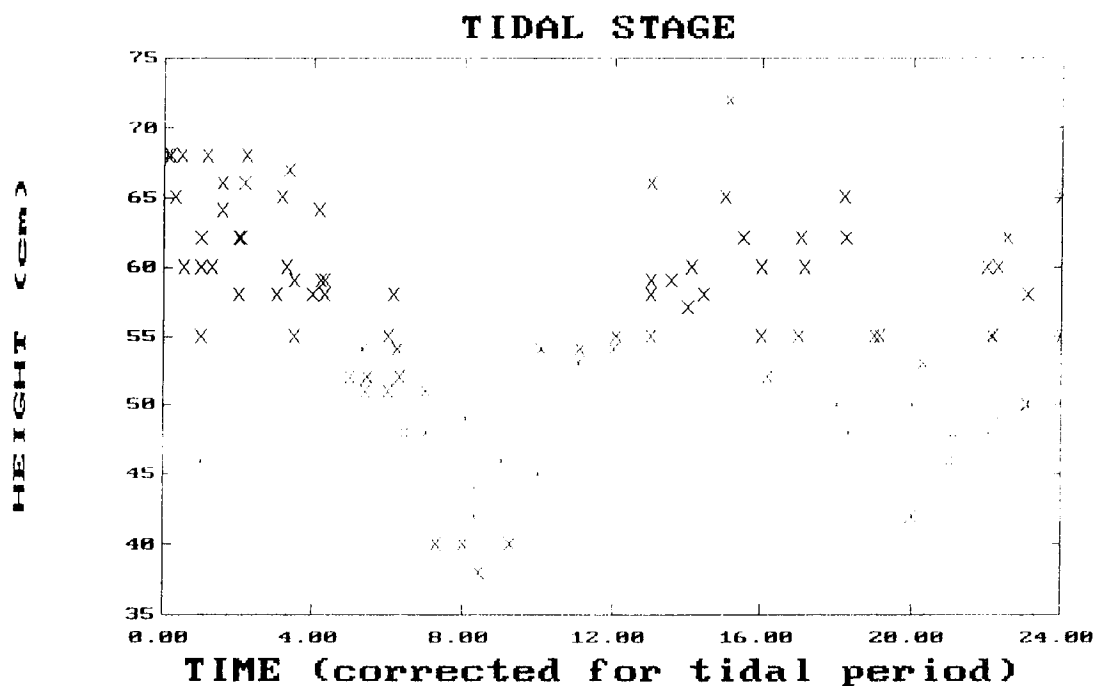
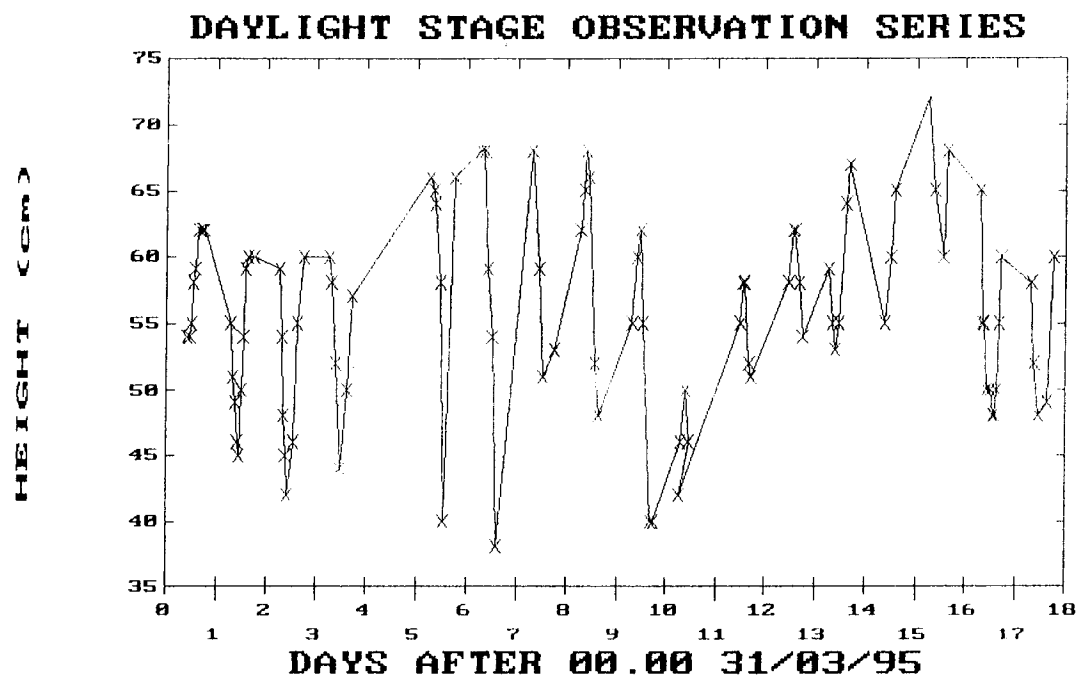


FIGURE 3. SUMMARY OF TIDAL LEVEL DATA COLLECTED AT HUNTING CAY DURING APRIL 1993.

