

Report on sedimentological investigations
as part of the CICAR-Programme 1970-1972

Part I

A reconnaissance survey of bottom
sediments in the Amazon's mouth
region

by

E.C. Tjoe-Awie

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SUMMARY

As part of the CICAR programmes, carried out in September - October, 1970 and in May 1971, both suspended matter and bottom sediments were collected in the Amazon's mouth region.

The materials were used for an investigation regarding the spreading of bottom sediments in that area.

The highest concentrations of suspended matter are found near the bottom. From bottom to surface of the water the concentration of suspended solids decreases rapidly. Furthermore the amounts of suspended solids found at a certain depth, greatly depends on the phase of the tide.

In the superficial waterlayer the concentration of suspended matter decreases with the distance to the coast. The 20 - metres isobath was found to parallel the 5 mg/l isoconcentration line, which should be considered the outward limit where appreciable amounts of Amazon - transported solids can be found in the surface waters.

Analyses of bottom sediments with regard to their bulk densities, carbonate content, grain-size distribution, C/N ratios and cation exchange characteristics have been carried out. From the data it appeared that differentiation of the Amazonas-transported sediments are brought about in accordance with prevailing hydrodynamic conditions of the environment.

Some results point to mixing of Amazon-derived sediments with the slightly different River Para - transported deposits.

The thus produced generalized map of bottom sediments strongly bears a genetic character.

1. INTRODUCTION

In October 1967 the Intergovernmental Oceanographic Commission of the UNESCO accepted the programme for CICAR (Cooperative Investigation of the Caribbean and Adjacent Regions). Thus it was decided that widely branched research should be done in those regions.

The actual execution of the programme, in which some eighteen countries participated, took place from 1970 up to 1972 inclusive.

In this period many scientists - belonging to a variety of disciplines - investigated the influence of the River Amazon upon the Atlantic Ocean.

Our contribution to this project should be a search for regional differences in the near-coastal sediments. Therefore both bottom sediment and suspended matter were sampled in several places along the Guianese Coast between the River Amazon and Corantine.

Samples, which will be dealt with in this paper were taken about September/October 1970 and May/June 1971 on board of the Brazilian Navy vessel "Noc. ALMIRANTE SALDANHA".

With a draught of 6 metres this ship could not always come close enough to the coast. Moreover our request to enter the Amazon's estuary was refused. Thence the marked scarcity of stations, there where the river debouches (see Figure 1).

Attempts to fill up this gap with a smaller boat in 1972, unfortunately failed because the Brazilian Government - for reasons unknown - did not permit us to do so. Indeed, a nice example of international cooperation!

The lack could partially be got over, because Dr. L.J. PONS kindly put some samples of that area to our disposal (see Figure 11).

ACKNOWLEDGEMENT

I want to extend my gratitude to the Netherlands Organisation for the Advancement of Pure Research (ZWO) for providing funds that enabled these investigations.

Realization of this report would not have been possible without the full support of the Netherlands Institute for Sea Research for which I gladly express my thanks.

Dr. L.J. PONS, Professor of soil science at the Agricultural State University in Wageningen, kindly put some samples from the study area to our disposal; a generous offer that is gratefully acknowledged.

I am much indebted to commanders and crews, sailing the "Noc. ALMIRANTE SALDANHA" in 1970 and 1971 for both their help and their hospitality.

2. GENERAL DESCRIPTION OF THE AREA

MABESOONE & NÓBREGACOUTHINO (1970) report that the Amazonian Coast can be subdivided into three parts.

1. The Guiana coast - between Cape Orange and Cape Norte. A low lying marsh area of mangrove swamps, constructed of recent sediments.

2. The Amazonian Estuary; in Brazil preferably designated as Golfão (Gulf).

Because of the action of waves, tidal currents, varying river run-off and winds, the coastline here is extremely unstable. Huge quantities of sediments being deposited here, causes a constant shifting of banks, filling up the canals, etc.

3. The Eastern Amazonian Coast; up to the mouth of the river Parnaibo. A sandy area where dunes attain heights of several metres. It is typified by a great number of small estuaries, bordered by low cliffs.

The area being discussed in this paper, stretches from the City of Salinopolis in the East to the mouth of the River Oyapock in the North-west. Seaward extension is rather limited and does not go far beyond the 50 - metres depthline.

This zone is part of a more extensive festoon of finely grained deposits, ranging from the mouth of the River Amazon to that of the Orinoco.

The question where all these apparently uniform materials have come from, has been matter of dispute for many years. Most divergent views concerning their origin have been given - varying from local erosional products to long-distance transport from the African continent (BAKKER, 1963; van BAREN & von HARMSE, 1969).

ALLERSMA, (1968) carries on many arguments in favour of LYELL's (1832) hypothesis that the sediments are brought to the ocean by the Amazon River (cited from REYNE, 1961).

2.1. THE AMAZON BASIN

This tremendous depression is often erroneously called a geosyncline. In fact it is a composition of three originally different and independent physiographic units, namely:

- 1) the extensive and broad lowlands of the Upper-Amazon, between the Andes and the City of Manaus.
- 2) the narrow W-E stretching groove between Manaus and the mouth of the Xingu river, which happens to be a typical rift valley
- 3) the lower Amazon, extending from the mouth of the river Xingu unto the ocean; a characteristic funnel shape is determinative for this part of the river.

The present day hydrographic unity, known as Amazon basin, was accomplished by junction of these elements. Supposedly the joint was

not completed before the Pliocene epoch, after the Andean Chain had arisen and prohibited Westward draining of the upper Amazon.

For more details the interested reader may be referred to the adsorbing description by BEURLEN (1970), from whom this paragraph has been abstracted.

2.1.1. DISCHARGE AND SEDIMENT LOAD

The Amazon basin and its tributaries comprises an area of 6.5×10^6 km² (SIOLI, 1964).

As a whole this area receives more than 1,500 mm of rain a year, while in its largest part even more than 2,000 mm is totaled (BEURLEN, 1970).

Since most of the rain comes down during the "wet season", the regime of the river clearly reflects seasonal conditions of the hinterland. Consequently discharge of water varies widely during the year. Around May/June, for instance, values of 240,000 m³/sec may be reached, whereas only 80,000 m³/sec can be measured about October/November. Between these extremes the annual mean has been estimated at 175,000 m³/sec (OLTMAN, 1967) (= 5.4×10^{12} m³/year, or as much as a 10 m thick layer spread over an area as large as the North Sea!).

Because of the higher concentration of suspended matter during the rainy time of the year as compared with the dry period, the amount of sediment that is carried to the ocean is even more liable to seasonal differences. Hence the maximum load exceeds the minimum load by a factor 15 or even more.

The discharge-weighted mean suspended solid concentration of the Amazon at its mouth is 90 ppm (GIBBS, 1967). So the quantity of sediment brought into the sea should run into 0.5×10^9 tons annually.

GIBBS (1967) calculated that 82 per cent of those sediments is

supplied from only 12 per cent of the total basin's area, namely the mountainous environment; i.e. above the 500 m level. He also stated that about 5 per cent of solids that passes through the river's mouth is carried in the bedload (material transport within 50 cm of the bottom).

According to AMES (cited from OLTMAN, 1967) the median diameter of bed material averages 200 μm , while ranging from 150 to 250 μm .

For the rest Amazon transported sediment is very fine textured with a median diameter of about 4 μm (GIBBS, 1967).

2.2. THE CONTINENTAL SHELF

2.2.1. PHYSIOGRAPHY

ZEMBRUSCKI et al (1971) mention several differences on account of which the shelf off northern Brazil can be divided in twain. The borderline between those lies about the mouth of the Para River.

Striking are:

1) the difference in depth of the continental break.

While extending to the 130-150 m depthline in the western part, a depth of only 70-85 m is reached in the eastern side.

2) the difference in slope of the shelf

East of the River Para the shelf has a fairly constant slope of about 1: 2,250 - West of the river however more differentiation is observed. Thus in front of the Isle of Mexiana a slope of 1: 1,850 has been measured, whereas off Maraca island a value of 1: 1,650 has been calculated.

3) the difference in steepness of the continental slope

As the gradient happens to be about 1: 9 on the East-side, only 1: 13 has been observed on the West-side.

Near the Amazon River mouth the continental shelf extends more than

300 km offshore. Its great width should partly be ascribed to the unusually great distance that the broad river estuary extends inland into the continent (TRUMBULL et al., 1958; EALEY, 1969). It is worth mentioning here that, according to OFF (1963) the occurrence of wide shelves is correlated with large vertical tidal ranges.

It is the tremendous sediment load, however, that greatly determines the physiography of this region. Thus rapid sedimentation has built up a shoal inner shelf, whereof the 20 m isobath extends 110 to 210 km from shore (EALEY, 1969). EALEY (1969) found a definite shelf break to be absent. A very gentle transition between the shelf and the outwards bulging continental margin - referred to as Amazon cone - appears to be an unique feature there. The cone itself slopes smoothly to the depth, with gradients ranging from 1: 50 to 1: 75 in its central part and being more steep on the sides (see Figure 2).

The same author reports further:

"The topography of the Amazon Cone is dominated by the Amazon Canyon and other large depressions. The Amazon Canyon appears to head on the outer shelf, widen seawards, and terminate at depths of between 1500 to 200 m. It has a relief of at least 500 m and is apparently partly filled with sediment".

The partition of the continental margin into regions East and West of the Para River respectively, seems to be extensible onto the ocean bottom. For, there the North Brazilian Ridge appears to be present only along that part of the coast that once was juxtaposed with Africa (HAYES & EWING, 1970).

Subsequent to this, there may be pointed out to BEURLEN's (1970) assumption. His argument boils down to the origin of the Amazon Graben as a consequence of transcurrent faulting during the Cretaceous Period. Others (MARTIN de REZENDE, 1972; de LOCZY, 1974) also advocate the

geotectonic pattern to be explained from rifting and drifting of the continent.

On the other hand, it should be borne in mind that more recent isostatic adjustment may have caused subsidence in the region off the Amazon (EALLEY, 1969; MILLIMAN & BARRETTO, 1975).

Finally the occurrence of shallow terraces must be noted down. According to TRUMBULL et al. (1958) near the mouth of the Amazon one such terrace at a depth of 7 m is 40 km across and another at a depth of 18 m is 96 km across. ZEMBRUSCKI et al. (1971) however only report that to the North-West of the Para River there is a sudden fall from the 30 m - to the 75 m isobath.

2.2.2. HYDROGRAPHY

Because of the tremendous discharge, the Amazon River exerts an impressive influence on the hydrography of the Atlantic Ocean. Since it debouches in a region where the strong Guiana Current flows and where trade winds prevail, one can readily surmise that its influence will be far reaching.

So unimaginable great is the amount of water which comes down the river, that even the penetration of salt water into the estuary is prohibited. Hence, there is a zone of thorough mixing near the river mouth.

Only some 60 to 80 km offshore vertical stratification is fully developed (GIBBS, 1970).

GIBBS (1970) also notes that the zone of turbulent mixing coincides with a somewhat constricted area where strong tidal currents meet the outflow. An area notorious for extremely rough seas. Presumably the well-known p o r o r o c a originates here. This is high tidal wave, that fiercely rolls up the estuary and thus causes much damage.

For the sake of completeness it should be mentioned that, unlike the Amazon proper, the entrance of the Para River does become brackish (EGELER & SCHASSMANN, 1964; RYTHER et al, 1967).

Furthermore it appears that the water of the Amazon River flows along the northern border of Marajo island. The outmost northern tip of the island, however, is not reached. There circular tidal currents keep the water of Amazon and Para River separated from each other (EGELER & SCHASSMANN, 1964).

The tide is semi-diurnal and has a maximal amplitude near Maraca island - being 11.8 m. From there on the amplitude decreases both in eastward and westward direction (NOBREGA COUTINHO & ONOFRE de MORAIS, 1968; ALLERSMA, 1968). Tidal currents may attain speeds up to 10 knots (ZEMBRUSCKI et. al., 1971).

A final word about a feature that was already observed a long time ago.

Huge lenses of low-salinity water can be perceived several hundreds of miles offshore (LE FLOCH, 1955; REYNE, 1961; RYTHER et. al., 1967; CALEF & GRICE, 1967; METCALF, 1968; GIBBS, 1970). Judging from their high silicate content, this must be river water. METCALF's (1968) point is, that in the vicinity of the Amazon River mouth there is a discontinuity in the current that passes along the coast. Consequently bubble of riverwater can cross the main axis of the current and thus be carried off.

GIBBS (1974), however holds the view that - on passing the brackish waters - the swifty flowing Guiana Current simply shears off and engulfs large lobes of low salinity water.

2.3. CLIMATIC CONDITIONS

The climate is humid tropical with fairly constant temperatures

throughout the year. In the superficial waterlayers values between 26° and 28° C are measured.

As regards the spreading of sediments, a role of importance must be attached to the trade winds. Broadly speaking, the northern trade wind system preponderates during winter of the northern hemisphere. Its southernmost limit ranges from 01° N to 07° N. In that time of the year the southeast trade runs approximately along the equator. About March the latter crosses the equator and invades the area under discussion (LUEDEMANN, 1966).

Figure 3 schematizes the frequency of wind directions. Wind speeds generally have values of 2,5 - 5 m/sec, while maxima of 7,5 - 10 m/sec occur in spring.

3. SUSPENDED MATTER

A thorough investigation of suspended matter will reveal much about transportation and sedimentation of terrigenous materials in coastal areas.

However, there is multiple interaction with other factors, that may cause great differences in the concentration of suspended matter - both spatially and temporally.

Without going into details, we may just point to the influence of tidal currents, wind drift, wave-action, physical condition of the bottom sediment and seasonal changes.

Therefore reliable data can only be gathered by continuous measurements over long periods of time.

Because of the wide-ranging character and the limited duration of the CICAR - project such an investigation was not feasible. Thus data presented here do not pretend to be more than a broad impression on the distribution of seston in this particular area of the Atlantic coast.

3.1. METHODS

Sampling techniques applied in 1970 differed somewhat from those used in 1971. The accuracy of the analysis, however, depends much on the collection technique (FOLGER, 1968). Nevertheless we may assume that, when taking an overall view of this matter, the differences growing out of different sampling techniques, are well within the limits of more serious errors due to other uncontrolled factors.

During the 1970 - cruise sampling of suspended matter was always preceded by measuring of the salinity and temperature profiles by means of an autolab salinometer. In accordance with the findings, the sampling depth was then decided.

For sampling of the surfacelayer a plastic bucket was used. Samples from deeper layers were either taken by a van Dorn sampler (6 l) or a Postma water sampler containing 1 or 2 litres.