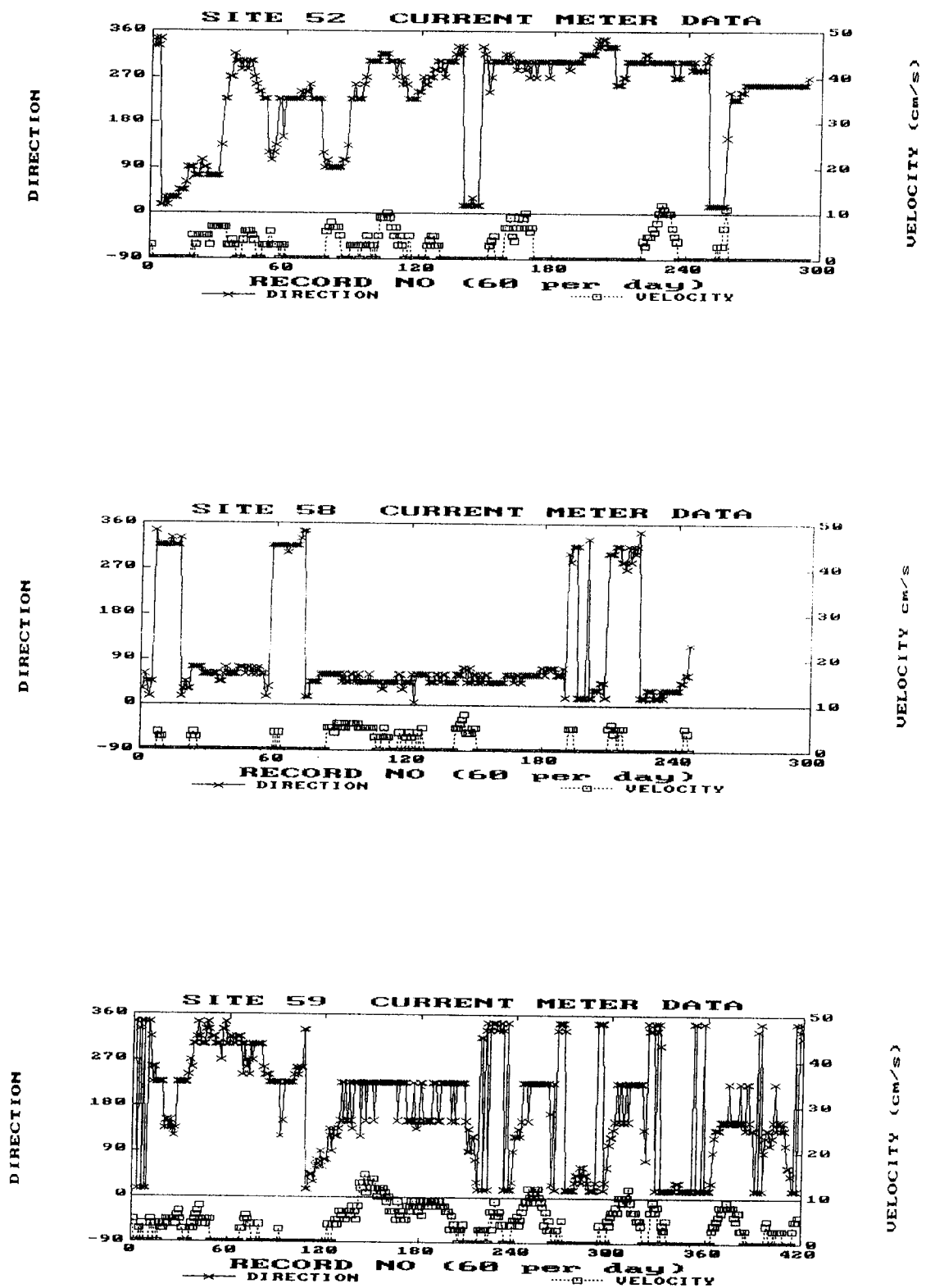


FIGURE 4. PLOTS OF CURRENT METER VELOCITY & DIRECTION DATA

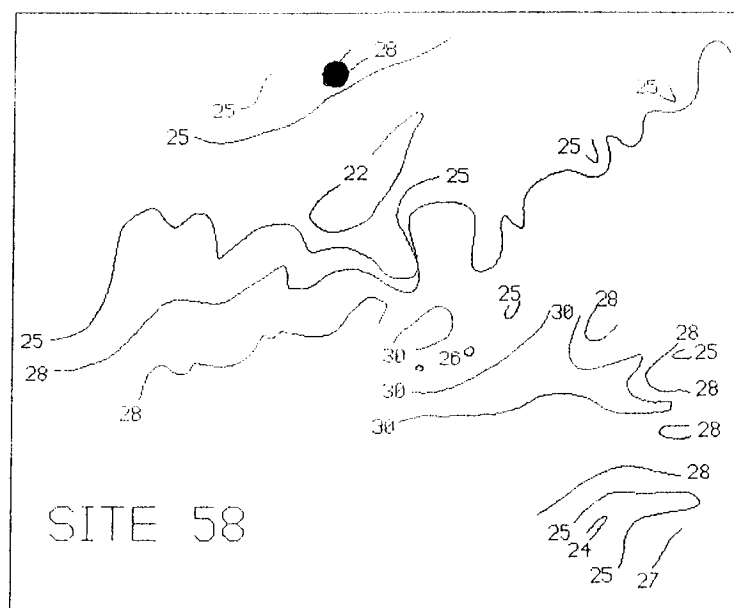
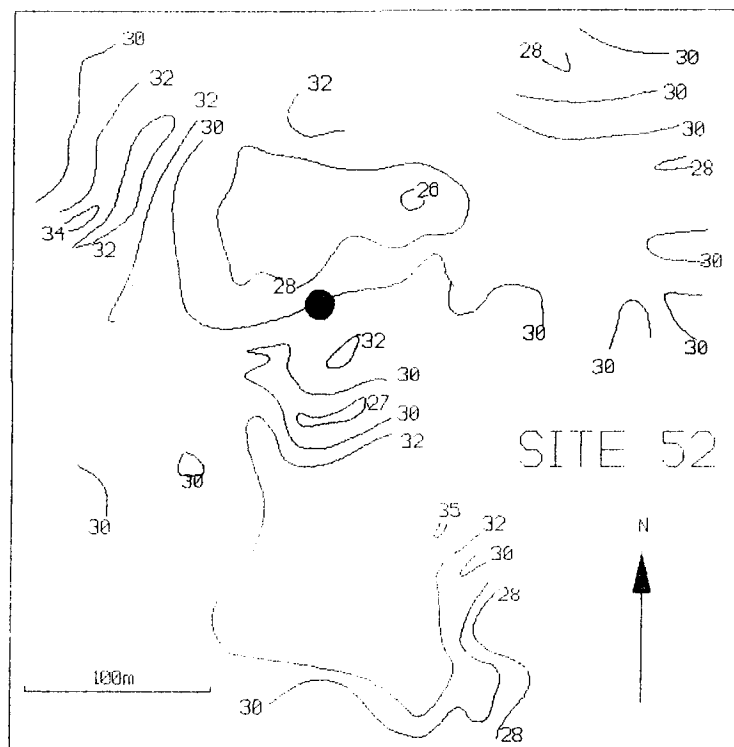


FIGURE 5. BATHYMETRY AT THE THREE SURVEY SITES.
 Depths in metres below mean sea level.
 Spot indicates location of sediment basin.

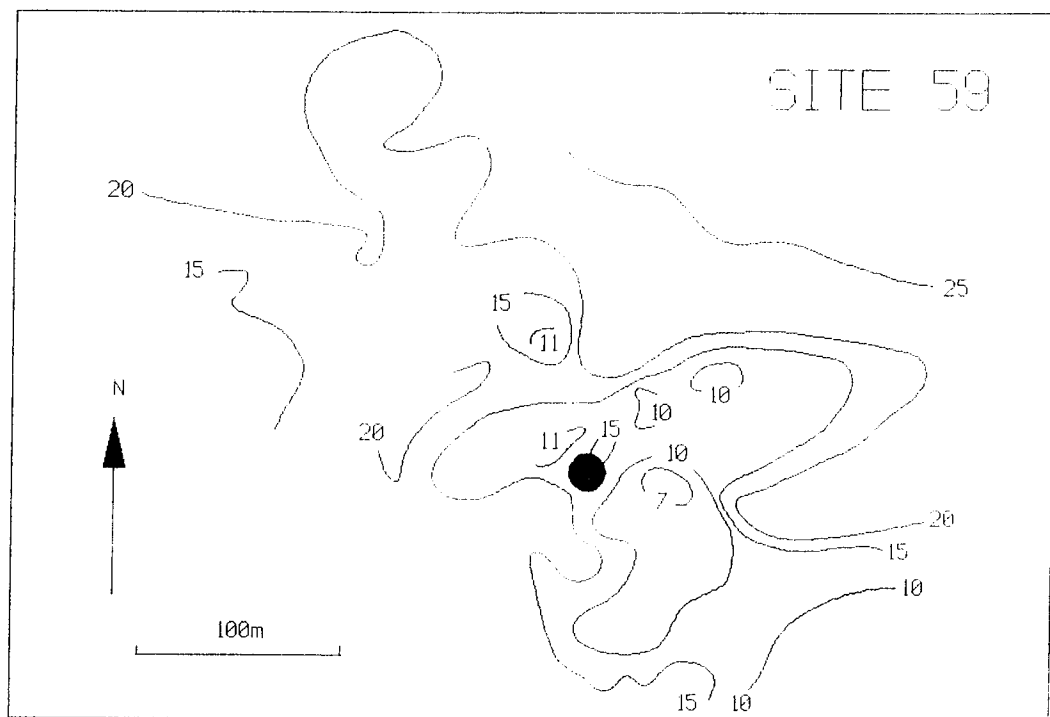


FIGURE 5...Continued.

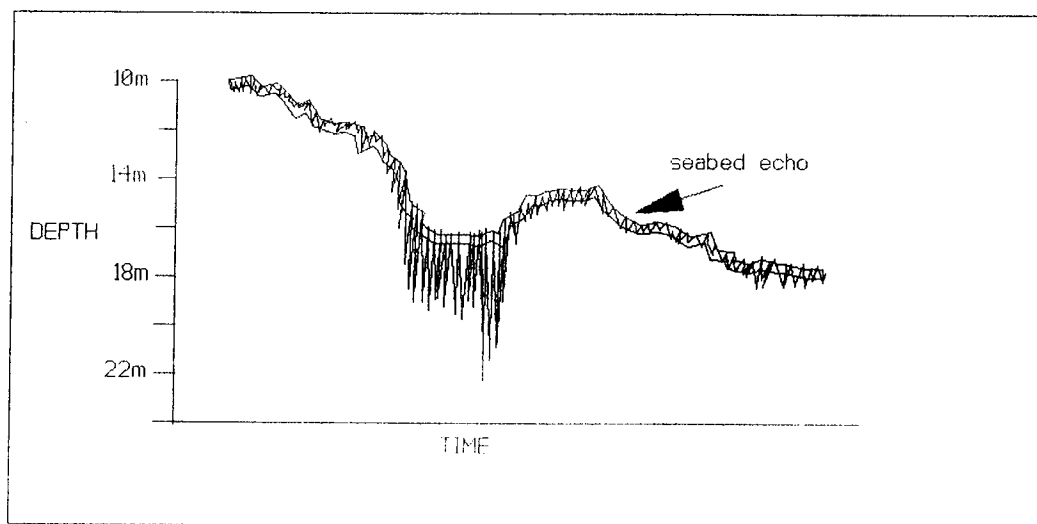


FIGURE 6. TYPICAL ECHO TRACE OVER A LARGE SEDIMENT BASIN.

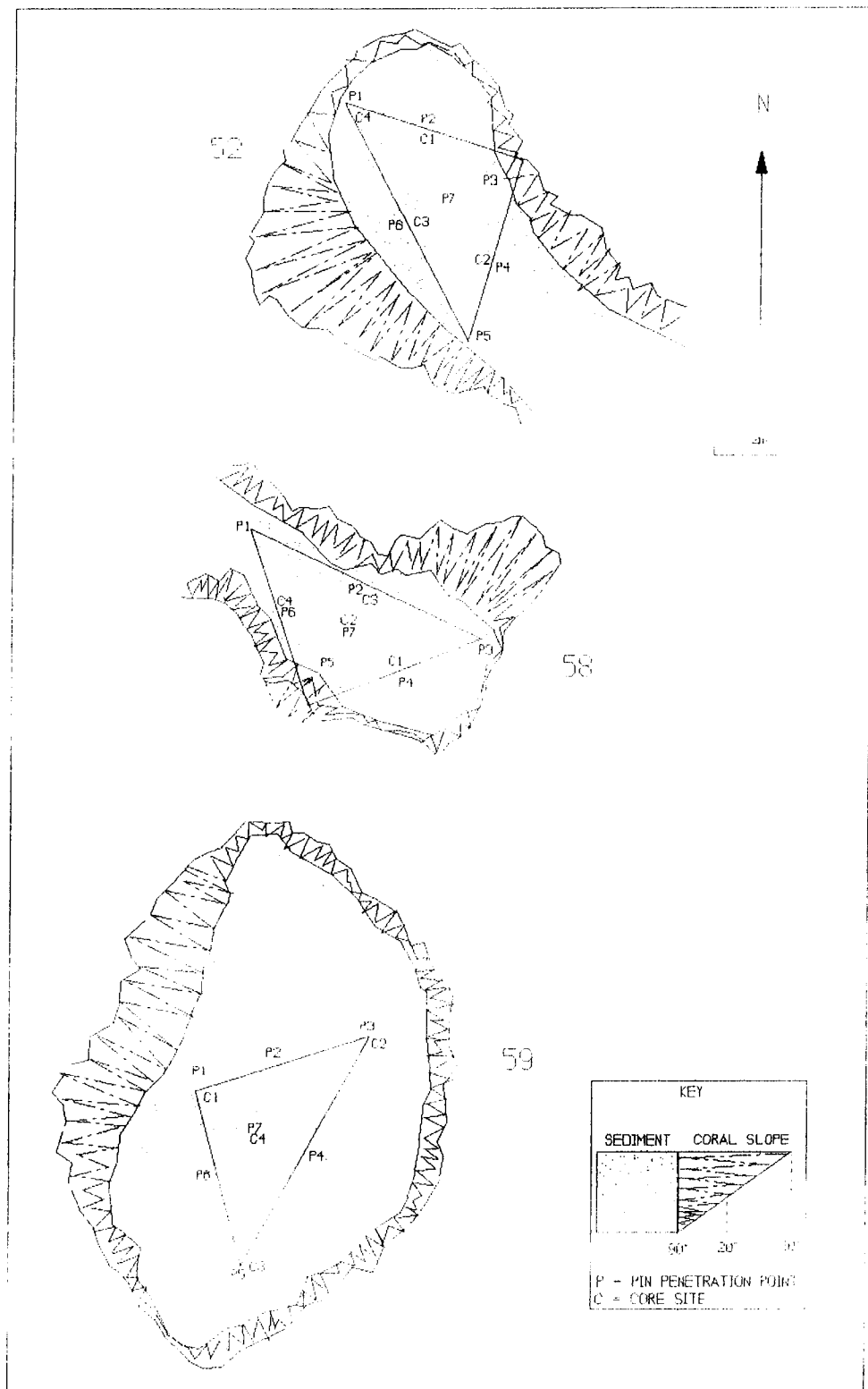


FIGURE 7. PLANS OF THREE SEDIMENT BASINS SURVEYED.

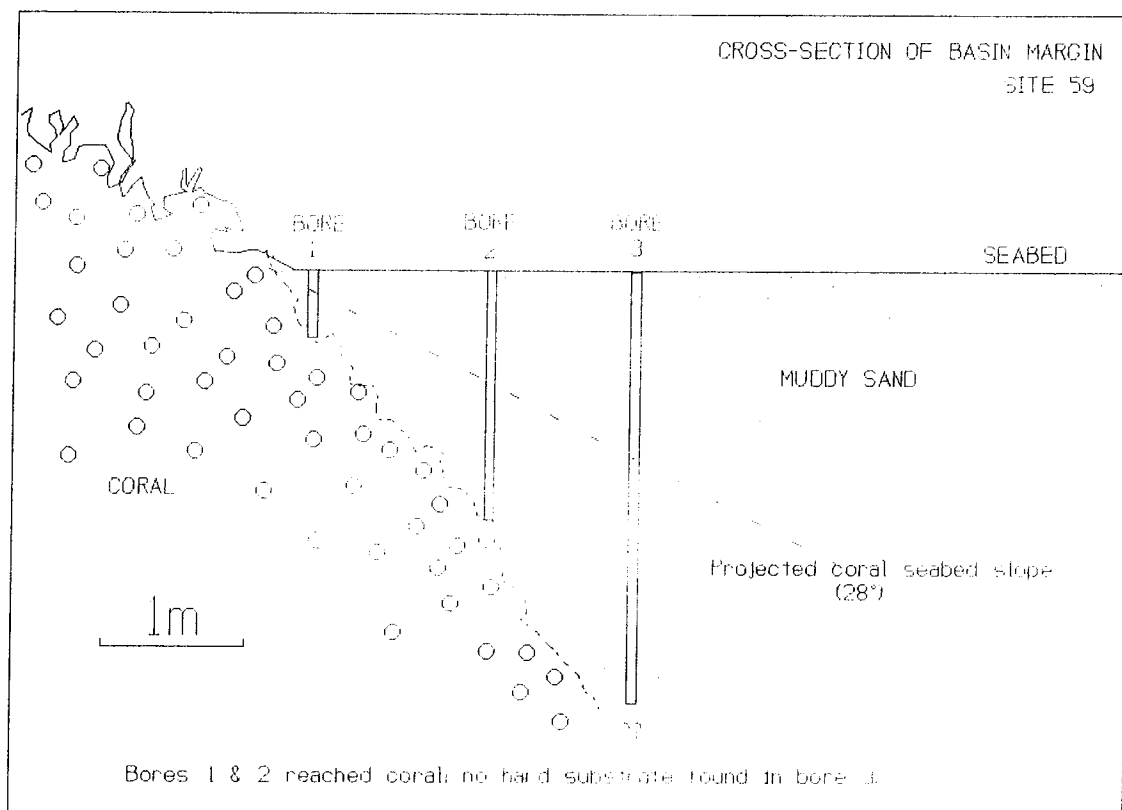


FIGURE 8. SUB-SEDIMENT BASIN MARGIN DETERMINED BY BORING.