A certain volume of the thus collected water was filtered under vacuum over a pre-weighted Millipore filter with a nominal pore diameter of 0.45 μm . The filter was rinsed with distilled water in order to remove salts, and then stored for gravimetric analysis afterwards.

In the laboratory the filters were heated overnight to 105^o C. Then they were placed in a dessicator for at least 30 minutes and finally weighed on an analytical balance (accuracy ± 0.1 mg).

Because of damage to our salinometer in 1971 no S- and T- profile measuring could precede the sampling. On that expedition those quantities were determined by the Brazilian Navy.

For temperature readings an ordinary turningover thermometer was used, while salinity was determined after Knudsen titration. Hence these data were only available afterwards.

In that year collection was always done by pumping up the water from desired depth. After a few minutes of flushing the hose, a sample was

brought into a storage container to be filtered afterwards.

Again in 1971 a modification was made. Now filtration was preceded by sieving over a 50 μm stainless steel sieve as to separate sand grains from the rest of the suspension (HORVAT & HEI, 1967).

3.2. RESULTS AND DISCUSSION

The sampling localities of which the positions have been determined by celestial navigation and dead - reckoning are indicated in figure 4.

On station 7, where the tidal difference amounts to 3 metres, the ship was anchored for 24 hours. We then made the same measurements during different phases of the tide.

The results thereof are illustrated in figure 5. For convenience' sake the simplifying assumption of a symmetric tidal curve has been adopted.

Some important features with regard to the behaviour of suspended sediment may be inferred from this figure. So the watercolumn happens to be pronouncedly stratified. There is a marked halocline at a depth of about 6 to 8 metres below the surface. The halocline appears to be permanent, so that stratification is maintained throughout the tidal cycle. Thus estuarine conditions still prevail at some 75 km offshore (see page 7).

Changes in the seston concentration with the depth are found to be related to the stratification of the water. Fine mineral particles flocculate namely in saline water to give a sponge-like fabric that contains much water. Such flocs are apt to sink rather rapidly till the halocline is reached. There they dwell upon until their contents has been exchanged completely for the denser salt water. Then the halocline is crossed and the velocity increases again (SAKAMOTO, 1972). Once the sediment has sunk through the interface of "fresh" and salt

water it cannot easily return to the surface.

Though the results only represent instantaneous conditions, we may yet- with all proper reserve- speculate on this subject as follows.

From the graph we can read that the concentration of the suspended matter is much lower in the toplayer than in the water underneath the halocline.

Furthermore we cannot find that this quantity depends on the tidal rhythm.

On the other hand, when considering the lower part of the water-column such a relation forces itself on us. The data suggest that the concentration there and the distance to the bottom are exponentially correlated. This in turn suggests settling and resuspending action. Hence one should be inclined to think that the amount of solids depends on the current velocity.

On the tidal curve the situation at 14.00 o'clock and that at 22.30 o'clock may be regarded as each other reflection. Yet there was much more sediment in suspension in the latter than in the former case. This phenomenon can be explained from the well-known fact that scouring of deposited particles requires higher current velocities than to keep the same in suspension.

The situations at 16.00 o'clock and at 22.30 o'clock are in another respect comparable too. In both cases it will slack within the same space of time. Again the ebb current appears to carry much more materials than flood does. This feature possibly indicates that the time-velocity curve is assymmetric (POSTMA, 1961, 1967; NICHOLS & POOR, 1967). In other words it turns out that the phase of the tide is determinative for the amount of seston that will be collected below the halocline; rather than the current velocity.

The figure point to an accordance with findings of other research

workers. Namely that about maximum ebb and flood velocities the highest concentrations of suspended matter are found, while shortly after slack the minimum concentrations occur (POSTMA, 1961; SCHUBEL, 1968).

However neatly the results seem to suit the hypotheses, one should be fully alive to the simplification one deals with. There is for instance the phase difference of the tide over the depth. This results in a time lag that may vary from a few minutes to several hours, in proportion to the depth considered (POSTMA, 1967). The need for more information is obvious!

The relative constant concentration of suspended matter above the halocline, points to physically and/or chemically different materials, as compared with those underneath that layer. Apparently we deal with a portion of suspended matter that can be carried far away before being deposited. Their low settling velocity may be due to either their fine grain size, or to their low specific weight. Noteworthy is SCHUBEL'S (1968) finding of a "natural background" of suspended matter with a Stokes' diameter of 3 microns.

According to MILLIMAN et al., (1975), already at a salinity of 6‰ most of the suspended matter in the surfacewaters off the Amazon is composed of diatom frustules.

Anyhow, we got the impression that stratification of the water might play an important part in differentiating the suspended sediment. In order to investigate this, however, more sophisticated sampling apparatus and techniques are required.

For the rest the results of our measurements have been listed in Table I and II. Cross sections indicated in figure 4 are represented in figure 6 and 7.

The isobaths reveal that below the 20-metres depthline there is a sudden increase in the slope of the shelf. Moreover high concentrations of suspended matter near the bottom happen to be restricted to depths shallower than 50 metres (and presumably not much deeper than 20 metres). Apparently there is the outer limit where the sediment can be resuspended. Thus the interplay of forces, by which action the sediment is transported and deposited, changes there.

Fine-grained particles coming into a saline environment usually flocculate and settle rapidly. Now, the size of the flocs - and thence their sedimentation velocity - is influenced by factors as salinity, agitation of the water, and composition and concentration of the suspended matter.

There is experimental evidence that flocculation takes place at chlorinities between 0 and 3 ‰ (MEADE, 1968) (i.e. salinities between 0 and 5.4 ‰). Besides, increase in salinity does not seem to cause further increase in the degree of flocculation.

The maximum size to which the flocs can grow will depend on the internal shear in the water (KRONE, 1962 - cited from MEADE, 1968).

Composition and concentration of suspended matter are important factors since they control cohesion and collision of the particles.

From the fore-going we may now deduce the following.

The suspended load of the Amazon River will flocculate immediately after being debouched. However, due to the intense turbulency of the water there (see page 7) growth of the flocs will be seriously hampered. In this way the fine materials are carried further. When being transported to deeper water, the influence of tidal currents and wave-action will steadily diminish. This causes the flocs to grow larger, which in turn will demand more energy to be scoured, resuspended and transported. At a certain depth an equilibrium is reached between deposition and erosion.

Provided that there is a net seaward flow, particles that are then still in suspension will be carried off. In that case the coarser ones will settle immediately beyond the equilibrium zone. There they will pile up until the critical depth is reached, above which the sediment will be scoured again. So the underwater delta can be built outwards .

The finer grains, however, are transported much farther and may even be deposited on the deep-sea bottom.

When the concentration of suspended matter decreases, serious problems arise as how to tell biogenic and terrigenous materials apart. Moreover, even ship derived contaminations may then cause non-negligible errors. In other words, the value of drawing isolines - referring to suspended matter - becomes doubtful since different lines may denote different components.

Regarding the concentration in the surface layer as indicated in Table I we get the impression that there is a "turbid belt". Beyond this area there is a rapid fall in the concentration of suspended matter. We, therefore, assume that the "turbid belt" should be considered as a region where river-born suspended load still dominates. That region appears to be approximately delimited by the 5 mg/l iso-concentration line. As shown in figure 8 there is a narrow parallelism between that line and the 20-metres isobath.

We may thus conclude that hardly any Amazon transported sediment is deposited East of the River Para's entrance; that the main depositional area reaches its maximal width in the direct extension of the Amazon proper, and that this area narrows in Northwestern direction.

The picture shown in figure 8 has reference to the situation in the dry season (September/October 1970). From the data in Tabel II we cannot infer that there is much of a change during the rainy season (May 1971), as far as the concentration in the surfacelayer is concerned.

Though conditions in the wet season would favour a more offshore transport.

There is in the first place the augmented discharge of the river. Consequently brackish water is found much further offshore during the rainy season than in the dry time of the year. Then, the amount of suspended matter brought down during the former is more than 15-fold that carried to the ocean in the later season. Furthermore the prevailing wind in the rainy time of the year (SE and E) does not necessarily maintain a coastward directed current. In the dry season on the contrary such a current may originate when the wind blows mainly from the NE.

The reason that the concentration of suspended matter in the surface layer yet hardly changes, might therefore be sought in the stratification of the water. Thus the more pronounced stratification of the water-column in the rainy season (cf. comparable stations in Table I and II) will prevent upward transport of suspended matter even more than it already does during the dry period of the year.

According to GIBBS (1974) the turbid water extends farther seaward in the period of high-water discharge than when the discharge is low. From the results he presents, however, this appears only to hold true for concentrations less than 5 mg/l.

GIBBS (1974) also investigated the optical transmission of the waters. That resulted in a more detailed pattern of distribution of suspended materials. It should be borne in mind however that the percentage of transmission does not depend only on the concentration of suspended particles. Other physical characteristics, such as colour and grain (i.e. floc) size of the materials are of great influence as well.

Finally it should be mentioned that no significant portion of sand could be separated from any of the samples gathered in May 1971. It thus looks like the suspended matter in the area under discussion consists fully of materials finer than 50 μm .

4. BOTTOM SEDIMENTS

The object of this study was to ascertain if the muddy deposits that border the northern coast of South America, can be differentiated.

Therefore we must focus on the clay fraction and try to determine its mineralogical content quantitatively.

Such a detailed investigation demands a clear delimitation of the terrain, so that the path of recent sedimentation can reasonably be followed. Besides, basic information about the sediments is essential to the interpretation of any difference that might grow out of clay mineralogical analysis. That's why some physical and chemical properties of the sediments have been determined first.

The determinations concern: bulk density, carbonate contents, grain-size frequency distribution, C/N ratio and cation adsorption characteristics.

The results of these items were combined to produce the enclosed map of bottom sediments. (enclosure I).

4.1. BULK DENSITY

The in geophysical research applied techniques are not seldom based on properties directly related to the porosity of the rock; e.g. seismic characteristics, thermal conductivity, rigidity etc.

Porosity of a sediment now, depends on a variety of factors. There is the grain-size distribution, for instance, that plays an important part. Then the shape of the particles too happen to qualify the size of the pores. While organic matter content and overall chemical condition of the environment are jointly liable for the final pore volume of a sediment.

In other words knowledge of the porosity may valuably contribute to any attempt for distinguishing different types of sediments. Hence this property was drawn into the frame of investigations.

The porosity has been calculated from bulk density values determined in the laboratory.

4.1.2. METHODS

Air-dried samples were carefully broken with a pestle, so as to disintegrate the clods without breaking single grains.

On a 2 mm sieve the material was then separated into a coarse ($> 2\text{mm}$) and fine fraction ($< 2\text{mm}$).

Regarding the samples analysed we noticed that, in case there was a coarse fraction, this was always less than 2 per cent of the sample. Moreover the composition of the coarse fraction differs greatly from that of the fine one. It mainly consists of shell-, coral and other organogenic fragments, together with some minor concretions.

It is obvious that just these "occasionally" occurring components may cause the analytical results to differ greatly. They were therefore excluded, and only the fine earth was further used for analyses.

The bulk density was determined by means of a Hilgard-apparatus (JAPANESE MINISTRY OF AGRICULTURE AND FORESTRY, 1955).

This consists of a cylinder of known volume (A), a ring (B) that closely fits on the cylinder and which can be covered with a lid (C) (see figure 9).

Cylinder and ring are joint and then filled with earth. The lid is placed on top and the box is fastened in a frame. The frame enables the sample to be transported and then dropped over a fixed vertical distance. This is repeated four times, whereafter the box is removed from the frame and the ring from the cylinder. The excess of soil is leveled with a spatula.

After the weight of the soil has been determined, the bulk density results from dividing weight by volume.

The percent porosity is calculated from the formula:

$$\phi = 1 - \frac{\rho_B}{\rho_G} \times 100 ,$$

ϕ = porosity in percentages

ρ_B = bulk density

ρ_G = grain density; we used 2,65 (the density of quartz).

4.1.3. RESULTS AND DISCUSSION

It would be better if we could dispose of undisturbed, saturated samples. However, lack of adequate devices to acquire such, compels to turn to physically transformed materials.

But, as a matter of fact, the composing component have not undergone any serious change. Hence we may reasonably assume that newly formed fabrics of originally different sediments will also be different. Thus the bulk density of an air-dried sample may yet be considered as an intrinsic property of the sediment.

Notwithstanding all that, this does not necessarily imply that different sediments always do have different bulk density values! Though differences in bulk density values strongly point to different sediment types.

To make sure that we are indeed dealing with an intrinsic property, the reproducibility was tested.

Fifty samples belonging to the clayey deposits along the French Guianese and Surinam coast, collected on widely spaced spots, were used. Not all samples were pretreated (disintegrated and sieved) by the same person. This was carried out by three analysts.

The result of the test was an average pore-volume of 68 per cent, ranging from 64 to 70 and having a standard deviation of ± 1.4 .

Based hereupon we considered deviations from the average of more

than 5 per cent as being significant. So our data could be grouped into four classes, as presented in Table III. For the sampling locations we refer to figure 10.

The areas occupied by different classes are shown in figure 11. From this picture we may conclude the following.

The least porous sediments are found East of the Rio Para's entrance. These are structureless single grained sands (Class IV).

On an isolated spot, facing the mouth of the Amazonas and to the North-West of this river the most porous sediments are found. Their well-defined structure-elements characterizes them (Class I).

The elements expose an angular external shape and appear to be firm compositions of fine-sized materials. Flocculation of the fine-grained particles probably caused such fabrics.

Among the samples of this Class there is one that is completely different from the others and which geographical position likewise attracts attention. This sample (stat. No. 9) has an extremely high contents of calcareous organogenic detritus. Its structure-elements are less firm and are composed of coarser elementary particles, while their rounded forms too are different from the otherwise angular type in this class.

Supposedly carbonate (and organic matter) caused granulation, which encouraged a fluffy, porous condition, resulting in a low bulk density value.

Sediments from the most seaward parts of the investigated region, and those spread in front of both the River Para and Amazon, appear to form a unity - as far as bulk densities are concerned. (Class III).

Again closer inspection elicits that sedimentologically this class should be subdivided. As this will be demonstrated later, the distinction must be based on granulometric characteristic and difference in carbonate content.

Situated between the sediments of class I and class III, there are deposits with intermediate bulk density values (Class II).

Among these soils there are those that have characteristics in common with both members of class I and class II.

This class too includes a calcarenite (stat. No. 34) for which --
m u t a t i s m u t a n d i s - the same holds true as stated about
the sample of station No. 9.