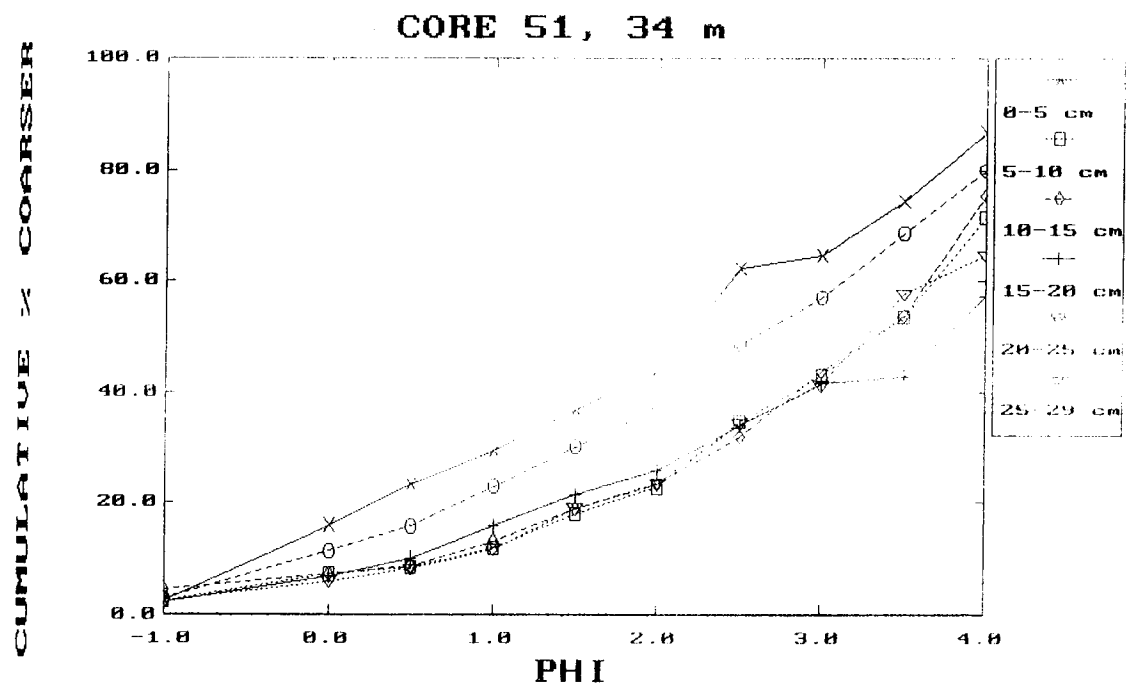


FIGURE 9. A: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

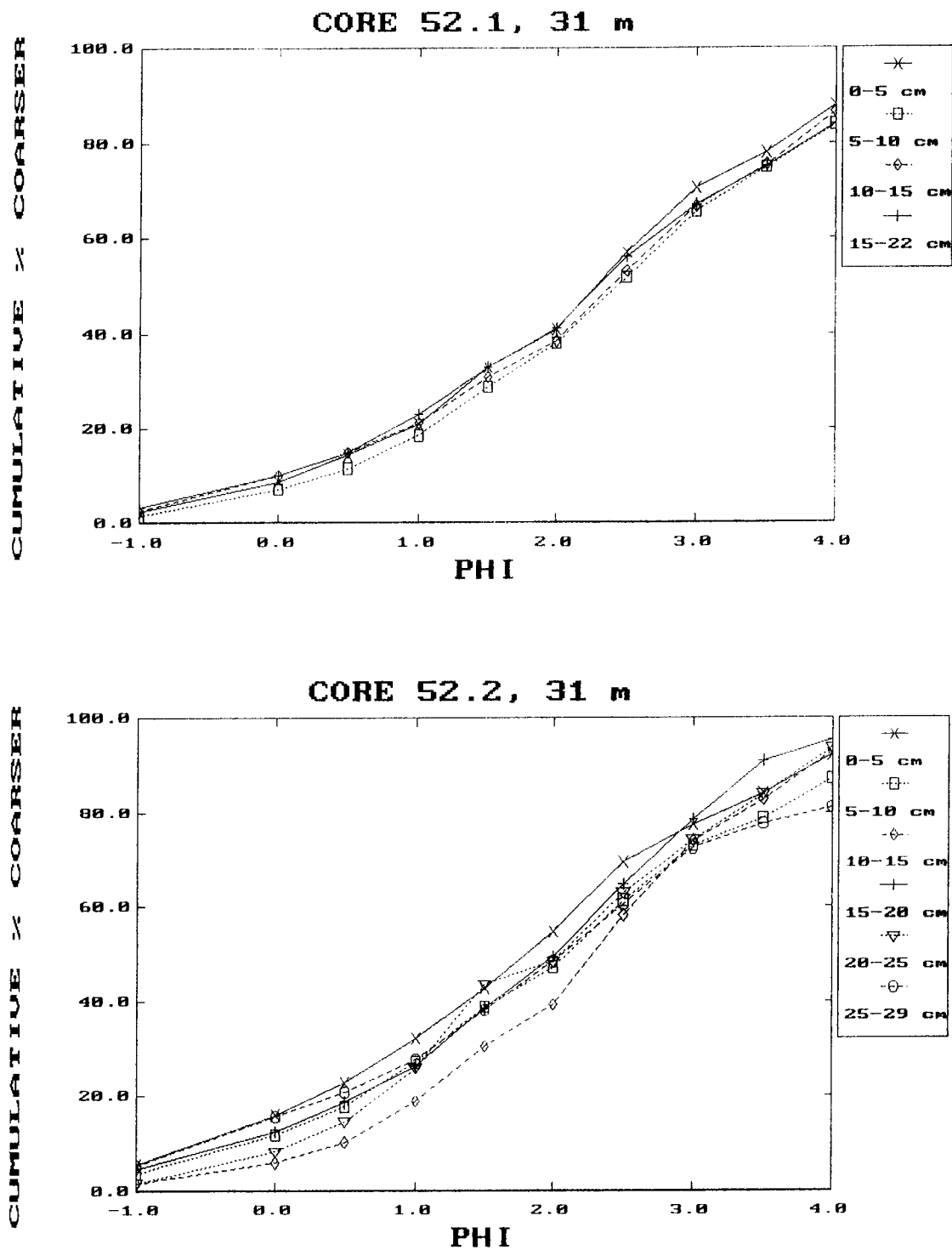


FIGURE 9. B: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