On the other hand this class comprises soils that hardly manifest any difference with those belonging to class I (stat. No. 2478, 2479, 2490, 2495). Whatever may cause these soils to have higher bulk density values, as compared with those of class I, their geographical position seems to justify a differentiation rather than to consider the values as accidental large deviations from the average of class I. We now just confine ourselves to the remark that stability of aggregations depends on the type of adsorbed cations and will be influenced by clay mineralogical composition as well.

Finally we report that in the field it has been observed that especially among the clayey soils there is much variation in consolidation. To our opinion this must be reflected in the bulk density values of saturated samples. As to dry earth, however, such differences could not be deduced from the figures. It is not unlikely that, by drying, the differences became neutralized due to shrinkage toward a minimum pore size.

4.2. CARBONATE CONTENT

The content of carbonate has been determined after SCHEIBLER (see BEGHEIJN & van SCHUYLENBORGH, 1971). The results are listed in Table IV, while isolines, for 1 and 10 per cent carbonate respectively, are drawn in figure 12.

This picture reveals the scantiness of carbonate in Amazon derived

sediments. Moreover, it appears that beyond the lime-poor zone the carbonate content increases rapidly with the distance to the coast. One can expect then, that this property will sharply indicate the main path of recent sediments.

It is thus brought out that carbonate-poor sediments are chiefly located to the West of River Para.

Unlike the rest of the region under discussion, the calcareous character of the sediments in the area between 0° and 1° northern latitude and 47° - 48° western longitude changes less drastically. This may be considered as a cue to mixing of sediments from different origin.

In front of Maraca island the lime-poor sediments happen to extend beyond the 50-metres isobath. That's the region, where we believe outwards building of a submarine delta to take place nowadays (cf. page 15).

4.3. GRAIN SIZE DISTRIBUTION

If we consider the geography of the lime-poor sediments as a genetic datum, and then compare this with the mapped bulk density values, it immediately becomes clear that differentiation obscures the interrelationship.

To bring about a differentiation among sediments, that can genetically be interpreted, is only possible after an adequate set of properties has been studied.

Particle size distribution - for instance - informs us about the prevailing hydrodynamic conditions at the time of sedimentation. In itself it does not have any genetic meaning. However, when regarded in mutual connection with other properties, it may lead to important conclusions.

4.3.1. METHODS

As regards to sand fraction ($> 50 \mu\text{m}$), analysis took place by sieving, while the pipette method was applied to study the pelite fraction ($< 50 \mu\text{m}$) (cf. BECHEIJN & van SCHUYLENBORGH, 1971).

One should take into account that again the analysis refers only to the fine fraction ($< 2 \text{ mm}$).

4.3.2. RESULTS AND DISCUSSION

Grain-size composition of the source materials, along with the complex hydrodynamic conditions during deposition, are the main factors that bring forth the final spreading pattern of deposits in a sedimentation basin. Grain-size frequency distribution might thus be a powerful tool to reconstruct the sedimentation processes. But, it can only be used successfully as such, when the analysis enables recognition of the points differentiating the one deposit from the other.

Though various processing methods have been proposed (DOEGLAS, 1946; 1955; 1971; SHEPHARD, 1954; CURRAY, 1960; SPENCER, 1963; FOLK, 1966; VISHNER, 1969; PASSEGA, 1972), they all appear to be limited applicable.

In the first instance we therefore simply grouped the samples as a whole (that is inclusive the coarse fraction) into classes, based on characteristics that might be considered as environmental indicators.

These are:

Class A: sediments containing no gravel and of which the sand content is negligible (less than 0.5 per cent) as well.

Class B: sediments with no gravel.

Class C: gravel containing sediments.

Then the results of the analysed fine earth ($< 2 \text{ mm}$) (presented in Table V) had to be depicted graphically.

As class A turned out to be numerically the most important one, the

fine fraction deserved special attention. In order to accentuate that fraction, cumulative curves were plotted on log-normal paper (VISHER, 1969).

So it soon became obvious that three main bundles of curves - as shown in figure 13 could be distinguished. But yet there remained some samples whereof the cumulative curve was not in accordance with the bundle that should represent the class it had been incorporated with. Representative examples of such are shown in figure 14. From comparison with figure 13 it becomes clear that they have characteristics in common with those of two sediment types. It was therefore then, that such soils have been considered as transitions of one type into another. A fact that is geographically not contradicted.

Then the spreading of sediments having grain size characteristics in correspondence with the respective bundle of curves was mapped out as presented in figure 15.

We shall now go further into the merits of that picture.

Deposits belonging to type I (see fig. 13) prove to be made up for more than 95 per cent of particles with an equivalent diameter of less than 32 microns.

Now it is common knowledge that fine mineral constituents flocculate in saline water. Moreover, particles with a size diameter of about 30 microns are the largest ones that may display such a behaviour (MIGNIOT, 1960). Thus sediments of this type have almost entirely been brought down in a flocculated state.

The analyses however, have been carried out with deflocculated materials. Hence, the frequency distribution as presented here differs from that under natural conditions. Anyhow, the straight line which would have to result from the presupposed log-normal distribution failed to appear.

The appearance of the curves suggest them to be made up of two parts. Such may indicate that we are dealing with different populations of particles (DOEGLAS, 1946; CURRAY, 1960). In that case log-normality may be accepted for the frequency distribution of particles with size diameters between 0.5 and 4 microns.

For the distribution of particles larger than 4 microns we cannot pronounce a judgement. Nevertheless subjoined speculations are made.

Before going further into the matter, we shall ride off on a side issue now.

As small particles are subjected to Brownian motion, an equivalent size diameter of 2 microns is generally considered to be the limit of reliable estimation by means of pipette analysis. One would then expect the concentration of smaller solids to remain more or less constant under such conditions. Yet, applying this technique to our samples, it turned out that below the 2 micron limit a steady decrease in concentration can be recorded, when measured after appropriate time-intervals.

The effect of aging might be a possible explanation for this paradoxical observation. Because of their long sedimentation time particle-aggregation may then occur. Brownian movements are thus overcome and the final result will be a decreased concentration of suspended solids.

On standing for more than a week however, the suspensions proved to be very stable. Therefore this effect should be considered to be of secondary importance.

One should now bear in mind that the fraction under discussion is constituted for an important part of leaf-shaped micaceous and other clay minerals. Their hydrodynamic behaviour should be such as to retard the falling velocity seriously. So there is a real chance that such particles have a greater mass than spherical ones, falling with the same velocity. This may cause the downward movement of such minerals - at

least to a 0.5 microns equivalent size diameter -- to dominate over eventual upward transport caused by Brownian motion or convection.

Particle size analysis as meant here, concerns the determination of the percentage by weight of distinct grain size fractions.

Gathering up the threads now, we may argue as follows.

If leaflets carry more weight than spheres; the frequency distribution of the former in suspension is likely to differ from that of the latter. Change in the slope of the curve may thus indicate a changing ratio of leaf-shaped particles to spherical ones.

Suppose that the distribution of mineral particles in non-flocculated state can be described as two log-normal functions intersecting at $4 \mu\text{m}$ (see fig. 14). The analysis, then, reveal that the concentration of particles with an equivalent size diameter of 8 microns do not accord with the supposition. In fact there is shortage of such particles.

This shortage, now, can be explained from the flocculation process. For, when the suspension comes to flocculate, sedimentation is fixed at an earlier stage. So particles are brought to settle there where they would otherwise remain in suspension.

Particles larger than about 30 microns are generally transported as single grains. In the sediment we are now dealing with, grains of that size are hardly present. Thus, likewise, flocs of equivalent diameter were practically absent during deposition.

It is assumable that such large-sized flocs are, for an important portion, made up of solids coarser than 8 microns. Hence, such particles might than have been lost due to anticipative deposition.

Those, still met with in the sediment, supposedly do not have a strong ability to flocculate. They, therefore, should have been deposited as single grains, rather than as part of a floc. In that case particles from 8 to 30 microns are, to some extent, indicative of the hydrodynamic

conditions during deposition. Still, their frequency distribution, when measured under peptized conditions does not contain any real information.

On the contrary, we may consider the transportation of particles, which equivalent size diameter is less than 8 microns, to be adaptable to environmental conditions. These materials namely, lend themselves well to the formation of flocs from various sizes. So they can be transported over a wide range of energetic conditions, without losing much of their original frequency distributional properties.

In conclusion we may state that sediments of type I are best typified by the ratio

$$\frac{\text{weight-percent of particles smaller than } 4 \text{ } \mu\text{m}}{\text{weight-percent of particles smaller than } 8 \text{ } \mu\text{m}}$$

We calculated this for 25 samples and found a value of 0.83 ± 0.02

It is beyond doubt that such a datum is more meaningful than statistical descriptors as median diameter and so on. Besides, the analyses can henceforth be restricted to the determination of two fractions only.

Sediments grouped under type II are principally composed of sands finer than 200 microns. Yet they contain enough peptitic (< 50 microns) materials to modify their fine sandy appearance. This is convincingly demonstrated by the grain size frequency distribution curves, that consist of two distinct sections. Those curves are namely made up of a straight line, and a more toward horizontality inclining "tail" (see figure 14).

Irrespective of size of the elementary particles, flocs appear to settle with a velocity varying from 0.15 to 0.60 mm/sec (MIGNIOT, 1968). This should correspond with falling velocities (at 20° C) of spheres having diameters between 13 and 26 microns (GIBBS et al., 1971). Consequently we may state that particles of which the frequency distribution is represented by the straight part of the curves, have been transported as a floc-free population. We thus presume that the straight line goes

back on a log-normal distribution of particles that are transported as bed-load.

As peptisation will not essentially effect a change of their original frequency distribution, certain conclusions about the prevailing current velocities during deposition can be drawn from that part of the curves. If we thus go by the grain size distribution of the sand, a disproportionate amount of silty and clayey particles is observed. Apparently flocculation caused a surplus of finer particles to settle. Hence the "tail" of the curves should be considered to represent the frequency distribution of particles, which have been brought down in suspension.

Simultaneous deposition of bed-load and suspended particles is not very likely. We rather believe then, that a graded sediment is born from successive deposition. Though we have not observed such structures, their existence on a micro-scale should not be excluded. Moreover, since the sediments under discussion occur in an area subject to tidal influences (see figure 15), some such supposition should not be considered improbable.

Unlike the sediments of type I, those of type II originated under more variable conditions. That's why in an attempt to characterize the latter, we are not in the position to indicate any such datum.

As distinct from the other deposits the carbonate content of sediments classed as type III is not negligible. Grain size analysis, however, regards the carbonate-free mineral particles only. Thus pretreatment of the samples can considerably change the original features of these sediments. Nevertheless, due to the carbonate-poor nature of the other sediments in the region, differences to one another becomes more out standing now.

In this manner sediments of type III can then be described as ill-sorted sands, being composed for more than 95 percent of particles coarser

than 80 microns. In figure 13 the grain size frequency distribution curve of a sample taken near the River Para's mouth (No. 26) is shown separately because it is notably coarser than the rest of these deposits.

The texture of the deposits points to an environment of high energy. Now it is doubtful if such conditions still prevail wherever these sediments occur. So, at least part of them should be considered as relict (see page 40). Consequently it is questionable whether sediments of type III must further be regarded as a class apart - unless just mapping out of a physical property is being pursued. For that purpose, however, it would have been enough to use only the percentage by weight of particles coarser than 50 microns as differentiating property.

Taking up this remark, it is worthwhile mentioning that according to DAVIS (1970) only one sieve separation is necessary to characterize Baratavia Bay sediments.

4.4. CARBON AND NITROGEN CONTENT

Suspended mineral particles play an important part in the extraction of organic matter from water. The organic matter is then incorporated in bottom sediments. As has experimentally been demonstrated, the adsorption process mainly depends on the type of clay mineral (BADER, 1962). Therefore differences in the composition of organic matter among deposits may tentatively reflect different clay mineral compositions.

Especially the ratio of carbon to nitrogen (C/N) is often claimed to be a valuable characterization of organic matter, both in soils and sediments (ARRHENIUS, 1950; BADER, 1955; BORDOVSKIY, 1965).

In general the concentration of organic matter augments with decreasing particles size of the sediments (BORDOVSKIY, 1965), while the nitrogen contents sometimes strikingly seems to adopt this line (KEMP, 1971). Yet one can think of various factors that may influence this ratio. For

example redox potential, pH and sampling depth beneath the bottom surface may be mentioned as such.

Oxidative conditions cause the organic matter to be depleted of nitrogen. In that way the organic matter can drastically be changed and particularly the C/N ratio may be affected.

STEVENSON & TILO (1966) suggested that in calcareous sediments polymerization of nitrogen constituents can take place, due to favourable pH.

According to KEMP (1971) organic matter in the top 20 cm of modern lacustrine and marine sediments can be changed rapidly because that zone is often densely populated by benthic organisms. Below that level the sediments remain unaffected and alteration of organic matter is probably slow.

Despite all that, constant carbon to nitrogen ratio or otherwise, nature and origin of organic matter in marine sediments may provide information on environmental conditions. So STEVENSON & CHENG (1972) have demonstrated that, due to diagenetic processes, different organic matter levels can be found in Argentine Basin sediments, that - besides - appear to be closely related to Quaternary climatic changes.

It thus appears that the line along which transformation has come about may be indicative for prevailing conditions. However, one should keep in mind that such transformations can only be fully understood when we are able to analyse the various organic matter constituents in freshly deposited sediments.

4.4.1 METHODS

In this investigation organic matter of bottom sediments will only be used as a complementary characteristic for mapping purposes. As such it is no use to make a detailed analysis of a far too complex matter.

Therefore we confined ourselves to the determination of organic carbon and a, as yet unknown, fraction of organic nitrogen.

Organic carbon was determined with an automated micro-Dumas apparatus (Coleman Carbon Analyzer) as described by STEWART et al., (1964). Prior to analysis, samples were ground in an agate mortar. Carbonate containing sediments were previously treated with 1N hydrochloric acid, washed with distilled water, oven-dried and ground.

Important quantities of nitrogen may be fixed in the lattices of minerals; especially those of certain clays. Then the NH_4^+ ion can also be adsorbed by clays and other fine-grained particles. (STEVENSON & DHARIWAL, 1959; STEVENSON, 1960; STEVENSON, 1962; ADAMS & STEVENSON, 1964; YOUNG & Mc NEAL, 1964; KEENEY & BREMNER, 1966; SILVA & BREMNER, 1966). Thus determination of total nitrogen content of sediments does not inform us about the organic fraction of this element.

In order to distinguish the organic fraction from the total nitrogen, each sample was split into two portions.

One portion was used for the determination of the total nitrogen content. For that purpose the semi-micro Kjeldahl distillation was adopted according to the description of HOFSTEE & FIEN (1971).