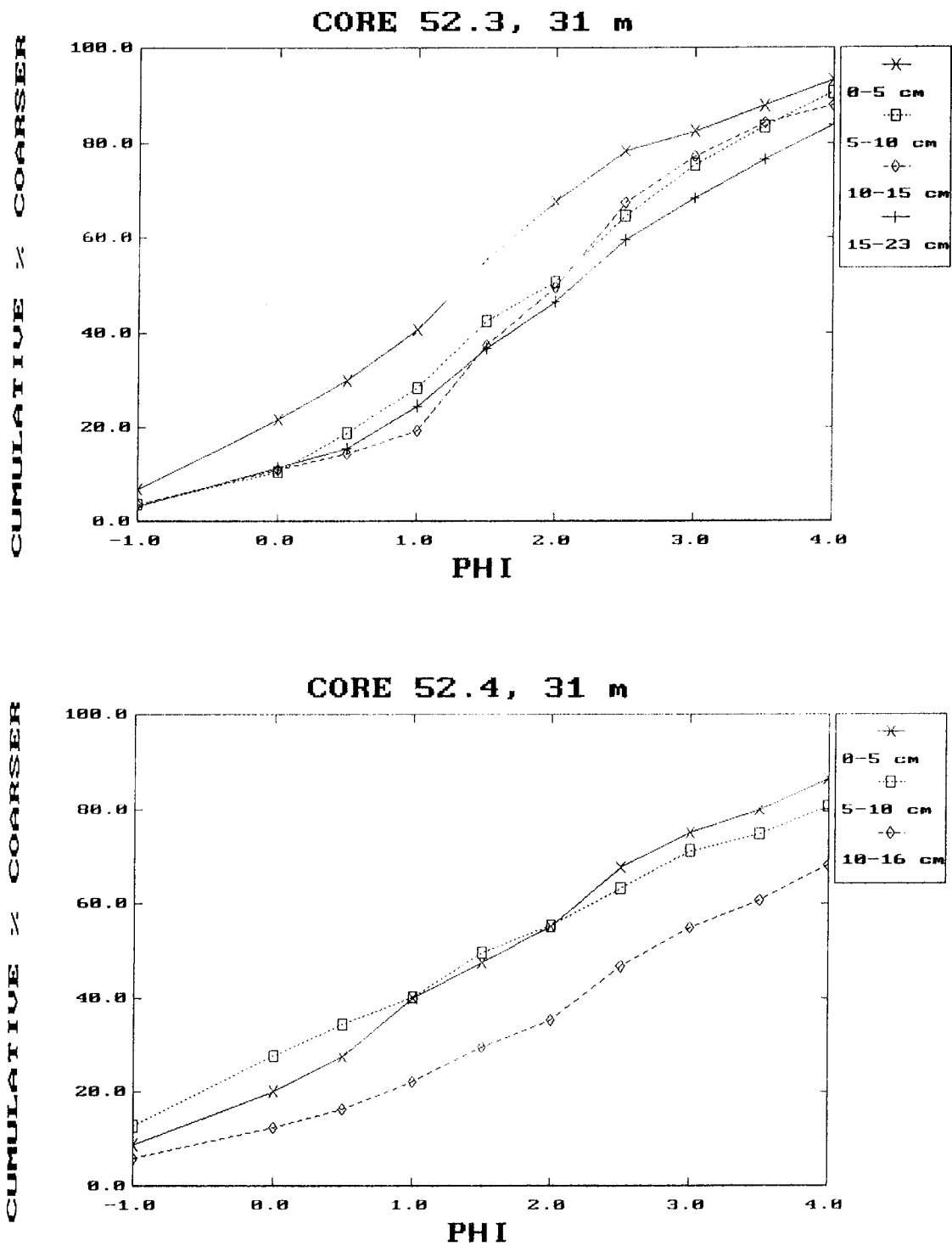


FIGURE 9. B: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

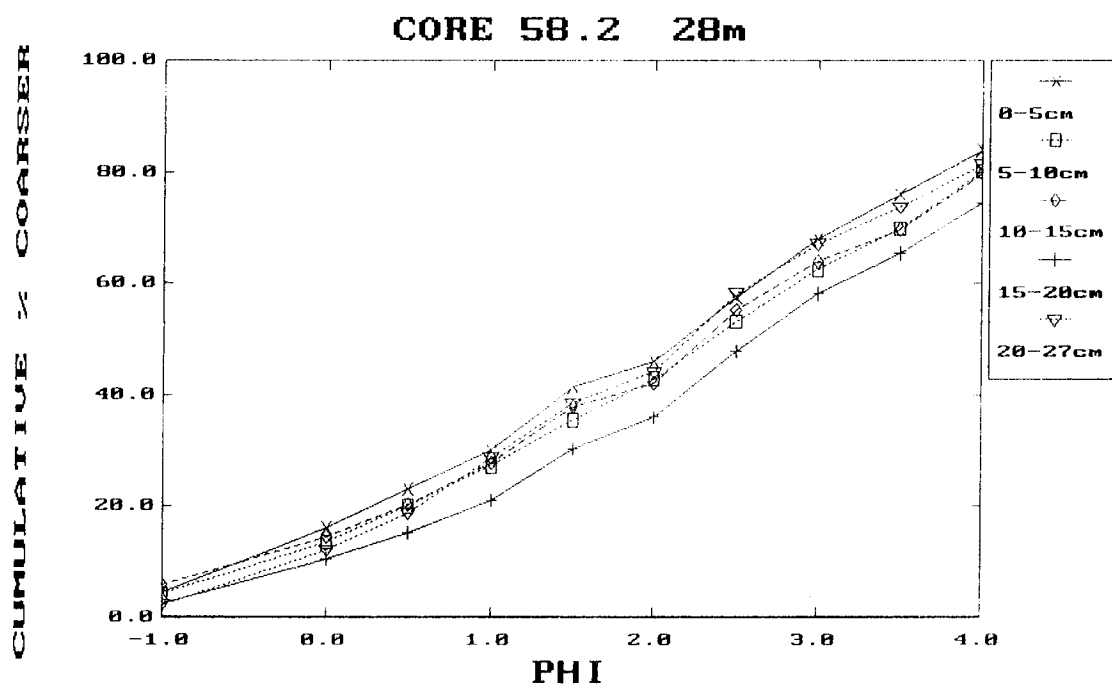
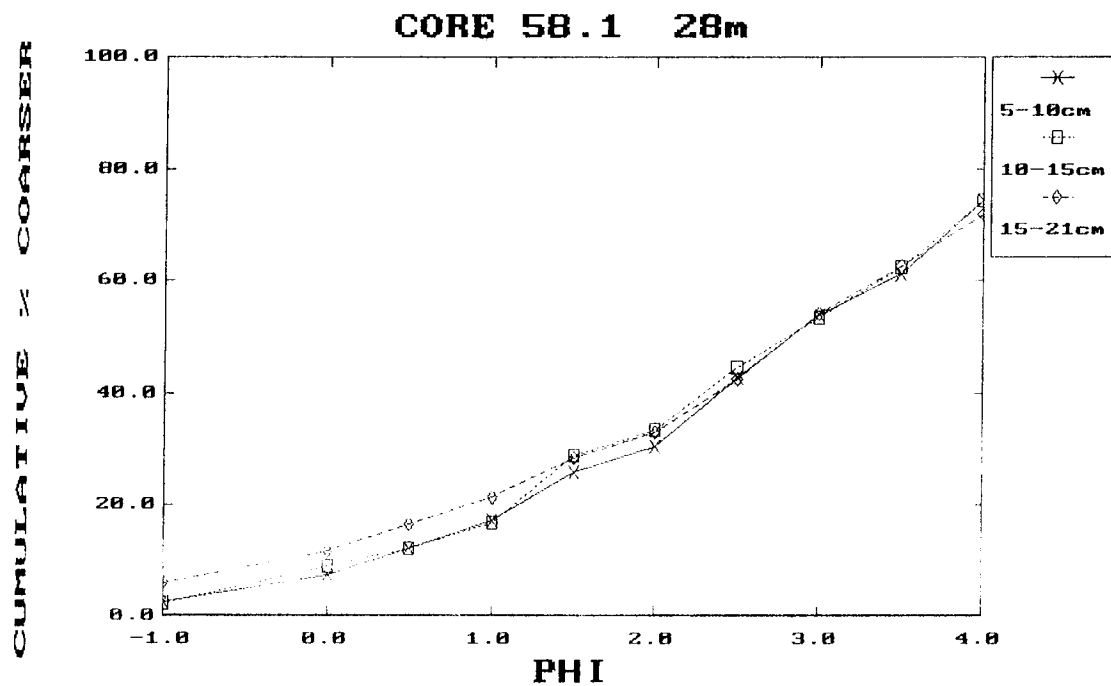