The other subsample was stripped of its organic matter before being used for Kjeldahl distillation. Decomposition of organic matter was thereby accomplished by means of a 30 per cent H_2O_2 - solution on a waterbath. After completion of the reaction the sample was carefully washed with distilled water, dried at 50°C , ground and brought into a distillation flask. The difference in nitrogen contents measured in both subsamples may then be ascribed to loss of organic nitrogen as a consequence of oxidation.

4.4.2. RESULTS AND DISCUSSION

From the analytical data it appears that the sediments in the Amazon's mouth region are rather poor in organic carbon content.

The percentages by weight of this element are shown in Table V. There they have been arranged in order of increasing sand to pelite (S/P) ratio. It then turns out that carbon content decreases noticeably only when there is a sudden increase in S/P ratio. Such happens to be the case when one passes from the one sediment type into another (cf. paragraph 4.3.2.). Here-toq sediments that should be considered as mixtures of different types have been treated separately. Inspection of the Table brings about that they fully deserve such.

Within the same type of sediment the carbon contents vary considerably with no consistent change being evident with increasing S/P ratio. The divergent results may be attributed to several factors, e.g. the activities of microorganisms in the over-lying water and/or in the bottom itself. Thereby it should be taken into account that the activities of the organisms are controlled by environmental conditions such as redox potential, concentration of nutrients and so on. Thus the correlation between carbon content and the texture of the sediment is demonstrated to be a rather broad one.

The average contents have been calculated for the different sediment types and are noted in the Table. The silty-clay deposits in which we are primarily interested contain 0.65 ± 0.10 per cent of carbon. It is noteworthy, however, that the contents of carbon in the samples collected in 1962 (C14 to C21 inclusive) are preceptible lower as compared with the rest of these sediments. We assume that loss of organic matter appeared during the long time of storage. If we exclude these samples, then a mean value of 0.70 ± 0.09 is calculated. This value is in better agreement with earlier investigations (OTTMANN 1959). Finally it is

shown that the reliability of the method decreases when the carbon content diminishes.

Should the carbon content of the Amazon-born sediments be a distinguishing mark, then it may not undergo appreciable changes after deposition along the coast. If that is true then the particulate matter from one litre riverwater would contain about 630 μg organic carbon (this can be calculated from carbon content of the silty deposits and the suspended matter concentration of the riverwater (90 ppm; see page 4)). It is therefore interesting to mention that WILLIAMS (1968) has reported a value of 740 $\mu\text{g}/\text{l}$ for the estuary of the river. The same author found much higher values for water of the Rio Negro. That river, now, is known to have a low suspended sediment concentration (SIOLI, 1957). Moreover, the topsoils in the area drained by the Rio Negro happen to have rather high organic matter contents (KLINGE, 1963). On the other hand WILLIAMS (1968) found the particulate matter suspended in one litre water of the River Solimões to contain only 900 μg organic carbon. As SIOLI (1957) mentions, this river carries quite an amount of suspended sediment.

It should be admitted that in view of the limited data, foregoing estimations are from sheer necessity very rough. Yet, it cannot be denied that their merits are such that at least they call for more extensive investigations.

Results concerning nitrogen analyses are listed in Table VII. In column 2 the percentages of total nitrogen contents are shown. Differences that are observed there are of two kinds. On the one hand there are the clear differences between deposits of different grain-size classes; on the other hand the variations among samples of the fine textured deposits are flagrant.

Regarding the latter we point out that especially freshly sedimented

organic matter may lose nitrogen due to volatilization when the samples are air-dried. Thus the homogeneity of the samples must be doubted; certainly when semi-micro analyses are carried out.

It is likely that, due to its low specific weight, fresh organic matter will be precipitated along with fine particles rather than with coarser ones. Moreover, a better aeration of coarse sediments facilitates equable volatilization when the samples are being dried. However, the association of organic matter with and the incorporation of nitrogen in clay minerals may cause the content of nitrogen greatly to depend of the composition of the clay fraction.

To form a notion of the anorganic portion of the nitrogen, the organic matter was oxidized with H_2O_2 , previous to Kjeldahl distillation. The results thereof are shown in column 4. It is obvious that the variations among the samples has become far less then. Calculation of the percentages of total nitrogen that thus remained in the samples, elicits that a minor portion of nitrogen was removed by treatment with H_2O_2 (see column 6). One also becomes aware of the tendency that by this treatment less nitrogen is removed from the sediments of type II than from those of type I. So that the nitrogen which occurs in minerals seems to increase with decreasing nitrogen content.

It is premature to conclude that the major part of the nitrogen is associated with the mineral portion of the sediments. For, however it may be, hydrogen peroxide might not have been able to oxidize the organic matter entirely. In experiments with terrestrial soils BREMNER et al., (1967) have found that more than 90 per cent of organic carbon is removed by hydrogen peroxide treatment. We verified some of our H_2O_2 - treated samples by means of a Coleman Carbon Analyzer and found up to 25 per cent of carbon to resist oxidation by peroxide. Presumably this portion of organic matter is mainly made up of lignins. According to BADER (1955) part of the lignins has the possibility of developing ligno-proteins

via bacterial activity and such complexes should be extremely resistant to decay.

BREMNER et al., (1967) also mention that oxidation of terrestrial soils with H_2O_2 in the absence of KCl may cause extensive fixation of the released ammonium.

In our procedure, however, we did not apply KCl. We are namely dealing with marine sediments and therefore one may expect the fixation ability to be greatly reduced because of lattice restoration by means of K^+ ion from seawater. Moreover, if despite that, there might still be NH_4^+ -fixing clays, it is desirable that such peculiarities are recognized. Therefore the use of KCl has been left undone.

To ascertain whether part of the nitrogen found in the samples after H_2O_2 treatment should be attributed to an organic origin or not, more detailed investigations are necessary. The data presented may then indicate lines along which such should be done. Yet, that is beyond the aim of our research. We may well remark that STEVENSON & DHARIWAL (1959) found subsurface layers of soil profiles to contain up to 60 per cent of the nitrogen as fixed ammonium. On the other hand, however STEVENSON & CHENG (1972) found only 10 to 30 per cent of nitrogen in Argentine Basin sediments to occur as ammonium bound to clay minerals.

We assume that nitrogen is principally associated with the pelite fraction. Thus the content of this element per 100 gram pelite should bring about differences in composition that might eventually be concealed in that fraction. Such is listed in column 7. Again the difference between sediment type I and II is clear.

Therefore it is not unreasonable to suppose that the clay mineralogical content of these types will be different too.

Among type II the samples C 27, C 34 and C 35 seem to have extremely high fixation abilities. Visual inspection of these samples learn that

mica is an important constituent. Because the coarser fractions may then also contribute to the fixation, the figures should be considered as giving a somewhat overestimated content.

From the foregoing it is obvious that quantities as C/N ratio should be considered with all possible reserve. The in literature often mentioned low C/N ratios should probably be attributed to analytical errors due to fixed ammonium.

In column 8 and 9 the ratios calculated for total nitrogen content and for nitrogen released with hydrogen peroxide respectively, are presented. The figures in the latter column might be overestimations because some nitrogen may have been excluded. Those of column 8 on the other hand are certainly underestimations because fixed ammonium have been included.

In conclusion we may state that the C/N ratio should no longer be used to characterize the organic matter in sediments.

4.5. CATION ADSORPTION CHARACTERISTICS

To make clear if the thus recognized types can further be differentiated the investigation will have to be focused on the mineralogical composition of the sediments. In view of the preponderant part played by clayey and silty deposits, clay mineralogy has to come in now. Because that is a tall order, only a modest start could be made here.

One of the most outstanding characteristics of clays is their ability to adsorb cations in an exchangeable way. The cation exchange capacity now, generally differs widely for different clay minerals. In soils and sediments however it is controlled by quite a variety of factors (CARROLL, 1959; GRIM, 1968). Therefore the determination of cation exchange capacity was undertaken to trace differences which might be found within the so far

distinguished sediment types.

4.5.1. METHODS

A barium chloride solution, buffered with triethanolamine (pH 8.1) was used to prepare Ba-saturated soils. The Ba^{++} was exchanged for Mg^{++} by means of a magnesium sulfate solution. The excess of $MgSO_4$ was back-titrated with EDTA and thus the CEC could be calculated (BASCOMB, 1964).

4.5.2. RESULTS AND DISCUSSION

Values of cation exchange capacity (CEC) arranged consecutively to S/P ratio are noted down in the Tables VIII to X inclusive. The exchange capacities are given in the usual way, namely in milliequivalents per 100 gram of soil (column 1). Cation adsorption however, primarily depends on the specific surface of both mineral and organic constituents. It is for that reason then, that the exchange capacity is closely related to the relative amounts of pelite in sediments. As the latter fraction is being diluted when the S/P ratio increases, appreciable reduction of the CEC may be expected in that case. To provide a picture of relationships which may be found in sediments with similarly composed pelite fractions, the CEC values have also been calculated per 100 gram of pelite (column 2). Yet, the density of adsorption sites on mineral particles is determined by isomorphous substitution within their lattice structures. Such substitutions now, occur most frequently in the lattices of clay minerals. Thereby they give rise to charge densities that are more or less characteristic for the type of clay mineral. So calculation of CEC per 100 gram of clay may aid to trace differences in constituents of the clay fraction in otherwise similar sediments. Such have been done and listed in column 3. Finally the mutual connection of quantities show to full advantage when the ratios of clay to silt are considered too. Therefore

the percentages of clay in the pelite fractions are shown in column 4.

Thus, until further notice, we may conclude from the Tables as follows.

Among the sediments of type I the samples 2496, 2477 and 2497 obviously appear to be different from the rest of the groups, in both pelite and clay fraction (for location of the samples see figure 10).

CEC values of sediment type II display much variation. However, this should mainly be attributed to grain-size differences within the pelite fraction. Among these deposits the high values for sample C27, when related to 100 gram of pelite or clay respectively, should be considered as non-realistic. In other words the low CEC of this sediment cannot be explained merely from dilution of highly adsorbing constituents. Therefore it is believed that the coarse fraction is also involved in adsorption processes. Since the sample contain high amounts of mica, one may regard the contribution of the sand fraction to such processes as being reasonable. To some extent the same holds true for samples C34 and C35.

In view of the low clay contents of deposits belonging to type II, we cannot tell whether the clay fraction of these sediments differ qualitatively from those of type I or not.

From Table X we may read that the samples C 22 and 2479 - as to their fine fractions - are related to type I. The "dilution range" of samples 2484, 29 and 006 appears to be nicely corrected by increasing clay contents. Yet, when one regards the pelite fraction of samples 29 and 006 they appear to have the same clay to silt ratio as sediments of type I. Therefore we believe the former deposits to have a clay mineralogical composition which is different from that of type I sediments.

In conclusion we report that no mention has been made of the contribution of organic matter to the CEC of the deposits because their content is too low.

For clearness' sake it should be mentioned that determination of CEC at pH 8.1 also includes pH-dependent adsorption sites, that would otherwise have been positively charged. Such charges should be attributed to SiOH groups (DE VILLIERS & JACKSON, 1967) and to iron oxides as well (SUMNER, 1963). The above mentioned results should therefore only be considered as hints for further research. A central place should thereby be given to detailed investigations of clay mineralogical composition. Such, however, requires refined techniques for quantitative analysis of the clay fraction. To our knowledge science have not made great progress in this field up to now (TJOE-AWIE & VAN DER GAAST, in press).

5. SYNTHESIS

Based on the investigated items a generalized map of bottom sediments has been drawn, which is presented as enclosure I.

The huge quantities of sediments being deposited in front of the Amazonas, influences extensive parts of the inner shelf there. As can readily be seen from the bulk density values of these deposits (cf. figure 11) differentiation takes place immediately after being brought into the ocean.

From the grain-size analyses it appears that, unlike generally would be expected, no evidence of drastically diminishing current velocity is reflected in the character of the sediments in the region of the river's outflow (see figure 15). Moreover, it appears from the grain-size distribution that an association of fine to medium coarse sands stretches out from the entrance of the Rio Para in eastern and north-western direction. The sands happen to form an unity with those at the seaward border of the investigated region in front of the outlet of the Amazonas.

The River Para now - carrying far less sediment than the Amazon proper (MILLIMAN et al. 1975a) - seems to decant most of its sediment as sand-bank

in the direct vicinity of its mouth (cf. OTTMANN, 1959). Furthermore, it appears from the carbonate content of the bottom sediments that the lime-poor deposits (an identifying mark of Amazon-derived sediments) are situated in a restricted area near the Rio Para's entrance (cf. figure 12). We therefore believe the carbonate containing sediments to be relict deposits from the Pleistocene epoch as have been pointed out by several research workers before (KEMPF et al., 1967; DAMUTH & FAIRBRIDGE, 1970; ZEMBRUSCKI et al., 1971; MABESOONE et al., 1972; DAMUTH & KUMAR, 1975).

On the generalized map the sands have been subdivided into sediments containing more than 10, those having from 1 to 10 and a minor portion that contains less than 1 per cent of carbonate.

The calcareous position of these sediments is mainly made up of biodebris. We believe that a biogenous facies of sediment, formed at a time of regression of the sea is situated at a deeper part of the shelf. During the subsequent transgression phase the biodebris components should have been transported in coastward direction, due to the winnowing action of the waves. Thus the resulting distributing of carbonate would have been one of gradual increase when crossing the shelf from the coast to the sea.

The higher sea-level, however, caused the recently transported sediments to be captured on the inner shelf. Their lime-poor character now, causes a steep gradient of carbonate contents, which appear to be far more outstanding in front of the Amazonas as compared with that in front the River Para. Moreover, if the carbonate content is considered as

a genetic datum, sediments facing the River Para's mouth seem to reflect a westward directed current.

Immediately to the west of the River Para clayey deposits are found. As to their origin the Amazon proper should be considered as the source of these sediments. The eastern border of these deposits should be determined by circular tidal currents that keep the water of the Amazonas and Rio Para apart (EGLER & SCHASSMANN, 1964).

So the Amazonas transported sediments settle in front of the funnel-shaped mouth to form a tremendous fan-like body. In seaward direction the texture of the sediments becomes finer due to diminishing currents velocities. Eastward extension of the fan is hindered because of tidal currents near the Rio Para. In westward direction, on the contrary, the fan can fully be developed. As a matter of fact in that direction it is even built out further because such is promoted by westward directed currents (see page 7). Thus in the region under discussion a huge asymmetric under-water delta is being originated.

In the direct extension of the river, current velocities appear to be that strong, that the formation of clays is prevented.