FIGURE 9. C: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

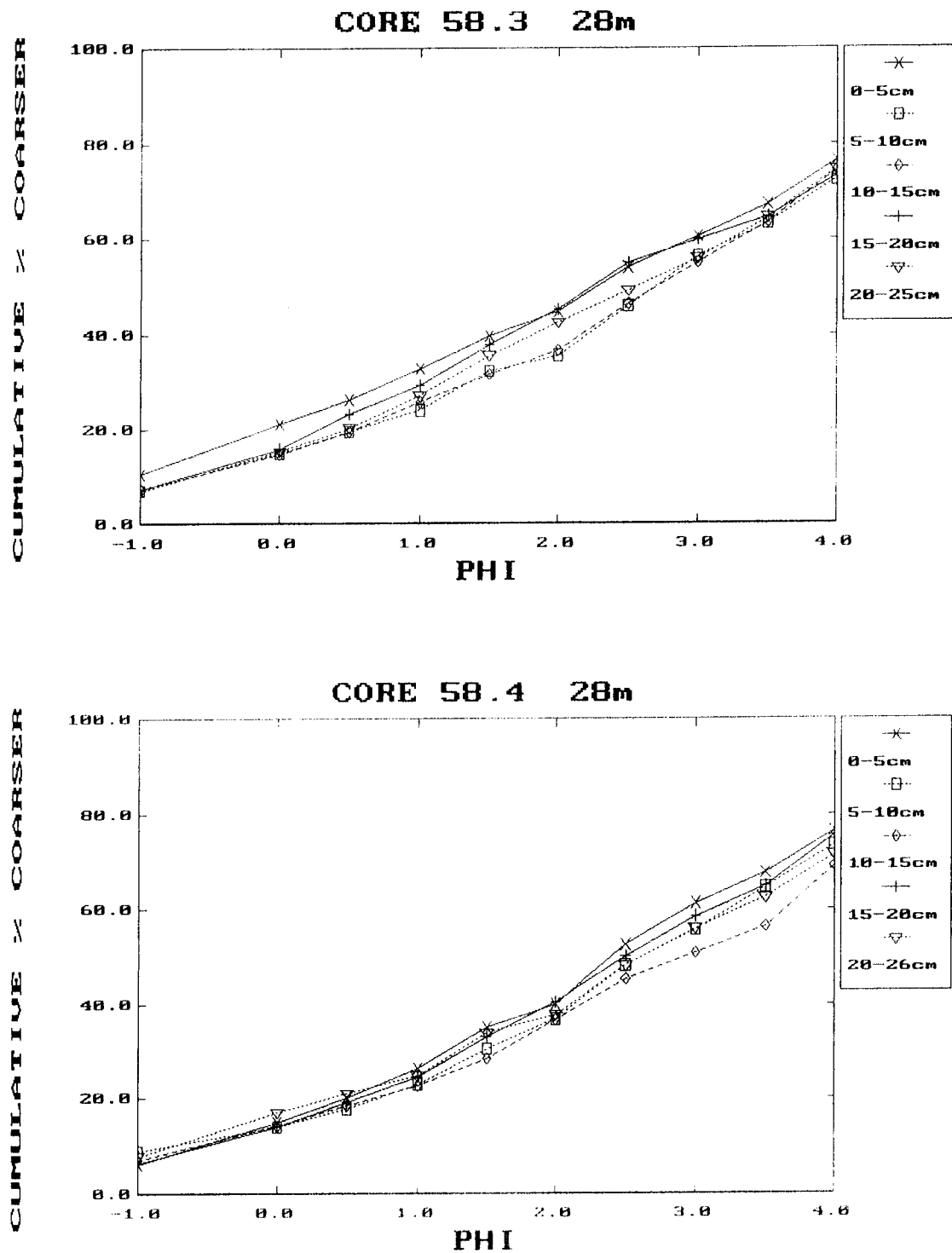


FIGURE 9. C: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

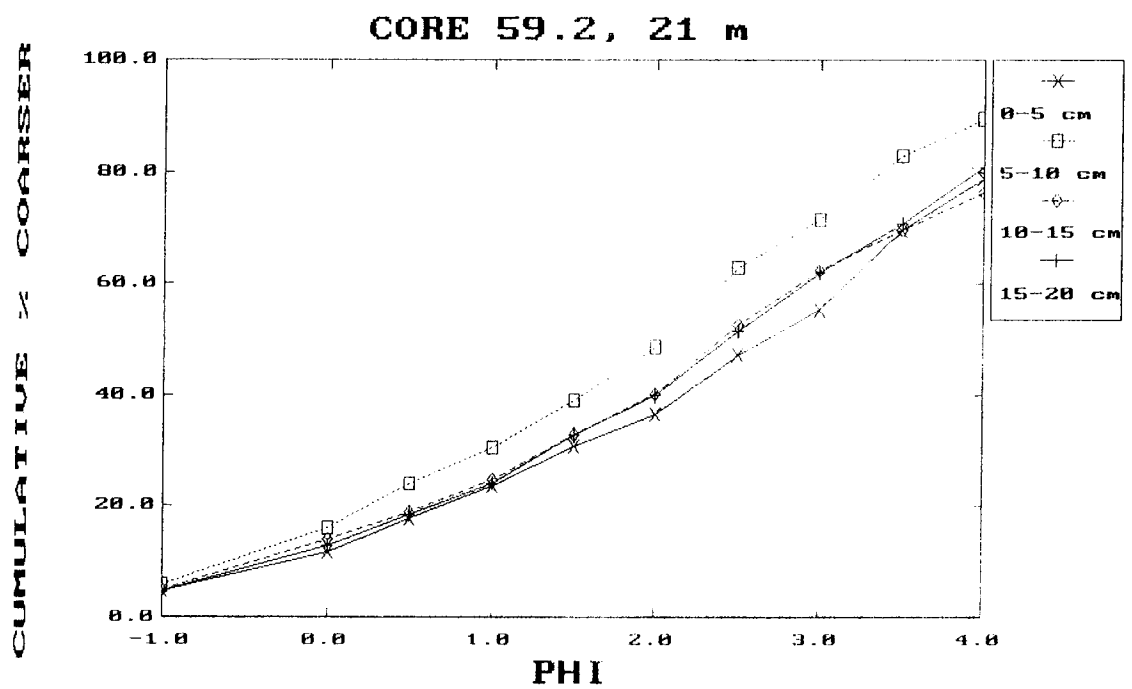
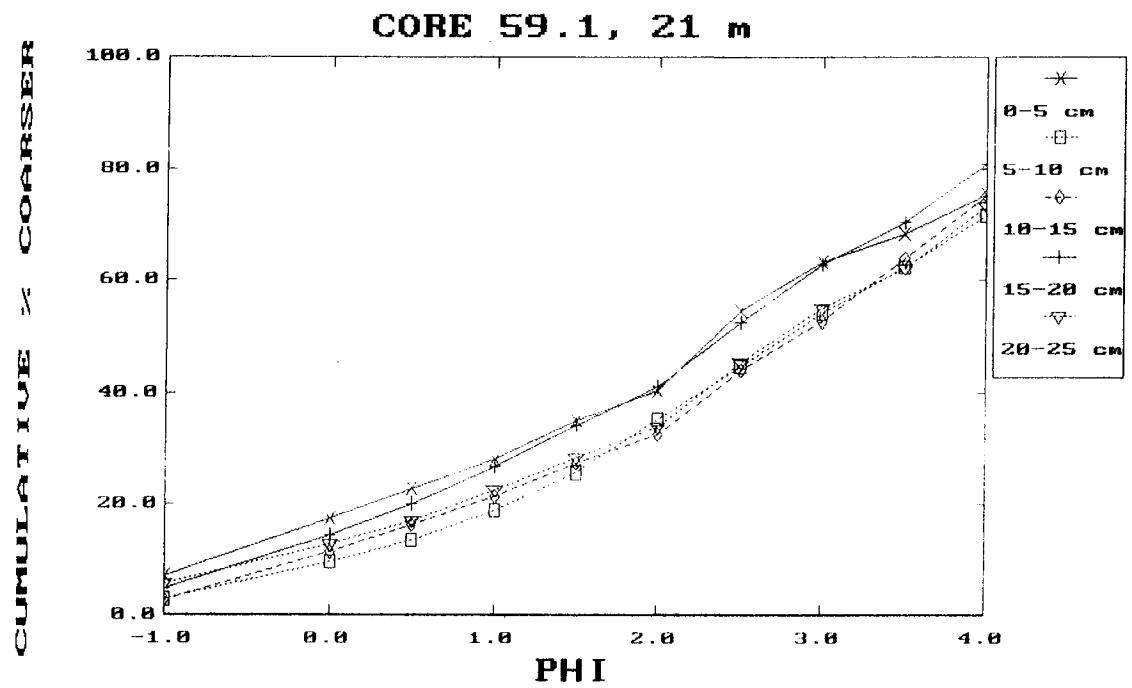