From our data concerning nitrogen content and cation exchange characteristics, we found indications that even the main current possibly can be traced, because of the amounts of micaceous minerals in the sediments there (cf. paragraph 4.4.2 and 4.5.2).

Cation exchange characteristics give some interesting cues for more detailed differentiation. So we found the samples 2477 and 29 to have lower CEC values when calculated per 100 gram of clay (cf. Table VIII and X). For the moment being we can only speculate about this feature as follows.

Amazon - derived clays are known to contain high amounts of montmorillonite that should have been brought down from the Andes (GIBBS,

1967; EISMA & van der MAREL, 1971). The Rio Para, however, mainly drains the granitic Brazilian Shield, and may therefore be expected to carry down a sediment, which fine fraction will probably contain quite some kaolinitic clays. Indeed, MILLIMAN et al., (1975a) recently have reported high concentration of kaolinite in bottom sediments from the River Para's mouth.

Though the water of the two rivers are principally separated from one another, we believe that after the tide has reached its maximal current velocity, the wind - promoted westward transport will cause clays of the Rio Para to mix with those of the Amazonas and thus dilution of montmorillonite will result in a lower CEC value.

CEC analysis also pointed to a somewhat different composition of clays in front of the River Oyapock. Finally we found the CEC of clays along the Guiana coast to be lower at their most seaward extension.

As discussed in paragraph 3.2 we believe the equilibrium depth regarding scouring and sedimentation processes to be about 20 metres. Beyond that the depth, sediments that are once deposited, should not be resuspended. Thus it might be thought that a certain differentiation according to particle size and density may come about when the critical depth of 20 metres is crossed. In that case the original deposits should be depleted of montmorillonite, while at greater depth an increase in montmorillonite content might be produced.

However, unless the clay mineralogical contents of the sediments are analysed quantitatively, we cannot express a well-based opinion on the just reported differences.

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Table I (continued)

Salinity, watertemperature and suspended matter concentration near the Amazon's River mouth in September - October 1970.

Station number	Latitude N	Longitude W	Water-depth (m)	Sampling-depth (m)	Salinity ‰	Suspended matter (ppm)	Temperature °C
34	02°24.0'	048°24.0'	85	surface	36.18	6.3	27.6
				10	36.17	n.d.	27.6
				40	36.15	6.9	27.2
				80	n.d.	6.5	n.d.
40	03°34.9'	050°25.0'	44	surface	31.10	4.0	28.2
				5	31.10	n.d.	28.2
				10	32.23	7.2	27.4
				15	35.88	7.1	26.8
				20	36.00	n.d.	26.8
				40	n.d.	7.0	n.d.
41	03°47.0'	050°44.5'	27	surface	26.90	11.9	28.8
				5	32.50	15.9	27.1
				10	35.90	n.d.	27.0
				22	35.85	29.3	27.0

Table II

Salinity, water temperature and suspended matter concentration near
the Amazon's Rivermouth in May 1971.

Station number	Latitude N	Longitude W	Water-depth (m)	Sampling depth (m)	Salinity ‰	Suspended matter (ppm)	Temperature °C
2465	00°10.0'	047°31.0'	28	surface	n.d.	1.9	n.d.
2466	00°34.5'	047°22.5'	28	surface	n.d.	3.4	n.d.
2467	00°52.5'	047°16.0'	44	surface	n.d.	1.0	n.d.
2475	01°35.5'	048°03.5'	48	surface	n.d.	4.3	n.d.
				40	n.d.	0.8	n.d.
2476	01°11.0'	047°55.5'	45	surface	n.d.	2.8	n.d.
2477	00°59.0'	048°10.0'	19	surface	5.72	6.9	27.7
				6	24.41	n.d.	27.7
				11	33.05	n.d.	27.7
				15	n.d.	141.5	n.d.
2478	01°25.0'	048°31.0'	18	surface	6.60	n.d.	27.7
				3	n.d.	6.5	n.d.
				10	28.94	n.d.	27.7
				15	30.59	410.2	27.6
2479	01°26.0'	049°04.0'	13	surface	5.98	n.d.	27.8
				3	n.d.	36.5	n.d.
				5	10.26	n.d.	27.7
				10	18.45	845.4	27.7
2484	02°06.0'	048°44.0'	44	surface	8.79	n.d.	28.2
				4	n.d.	8.6	n.d.
				10	35.51	n.d.	27.3
				20	35.63	n.d.	27.2
				30	35.76	n.d.	27.0
				40	35.98	1.9	26.6
2490	02°48.5'	050°07.0'	19	surface	19.06	n.d.	27.7
				3	n.d.	1.9	n.d.
				5	33.61	n.d.	26.6
				10	n.d.	62.0	n.d.
				15	33.94	107.1	26.6

Table II (continued)

Salinity, watertemperature and suspended matter concentration near
the Amazon's Rivermouth in May 1971.

Station number	Latitude N	Longitude W	Water-depth (m)	Sampling-depth (m)	Salinity ‰	Suspended matter (ppm)	Temperature °C
2495	03°07.0'	050°14.0'	22	surface	16.52	2.5	27.5
				5	19.45	n.d.	27.2
				10	35.40	18.6	26.2
				15	35.65	n.d.	26.1
				18	n.d.	92.8	n.d.
				20	35.66	n.d.	26.1
2496	03°32.0'	050°24.0'	47	surface	13.14	n.d.	27.6
				3	n.d.	8.5	n.d.
				7	21.11	n.d.	27.6
				12	35.63	n.d.	27.2
				20	n.d.	3.13	n.d.
				25	36.10	n.d.	25.9
2497	04°00.0'	050°34.0'	54	42	36.14	n.d.	25.8
				surface	25.97	4.5	27.7
				10	35.62	n.d.	27.4
				20	36.06	n.d.	26.9
				30	36.12	n.d.	26.2
				40	36.21	n.d.	25.5
2498	04°12.0'	050°55.0'	25	50	36.26	n.d.	25.3
				surface	19.60	2.1	28.0
				7	34.02	n.d.	26.6
				15	36.15	4.8	26.1
				22	36.13	9.0	26.1

Table III

Sediments grouped according to their percentage pore volume.

Class I		Class II		Class III		Class IV	
Station number	Pore Vol. (%)	Station number	Pore Vol. (%)	Station number	Pore Vol. (%)	Station number	Pore Vol. (%)
7	65	29	60	C23	56	19	49
8	67	004	63	C24	56	24	49
30	66	006	61	C25	55	25	47
40	66	2477	62	C26	55	26	45
41	66	2478	62	C27	52	2465	45
002	67	2479	62	C28	55	2467	47
007	65	2484	62	18	57		
2498	65	2490	64	6	52		
C14	68	2495	64	28	53		
C15	67	2496	64	2475	52		
C16	69	2497	63	2485	57		
C17	69	C34	59	2499	54		
C18	68	C35	60	2500	53		
C19	68	005	59				
C20	67	34	59				
C21	67						
C22	67						
C36	69						
C37	67						
9	71						

Class I Range 65-71, Class II Range 58-64, Class III Range 51-57
 Average 68 Average 61 Average 54

Class IV Range 44-50 .
 Average 48

Table IV

Percentages of carbonate in sediments of the Amazon's mouth region
(in duplicate; Standard deviation ± 0.2).

Stat. nr.	Carbonate %		Stat. nr.	Carbonate %		Stat. nr.	Carbonate %	
7	*	*	C14	*	*	005	20.5	23.0
8	*	*	C15	*	*	2500	15.7	13.6
29	2.6	2.6	C16	*	*	2499	13.0	13.4
30	*	*	C17	0.5	0.9	6	15.7	16.6
40	*	*	C18	*	*	9	49.8	50.2
41	0.9	0.8	C19	*	*	2485	*	0.3
002	0.7	0.5	C20	*	*	18	2.3	2.5
004	0.4	0.4	C21	*	*	2475	0.5	0.7
006	4.9	5.6	C22	*	*	19	0.6	0.6
007	0.6	0.5	C23	*	*	28	3.5	3.4
2477	*	*	C24	*	*	2467	1.5	1.3
2478	*	*	C25	*	*	24	13.9	12.3
2479	*	*	C26	*	*	2466	2.9	3.3
2484	1.3	1.3	C27	*	*	2465	1.9	2.3
2490	0.3	*	C28	*	*	25	2.1	2.2
2495	0.6	0.5	C34	*	*	26	0.6	0.7
2496	5.7	4.8	C35	*	*	34	57.0	-
2497	0.9	1.0	C36	*	*			
2498	0.4	0.5	C37	*	*			

* ≤ 0.2

Table V

Percentage by weight of different grainsize fractions (microns).

Stat. nr.	>1000	1000 500	500 400	400 315	315 200	200 160	160 100	100 80	80 50	50 32	32 16	16 8	8 4	4 2	2 1	1 0.5	<0.5	>	50
7									0.2	2.6	11.8	13.5	12.0	9.6	8.5	41.6		0.2	
8									0.0	1.2	6.7	14.2	13.1	11.6	8.8	44.2		0.2	
30									0.0	6.6	14.5	13.1	10.3	8.8	8.6	37.9		0.2	
40									0.0	0.3	10.6	13.1	13.3	10.1	10.0	42.6		<0.1	
002									0.0	0.0	8.1	13.9	13.2	11.9	10.3	42.4		0.2	
004									0.0	2.0	9.0	15.0	14.0	11.1	8.9	39.8		0.2	
007									0.4	1.6	9.5	16.5	13.1	10.0	9.5	39.2		0.2	
2477									0.0	3.9	15.1	11.5	11.6	11.1	9.0	39.0		0.8	
2478									1.4	4.9	16.7	13.1	11.3	8.0	8.7	35.9		<0.1	
2479									8.2	14.4	16.2	9.9	8.5	6.2	6.5	28.6		1.5	
2490									1.0	2.1	9.3	13.9	13.1	9.3	9.5	41.5		0.3	
2495									0.0	0.9	9.0	14.9	13.8	10.3	10.1	41.0		<0.1	
2496									3.9	3.6	16.5	12.3	10.0	7.5	7.8	37.7		0.7	
2497									0.1	3.2	12.9	12.0	11.1	10.0	9.8	40.0		0.9	
2498									0.0	0.0	10.9	14.5	10.8	11.1	9.5	43.0		0.2	
C 14									0.0	1.5	9.3	16.5	12.2	9.8	8.8	41.9		<0.1	
C 15									0.0	0.6	8.5	15.7	12.3	10.3	10.1	42.5		<0.1	
C 16									0.5	2.4	9.1	14.1	12.6	9.7	10.1	41.5		<0.1	
C 17									1.0	1.9	12.2	14.1	11.7	8.8	9.2	40.8		0.3	
C 18									0.5	2.5	10.5	15.9	11.5	10.1	10.6	38.4		<0.1	
C 19									0.0	1.4	8.3	14.7	12.4	10.8	9.2	43.2		<0.1	

Table V (continued)

Percentage by weight of different grainsize fractions (microns).

Stat. nr.	>1000	1000 500	500 400	400 315	315 200	200 160	160 100	100 80	80 50	50 32	32 16	16 8	8 4	4 2	2 1	1 0.5	<0.5	>50
C 20									0.5	2.4	12.8	14.3	11.4	9.6	8.5	40.5	<0.1	
C 21									0.4	4.4	12.9	14.3	10.1	10.0	8.1	39.7	0.1	
C 22									1.0	10.0	16.0	12.7	8.9	9.1	8.4	33.3	0.6	
C 36									1.5	4.9	14.8	19.3	-	-	-	37.7	0.1	
C 37									2.0	-	11.2	-	-	10.2	8.9	41.3	0.4	
41									0.0	1.5	10.0	16.0	12.5	11.0	9.0	40.0	0.0	
29		1.7	3.2	4.7	11.1	2.4	5.3	3.8	2.2	3.3	5.4	7.0	7.8	7.0	4.4	6.2	24.5	34.4
006					2.0	4.0	25.1	5.0	6.5	2.5	1.4	4.1	7.9	6.5	6.6	4.5	23.9	42.6
2484						0.4	1.8	8.7	9.7	15.7	16.4	6.6	6.6	6.7	4.0	24.2	10.1	
C 23					0.1	0.1	0.4	1.5	24.9	39.5	17.1	1.7	4.5	1.2			27.0	
C 24			<0.1	<0.1	0.1	0.1	1.2	1.6	12.4	55.1	16.3	3.5	0.9	1.4			16.0	
C 25				0.1	0.2	0.2	1.7	6.7	25.6	33.0	14.4	4.5	1.5	1.5			35.8	
C 26					0.1	0.1	1.1	4.7	30.1	39.2	10.7	2.9	1.3	1.4			36.6	
C 27				0.1	1.7	9.5	40.8	19.5	11.7	9.0	2.5	1.0	0.3	0.5			84.0	
C 28				0.1	1.0	0.1	3.0	9.0	33.2	22.0	15.1	5.8	1.2	1.2			47.6	
C 34				0.4	1.0	1.6	18.6	28.0	15.0	11.8	5.2	3.2	2.8	2.4			64.6	
C 35					0.3	2.3	4.6	72.0	10.0	2.0	1.0	1.0	-				79.2	
6	0.9	2.1	1.0	1.0	22.9	41.2	23.0	2.7	0.7	-	-	0.3	0.3	0.2			95.7	
25	0.4	1.3	4.1	19.5	49.8	17.1	5.6	0.1	<0.1	-	-	-	-	-			98.4	
26	0.7	20.3	21.0	35.4	17.7	0.9	0.3	<0.1	<0.1	-	-	-	-	-			100.0	
18	0.1	0.4	1.2	8.0	47.5	16.4	7.3	2.4	2.1	0.9	2.6	1.9	1.4	0.9			85.3	

Table VI

Organic carbon percentages arranged in order of increasing S(and)/
P(elite) ratio

Sediment type	Station nr.	S/P x 1000	Per cent org. carbon		Mean C _{org.}
I	2495	0	0.66	0.73	
	40	0	0.73	0.65	
	2478	0	0.68	0.64	
	41	0	0.49	0.60	
	C 14	0	0.59	0.51	
	C 15	0	0.63	0.59	
	C 16	0	0.56	0.49	
	C 18	0	0.55	0.49	
	C 19	0	0.57	0.55	
	C 20	1	0.60	0.55	
	C 21	1	0.59	0.56	
	8	2	0.73	0.94	
	30	2	0.70	0.84	
	7	2	0.71	0.68	
	002	2	0.65	0.65	
	2498	2	0.60	0.57	
	2490	3	0.80	0.79	
	2496	7	0.70	0.74	
	2477	8	0.75	0.72	
	2497	9	0.76	0.75	0.65 ± 0.10
II	C 24	190	0.27	0.26	
	C 23	389	0.26	0.22	
	C 26	557	0.22	0.27	
	C 25	558	0.20	0.17	
	C 27	5250	0.31	0.21	0.24 ± 0.04
III	18	5849	0.17	0.23	
	2467	17868	0.11	0.11	
	6	22256	0.16	0.27	
	2466	51631	0.11	--	
	2465	61500	0.05	--	
	19	70428	0.17	0.11	
	26	~	0.05	--	0.14 ± 0.06

Table VI (continued)

Organic carbon percentages arranged in order of increasing S(and)/
P(elite) ratio.