FIGURE 9. D: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

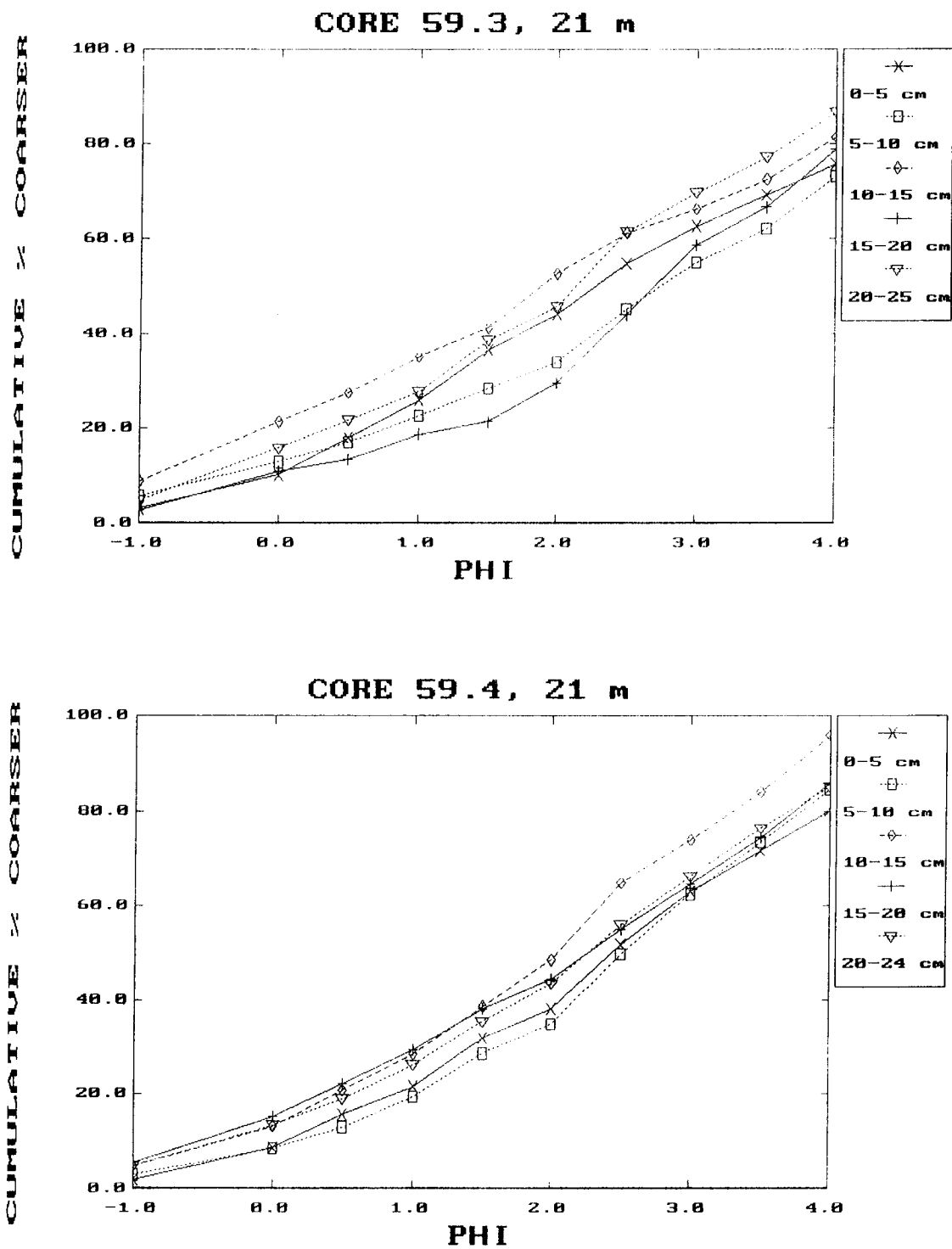


FIGURE 9. D: SAND FRACTION PARTICLE-SIZE DATA FROM CORES

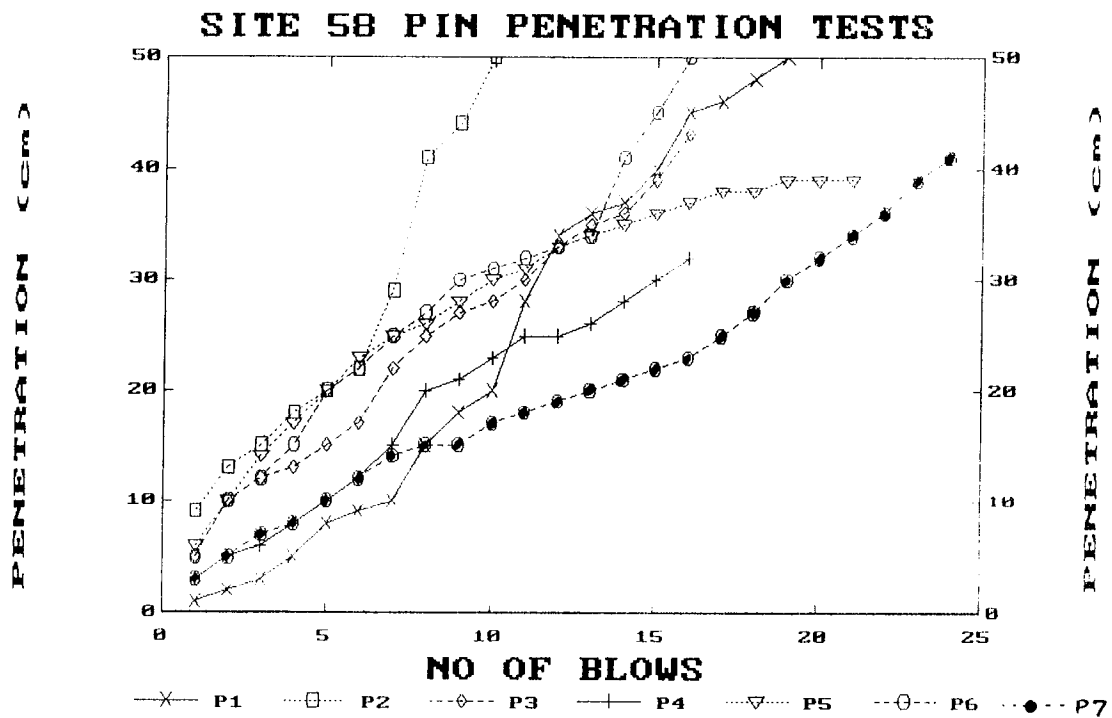
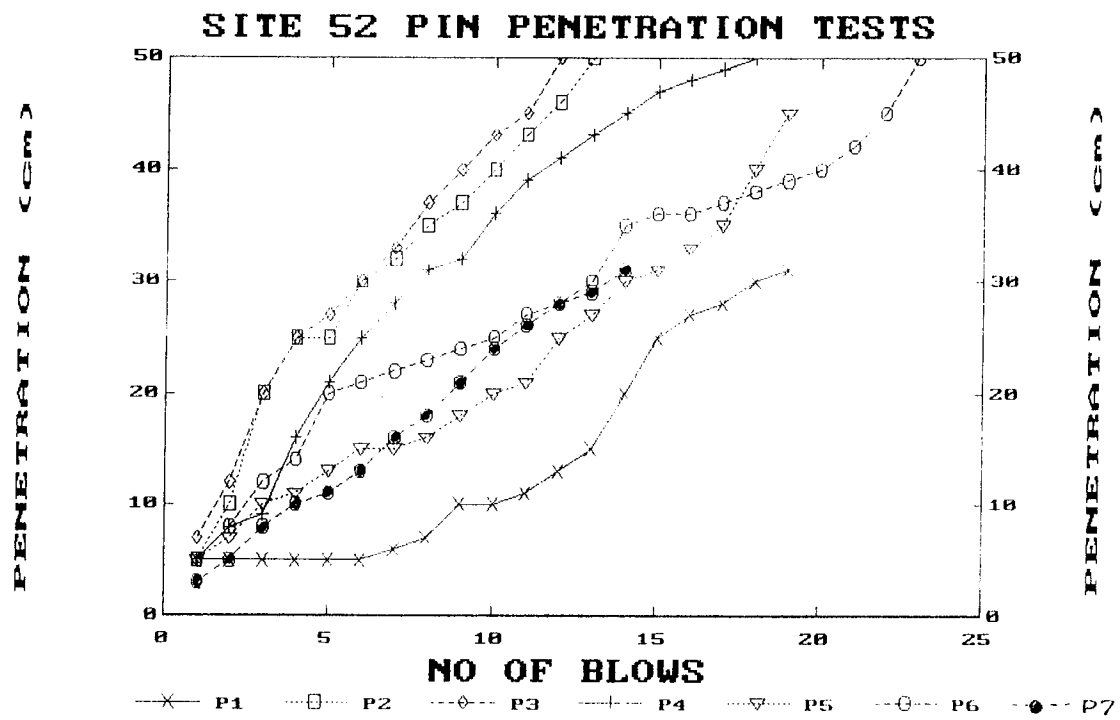


FIGURE 10. PIN PENETRATION TEST RESULTS

Graph showing Penetration (cm) vs. No. of Blows for seven different specimens (P1 to P7). The graph plots penetration depth against the number of blows for each specimen. P1 (crosses) and P2 (squares) show the highest penetration, while P6 (circles) shows the lowest. All specimens exhibit a non-linear increase in penetration with the number of blows.

No. of Blows	P1 (cm)	P2 (cm)	P3 (cm)	P4 (cm)	P5 (cm)	P6 (cm)	P7 (cm)
1	5.0	5.0	4.0	4.0	4.0	3.0	4.0
2	6.0	10.0	6.0	6.0	6.0	4.0	6.0
3	8.0	13.0	8.0	8.0	8.0	5.0	8.0
4	10.0	16.0	10.0	10.0	10.0	6.0	10.0
5	12.0	18.0	12.0	12.0	12.0	7.0	12.0
6	14.0	22.0	14.0	14.0	14.0	8.0	14.0
7	16.0	26.0	16.0	16.0	16.0	9.0	16.0
8	18.0	30.0	18.0	18.0	18.0	10.0	18.0
9	20.0	33.0	20.0	20.0	20.0	11.0	20.0
10	22.0	34.0	22.0	22.0	22.0	12.0	22.0
11	24.0	36.0	24.0	24.0	24.0	13.0	24.0
12	26.0	37.0	26.0	26.0	26.0	14.0	26.0
13	28.0	38.0	28.0	28.0	28.0	15.0	28.0
14	30.0	39.0	30.0	30.0	30.0	16.0	30.0
15	32.0	40.0	32.0	32.0	32.0	17.0	32.0
16	34.0	42.0	34.0	34.0	34.0	18.0	34.0
17	36.0	44.0	36.0	36.0	36.0	19.0	36.0
18	38.0	46.0	38.0	38.0	38.0	20.0	38.0
19	40.0	48.0	40.0	40.0	40.0	21.0	40.0
20	42.0	49.0	42.0	42.0	42.0	22.0	42.0
21	44.0	50.0	44.0	44.0	44.0	23.0	44.0
22	46.0	51.0	46.0	46.0	46.0	24.0	46.0
23	48.0	52.0	48.0	48.0	48.0	25.0	48.0
24	50.0	53.0	50.0	50.0	50.0	26.0	50.0
25	52.0	54.0	52.0	52.0	52.0	27.0	52.0

PIN PENETRATION TO ≥ 2 mm CORRELATION

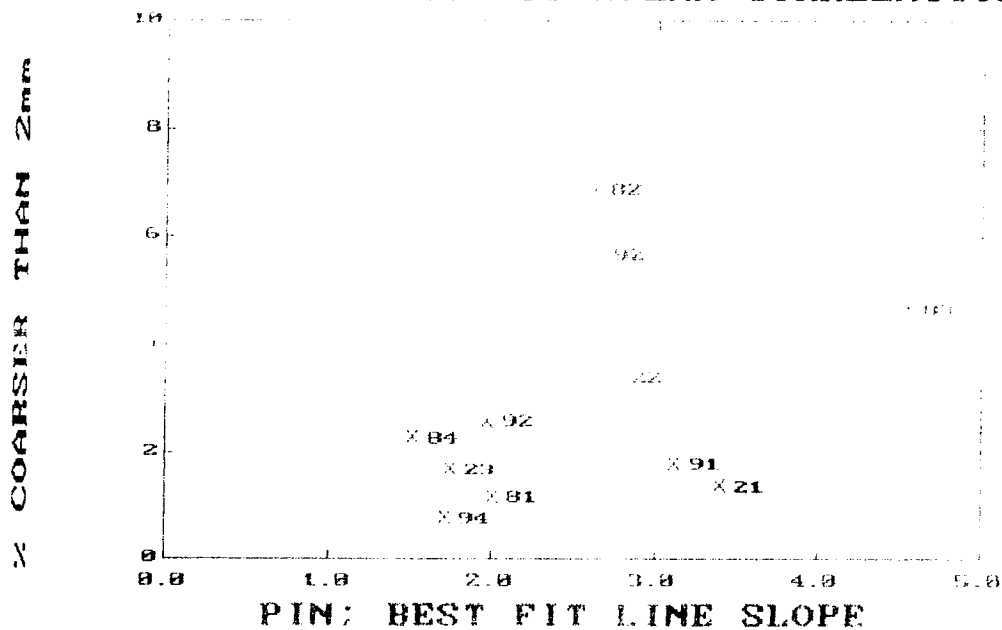


FIGURE 11. RELATIONSHIP BETWEEN MEAN PIN PENETRATION RATES AND PARTICLE-SIZE OF SEDIMENT (coarse fraction content).

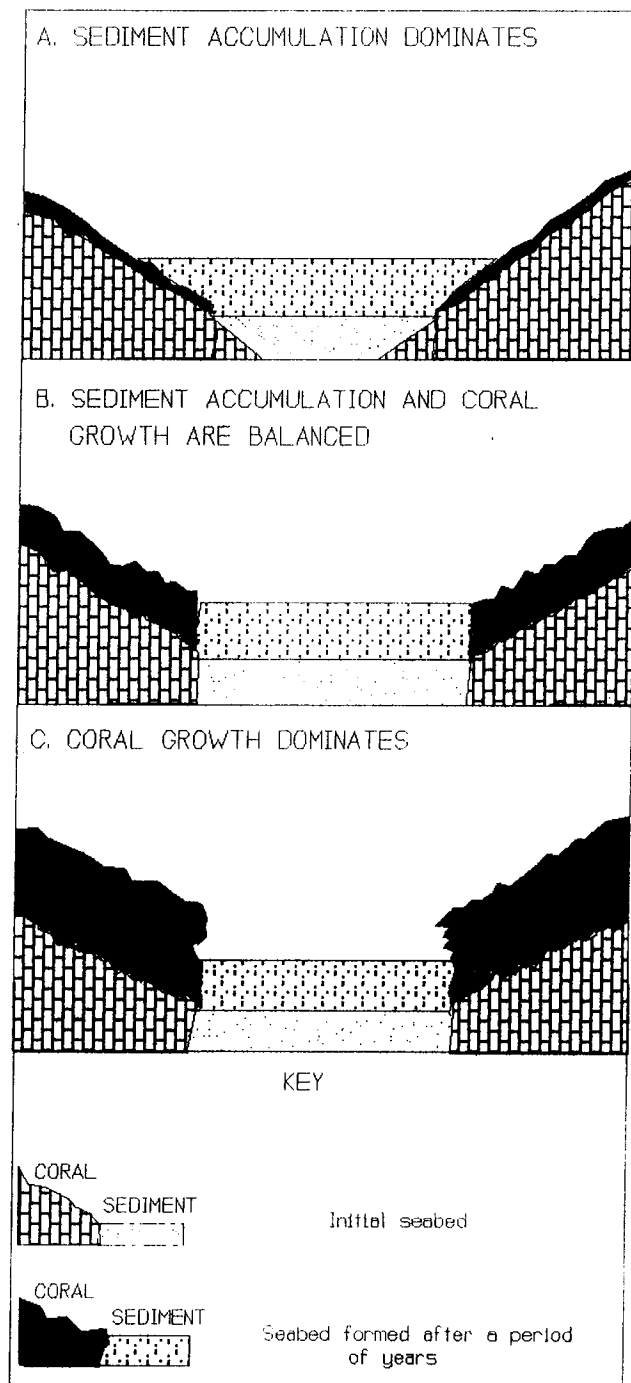


FIGURE 12. SEDIMENT BASIN FORM AS A FUNCTION OF DIFFERENTIAL RATES OF CORAL GROWTH AND SEDIMENT ACCUMULATION.