Sediment type	Station nr.	S/P x 1000	Per cent org. carbon	Mean C _{org.}
Mixed	C 22	6	0.56	0.49
types	2479	15	0.63	0.58
	29	524	0.60	0.46
	006	742	0.43	0.41
	28	10236	0.29	0.16
	2485	27571	0.27	0.24

Table VII

Nitrogen contents and C/N ratios of sediments arranged in order of increasing S(and)/P(elite) ratio.* 1. % Sand to % Pelite ratio x 1000; 2. per cent N-total (in duplicate); 3. per cent N after treatment with H₂O₂ (in duplicate); 4. percentage of the total N content that remained after H₂O₂-treatment; 5. mg N/100 g pelite after the samples were treated with H₂O₂; 6. % organic Carbon to % Nitrogen-total (C/N_{-tot}); 7. % organic Carbon to % H₂O₂-oxidizable Nitrogen (C/N_{-org.} ?).

Sediment type	Stat. nr.	(1)*	(2)*	(3)*	(4)*	(5)*	(6)*	(7)*		
I	2495	0	0.104	0.108	0.063	0.057	57	60.4	6.5	15.1
	40	0	0.112	0.097	0.068	0.059	61	63.7	6.6	16.8
	2478	0	0.113	0.112	0.055	0.050	47	52.9	5.9	11.0
	41	0	0.097	0.087	0.051	0.048	54	49.7	5.9	12.8
	C14	0	0.105	0.085	0.051	0.054	55	52.3	5.7	12.9
	C15	0	0.101	0.114	0.055	0.062	55	64.1	5.7	12.4
	C16	0	0.082	0.093	0.069	0.065	76	66.5	6.0	25.6
	C18	0	0.092	0.095	0.052	0.058	59	55.2	5.6	13.5
	C19	0	0.097	0.099	0.059	0.059	60	58.3	5.7	14.4
	C20	0	0.092	0.095	0.057	0.057	60	56.1	6.1	15.7
	C36	1	0.092	0.102	0.053	0.055	56	54.5	-	-
	C21	1	0.093	0.084	0.049	0.051	56	49.6	6.5	14.9
	8	1	0.107	0.111	0.063	0.062	57	62.2	7.7	18.4
	004	2	0.095	0.098	0.061	0.067	66	64.8	-	-
	007	2	0.101	0.112	0.072	0.066	65	69.4	-	-
	30	2	0.096	0.093	0.045	0.046	48	45.5	8.1	15.7
	7	2	0.100	0.104	0.063	0.061	61	62.3	6.8	17.4
	002	2	0.098	0.106	0.058	0.070	63	64.4	6.4	17.1
	2498	2	0.101	0.113	0.053	0.053	49	52.5	5.5	10.8
	C17	3	0.089	0.085	0.059	0.058	67	58.5	-	-
	2490	3	0.134	0.120	0.070	0.058	50	63.7	6.2	12.6
	C37	4	0.089	0.089	0.054	0.053	57	53.8	-	-
	2496	7	0.089	0.089	0.049	0.046	53	47.5	8.1	17.3
	2477	8	0.113	0.115	0.053	0.056	50	57.5	6.4	12.9
	2497	9	0.104	0.106	0.059	0.057	55	58.3	7.2	15.7
Mean			0.100 ± 0.01		0.057 ± 0.06					

Table VII (continued)

Nitrogen contents and C/N ratios of sediments arranged in order of increasing S(and)/P(elite) ratio. *1. % Sand to % Pelite ratio x 1000; 2. per cent N-total (in duplicate); 3. per cent N after treatment with H₂O₂ (in duplicate); 4. percentage of the total N content that remained after H₂O₂-treatment; 5. mg N/100 g pelite after the samples were treated with H₂O₂; 6. % organic Carbon to % Nitrogen-total (C/N_{-tot}); 7. % organic Carbon to % H₂O₂-oxidizable Nitrogen (C/N_{-org.} ?).

Sediment type	Stat. nr.	(1)*	(2)*	(3)*	(4)*	(5)*	(6)*	(7)*		
II	C24	190	0.026	0.026	0.018	-	69	21.4	10.1	33.1
	C23	389	0.023	0.024	0.017	0.016	70	22.9	10.2	34.3
	C26	557	0.024	0.024	0.015	0.016	64	24.4	10.2	28.8
	C25	558	0.026	0.027	0.013	0.018	58	24.1	7.0	16.8
	C28	908	0.027	0.027	0.018	0.017	65	33.4	-	-
	C34	1825	0.028	0.032	0.017	0.016	55	46.6	-	-
	C35	3808	0.020	0.020	0.012	0.012	60	57.7	-	-
	C27	5250	0.013	0.014	0.009	0.009	67	56.2	19.2	57.7
Mean			0.024 ± 0.005	0.015 ± 0.003						
Mixed types	C22	6	0.082	0.083	0.052	0.051	62	51.8		
	2479	15	0.079	0.075	0.051	0.050	65	51.3		
	2484	112	0.086	0.102	0.036	0.041	41	42.8		
	29	524	0.080	0.080	0.030	0.026	35	42.7		
	006	742	0.078	0.078	0.032	0.036	44	59.2		

Table VIII

Cation exchange characteristics of sediment type I

Station nr.	S/P x 1000	CEC			
		1*	2*	3*	4*
2495	0	25.65	25.65	41.77	61.4
40	0	25.05	25.05	39.95	62.7
2478	0	21.70	21.70	41.25	52.6
41	0	27.05	27.05	45.08	60.0
C14	0	25.65	25.65	42.40	60.5
C15	0	26.60	26.60	42.29	62.9
C16	0	26.75	26.75	43.64	61.3
C18	0	25.85	25.85	43.74	59.1
C19	0	25.80	25.80	40.82	63.2
C20	0	25.45	25.45	43.50	58.6
C36	1	27.25	27.27	45.87	59.5
C21	1	26.95	26.98	46.63	57.9
8	1	27.05	27.07	41.87	64.7
004	2	25.10	25.15	41.97	59.9
007	2	23.85	23.90	40.63	58.8
30	2	23.90	23.95	43.22	55.4
7	2	25.75	25.80	43.13	59.8
002	2	24.90	24.95	38.54	64.7
2498	2	26.30	26.35	41.35	63.7
C17	3	26.60	26.68	45.24	59.0
2490	3	26.05	26.13	43.20	60.5
C37	4	26.05	26.15	43.13	50.4
2496	7	19.45	19.59	36.70	53.4
2477	8	22.20	22.38	38.88	57.6
24.97	9	19.00	19.17	31.77	60.3

* 1 : me/100 g sediment; mean values of analyses in duplicate \pm 1.35
2, 3, 4 see Table X.

Table XI

Cation exchange characteristic of sediment type II.

Station nr.	S/P x 1000	CEC			
		1 [‡]	2 [‡]	3 [‡]	4 [‡]
C24	190	7.70	9.17	118.46	7.7
C23	389	7.75	10.76	96.87	11.1
C26	557	8.70	13.72	110.13	12.5
C25	558	8.25	12.85	88.71	14.5
C28	908	8.45	16.12	119.01	13.5
C34	1825	9.25	26.13	92.50	28.2
C35	3808	5.55	26.68	81.62	32.7
C27	5250	7.40	46.25	274.07	16.9

[‡]1 : me/100 g sediment; mean values of analyses in duplicate \pm 0.54
2, 3 and 4 : see Table X.

Table X

Cation exchange characteristics of mixed types of sediments.

Station nr.	S/P x 1000	CEC			
		1 [‡]	2 [‡]	3 [‡]	4 [‡]
C22	6	23.25	23.39	45.77	41.9
2479	15	20.60	20.91	49.88	41.9
2484	112	11.65	12.96	33.38	38.8
29	524	11.50	17.53	32.76	53.5
006	742	11.20	19.51	32.00	61.0

[‡]1 : me/100 g sediment; mean values of analyses in duplicate \pm 0.94

2 : me/100 g pelite (fraction $<$ 50 μ m)

3 : me/100 g lutum (fraction $<$ 2 μ m)

4 : per cent of clay in the pelite fraction

$$\left(\frac{\% < 50 \mu\text{m}}{\% < 2 \mu\text{m}} \times 100 \right)$$

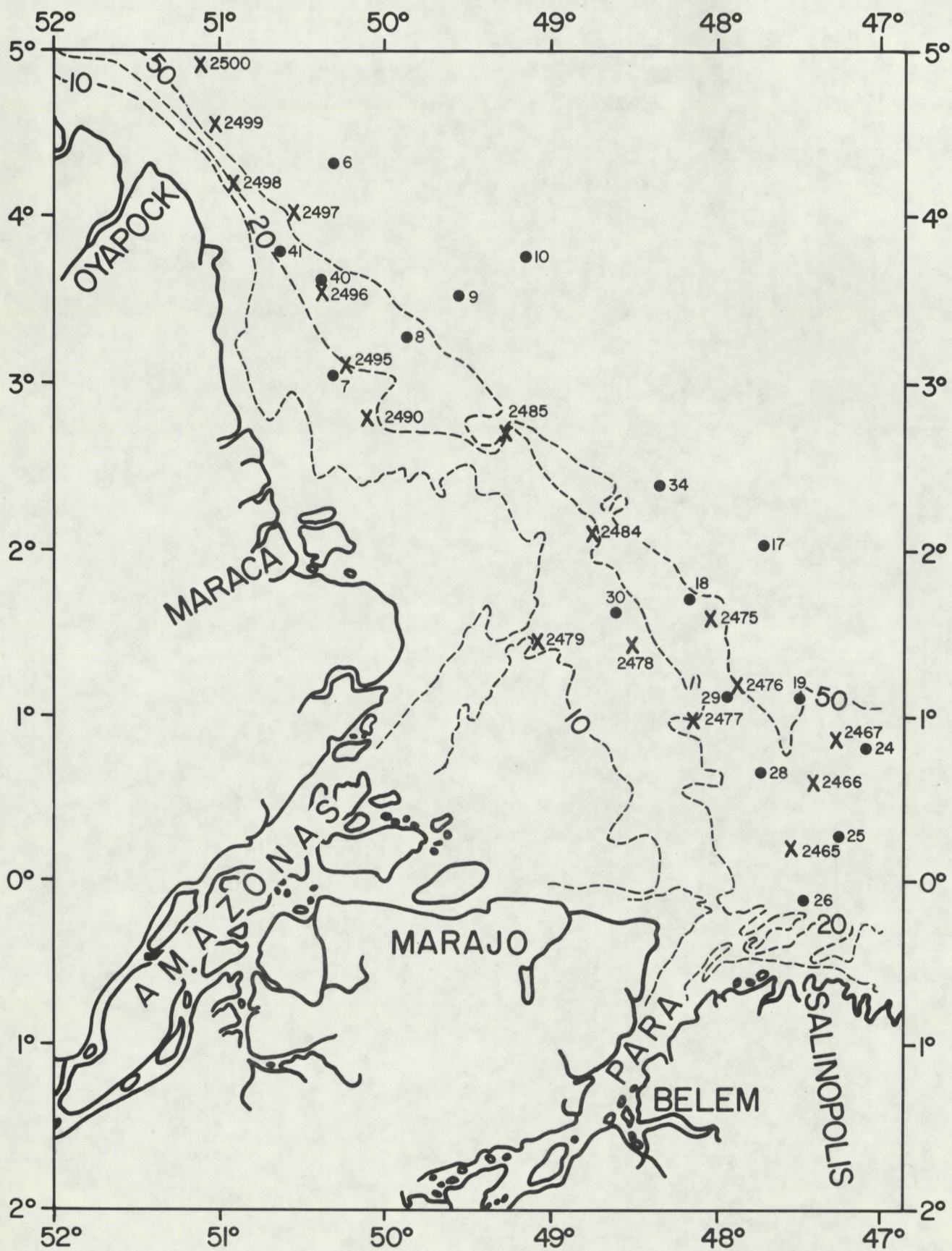


Fig. 1. Localities of samples collected on board of the "Noc. ALMIRANTE SALDANHA"; Sept.-Oct. 1970 (●) and May 1971 (x).

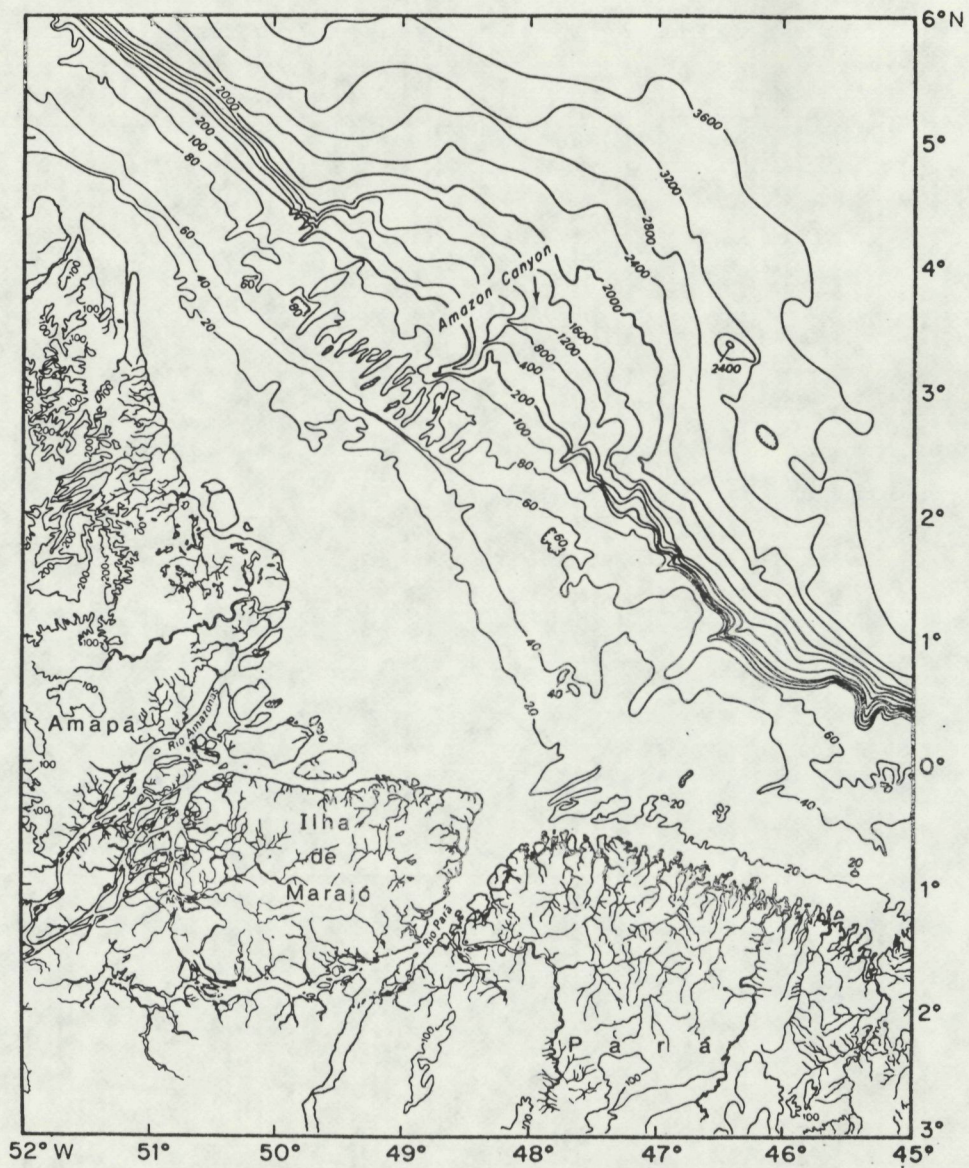


Fig. 2. Bathymetry of north Brazilian continental margin off Amazon River. Contours are in metres (After MILLIMAN et al., 1975).

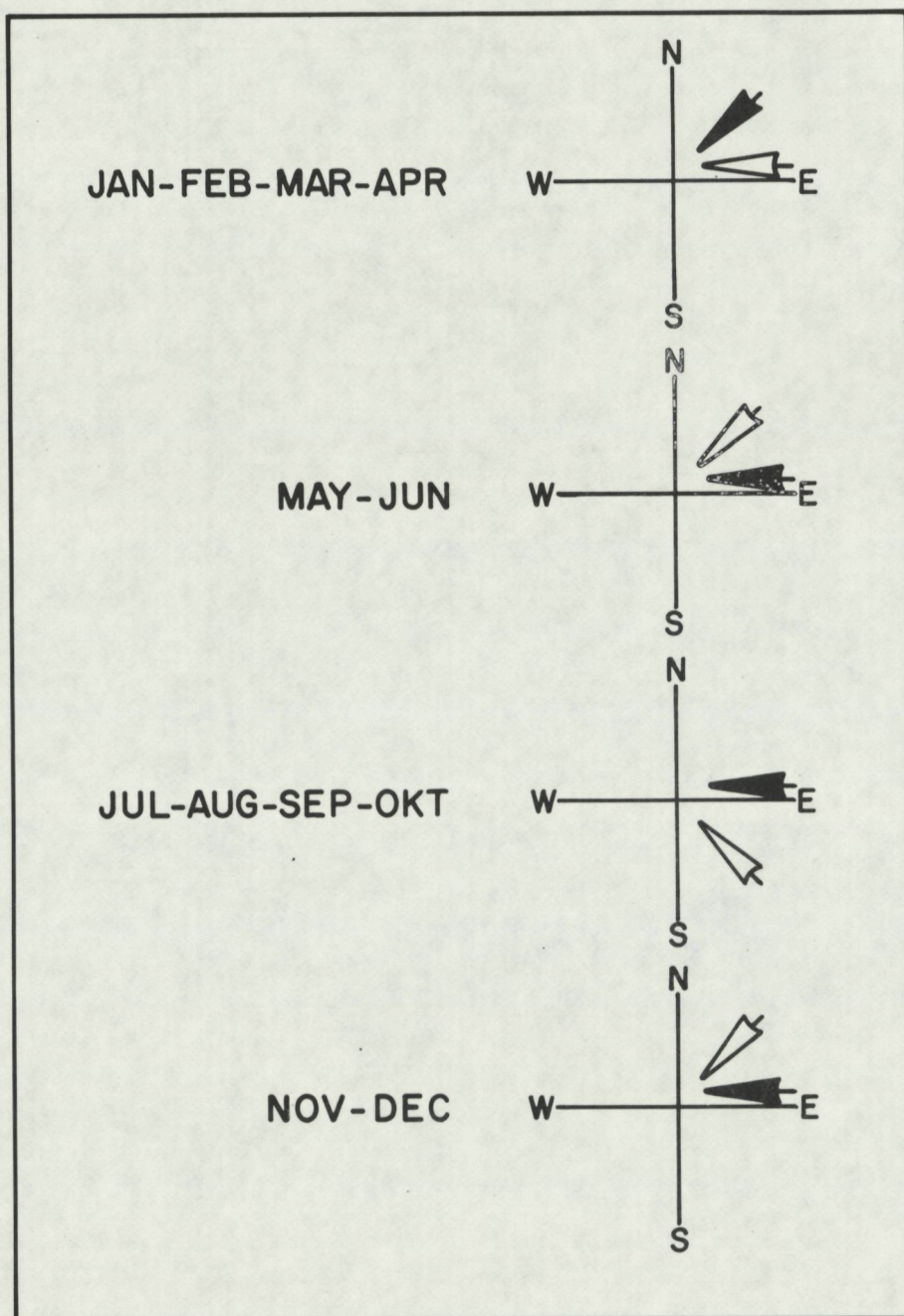


Fig. 3. Frequency of major (→) and secondary (→) wind directions in the Amazon's mouth region (After ZEMBRUSKI, 1971, personal communication).

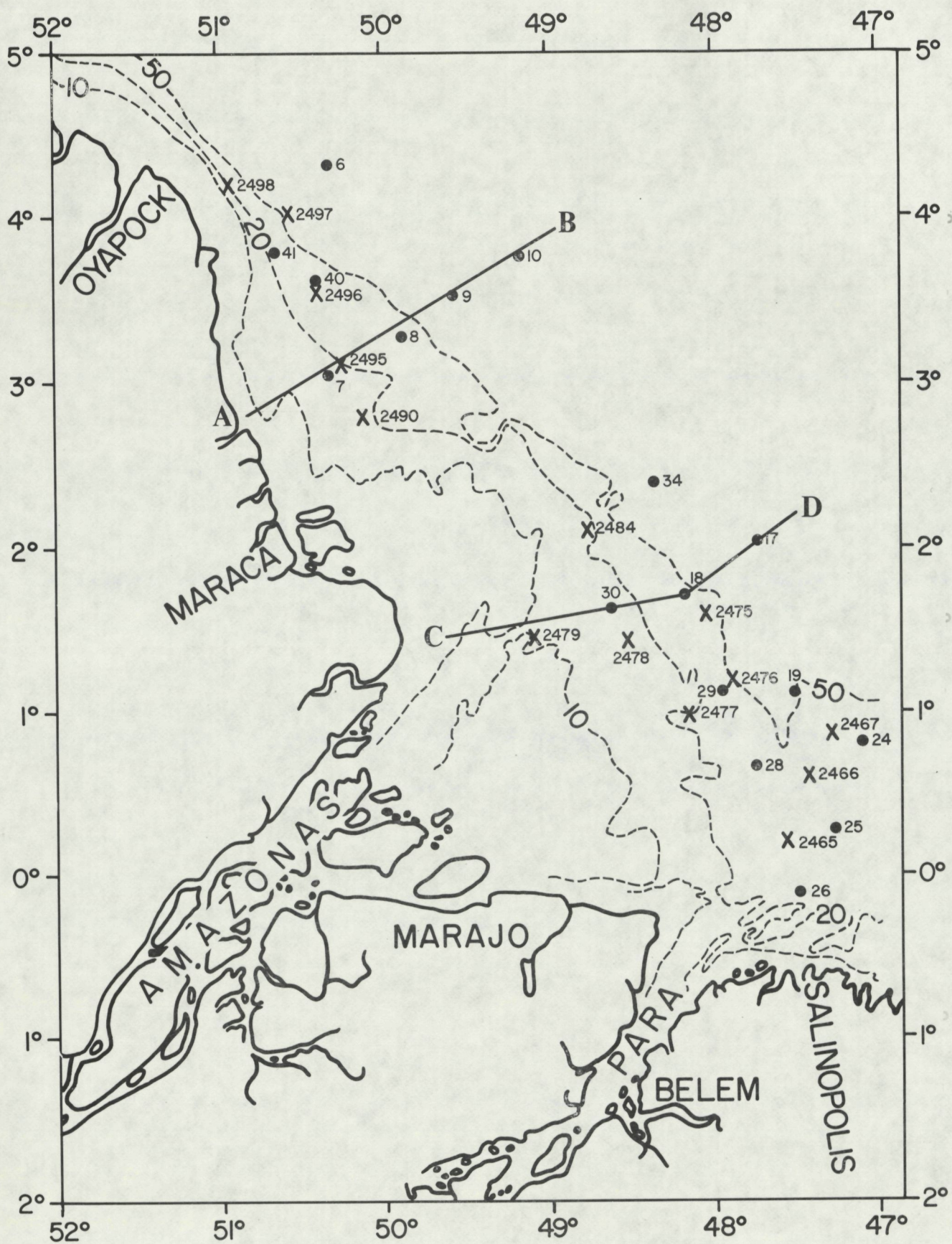


Fig. 4. Location of stations where suspended matter have been sampled; Sept.-Oct. 1970 (●) and May 1971 (x).

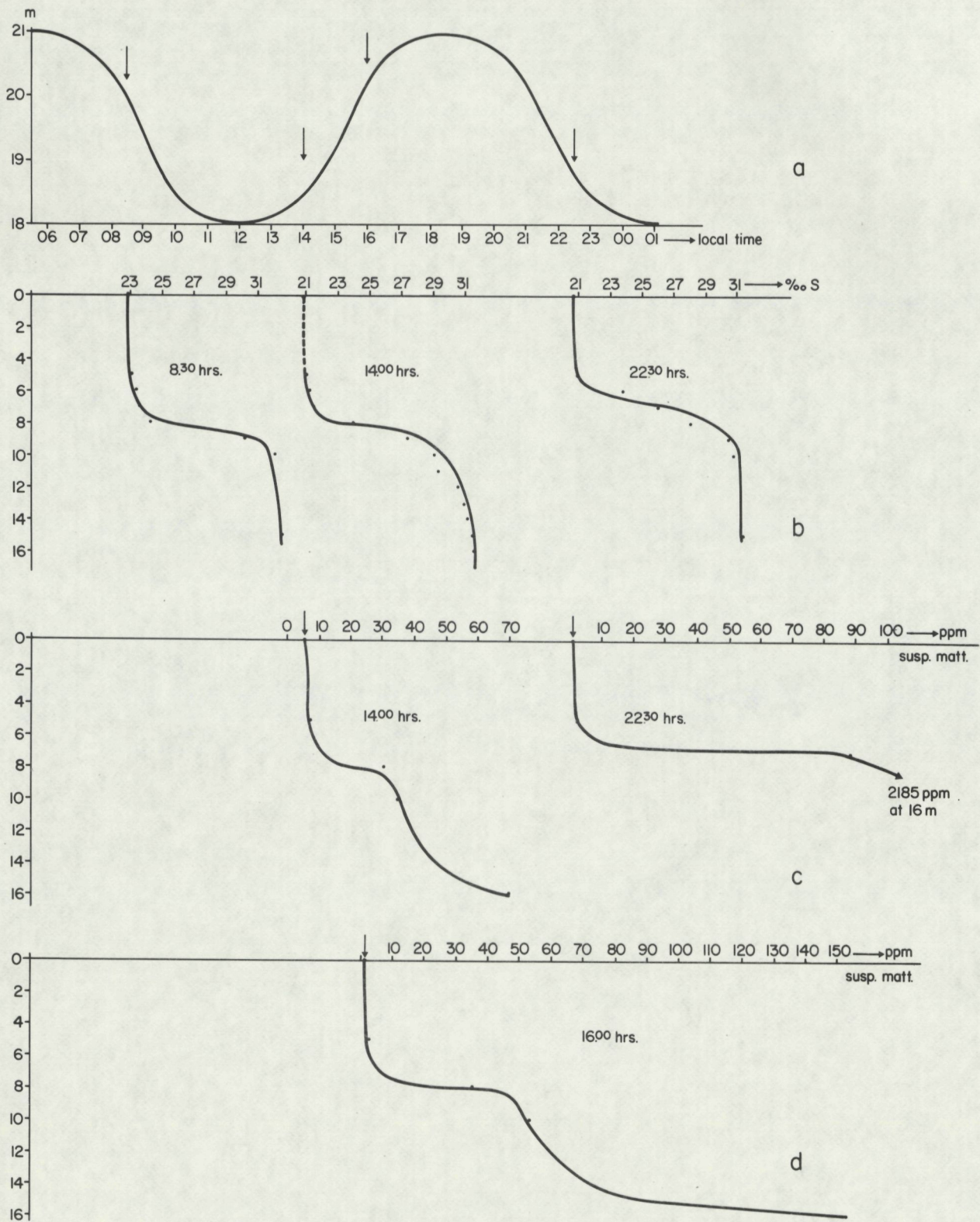


Fig. 5. Salinity and distribution of suspended matter over depth at different stages of the tidal cycle on station 7 (see Fig. 4).
 a. Tidal changes in height of the water column above the bottom.
 b. Salinity profiles at different times of the day.
 c. and d. Variations in concentration of suspended matter of the water column as related to varying bottom depth due to tidal changes.

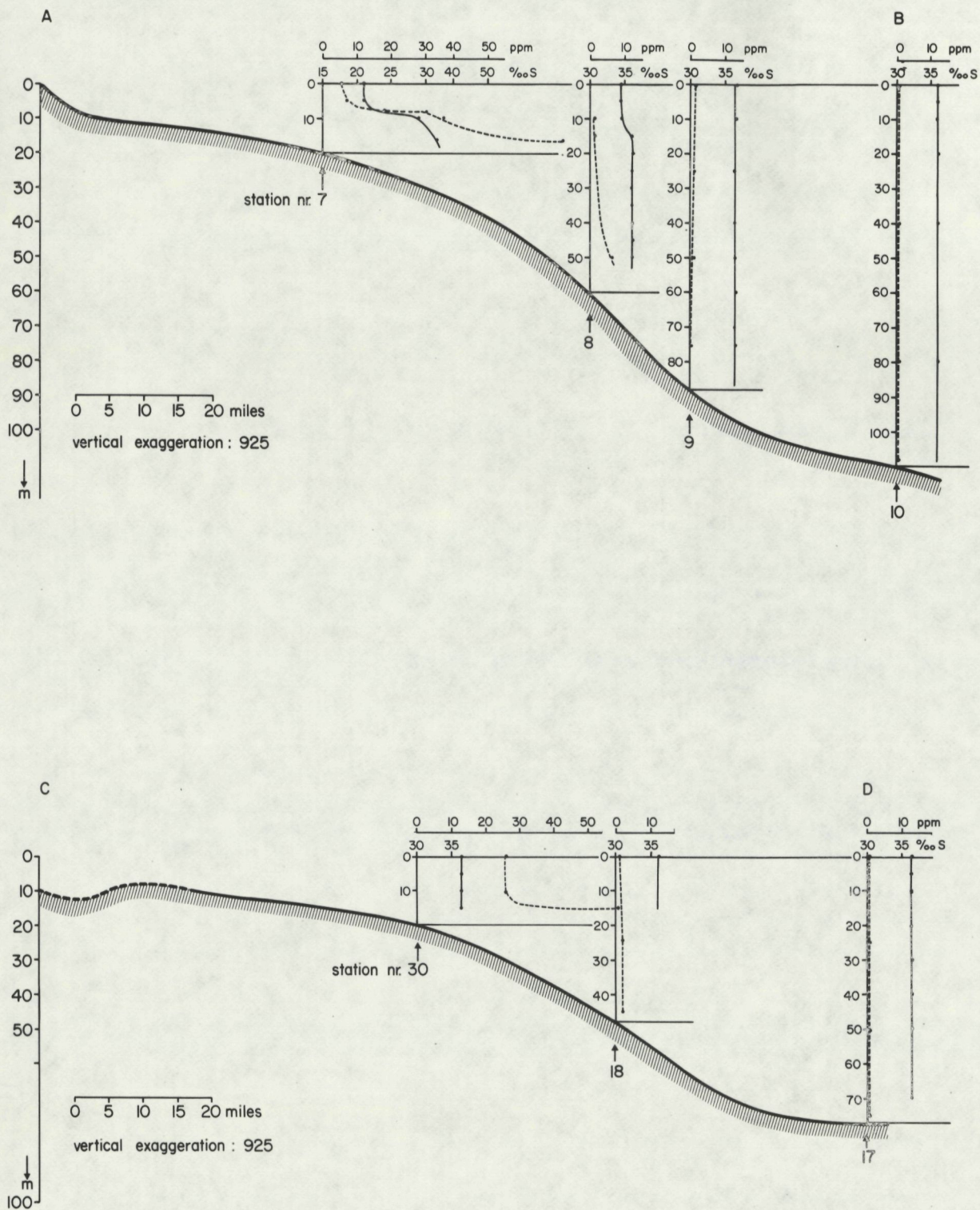


Fig. 6 and 7. Salinities (solid lines) and suspended matter concentrations (dotted lines) in cross selections along lines AB and CD (see Fig. 4).

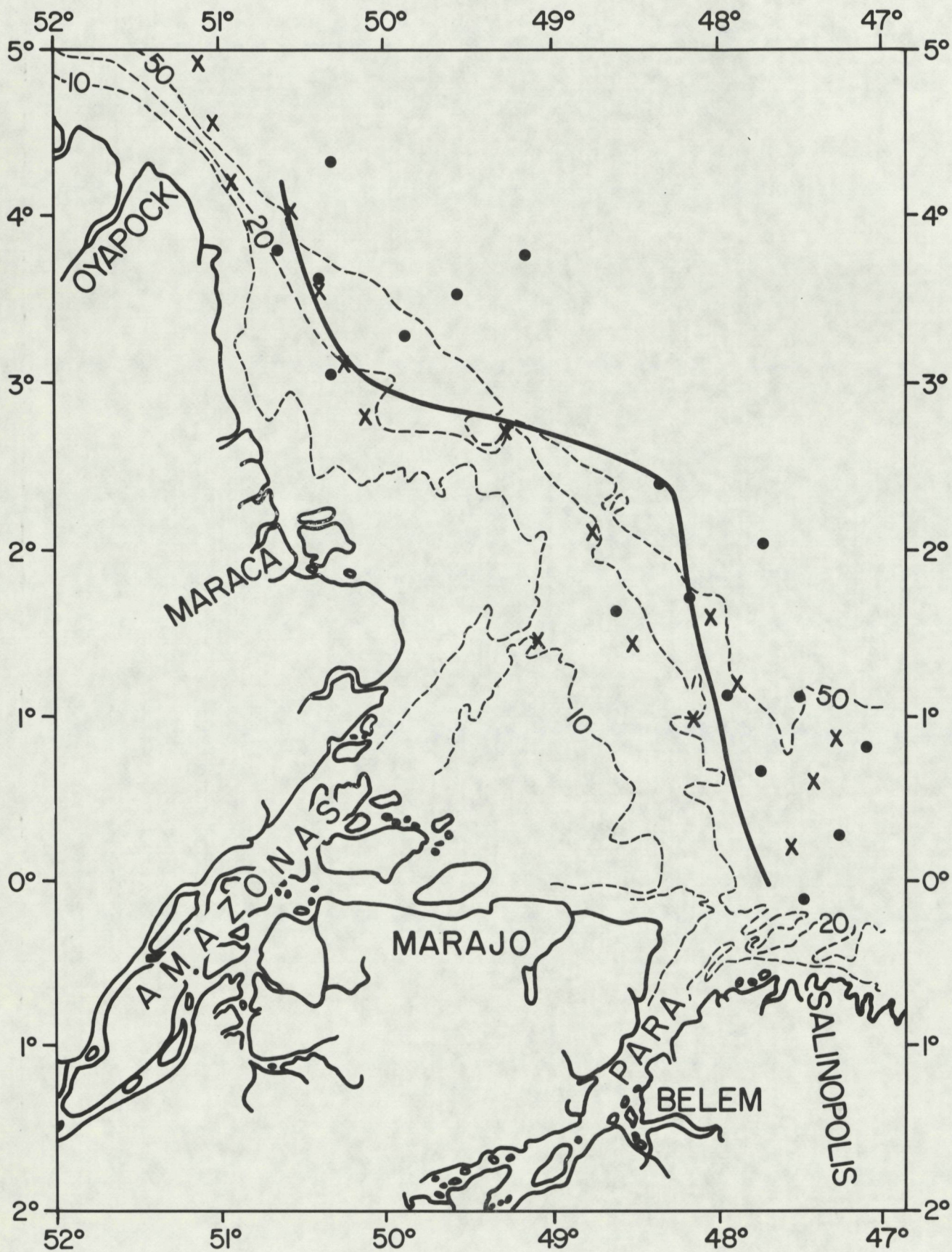


Fig. 8. Delineation of the area where river-borne suspended load dominates in the superficial layer. Solid line shows the path of the iso-concentration for 5 mg/l.

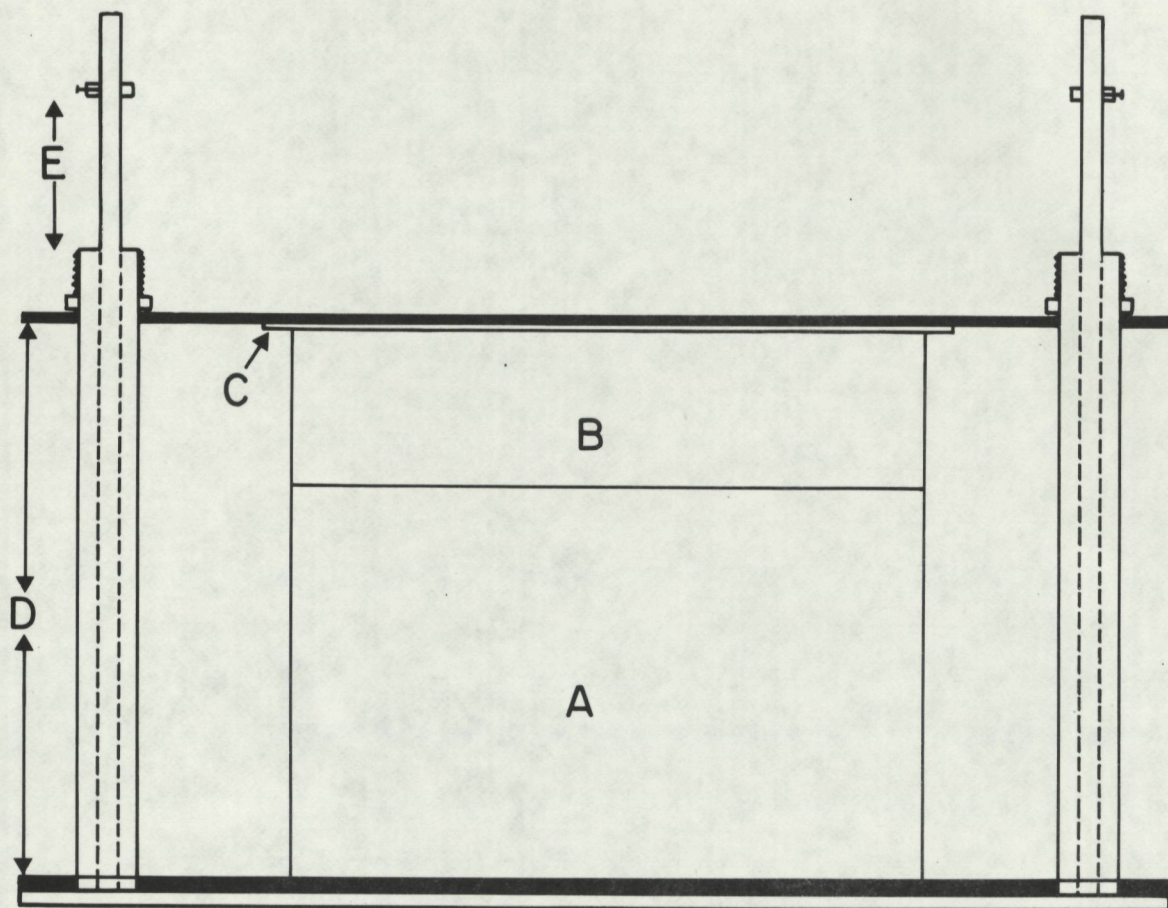


Fig. 9. Hilgard apparatus for determination of the bulk density of dry sediments showing cylinder of known volume (A), cylinder for overload (B), lid (C), liftcage (D) and height of fall (E).

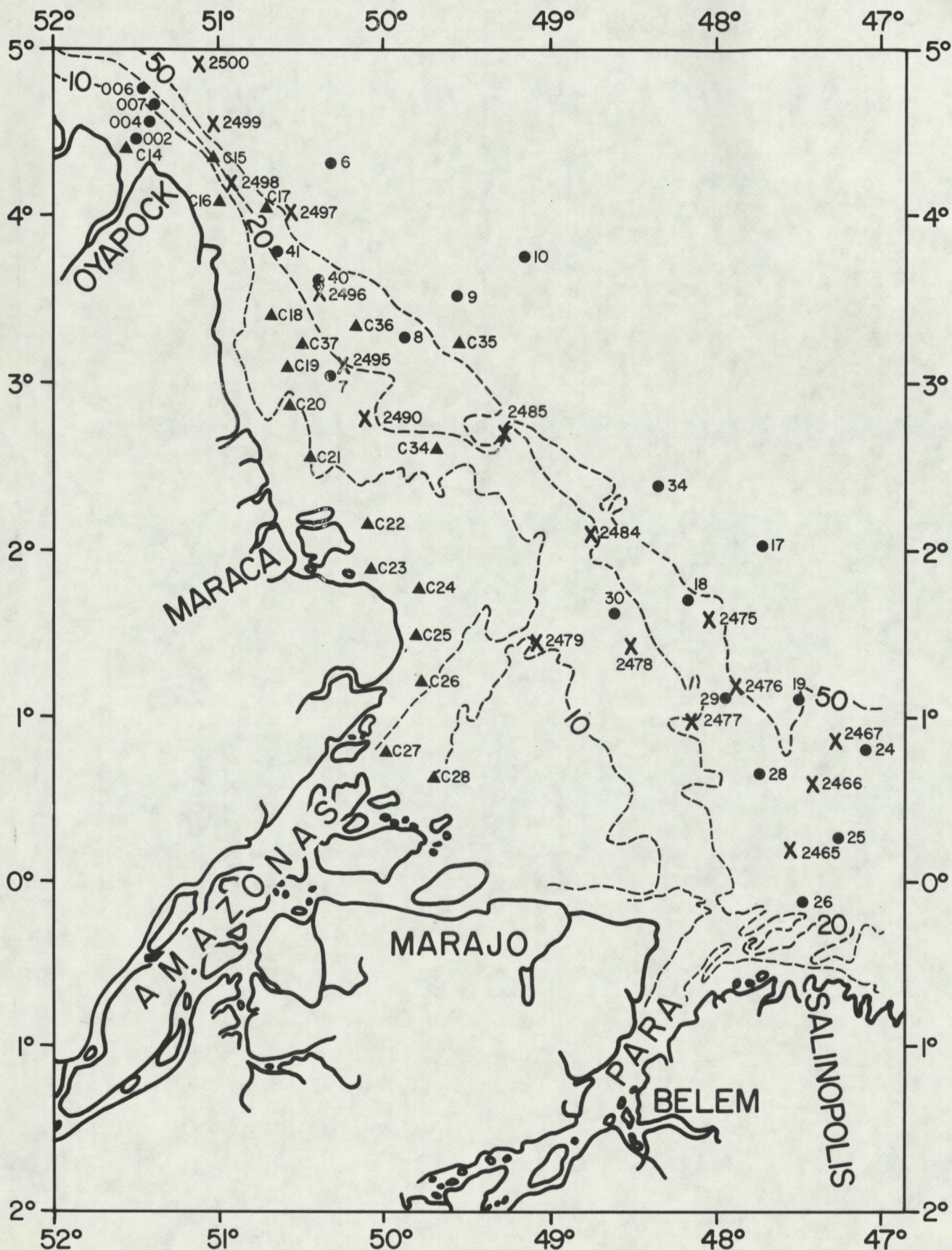


Fig. 10. Location of analysed samples; 002, 004, 006 and 007 were collected on board of the "H.M. LUYMES" in 1971; numbers prefixed by C, indicate the location of samples collected by Dr. PONS in 1962; the rest of the samples were gathered on board of the "Noc. ALMIRANTE SALDANHA" in 1970 and 1971 (cf Fig. 1).

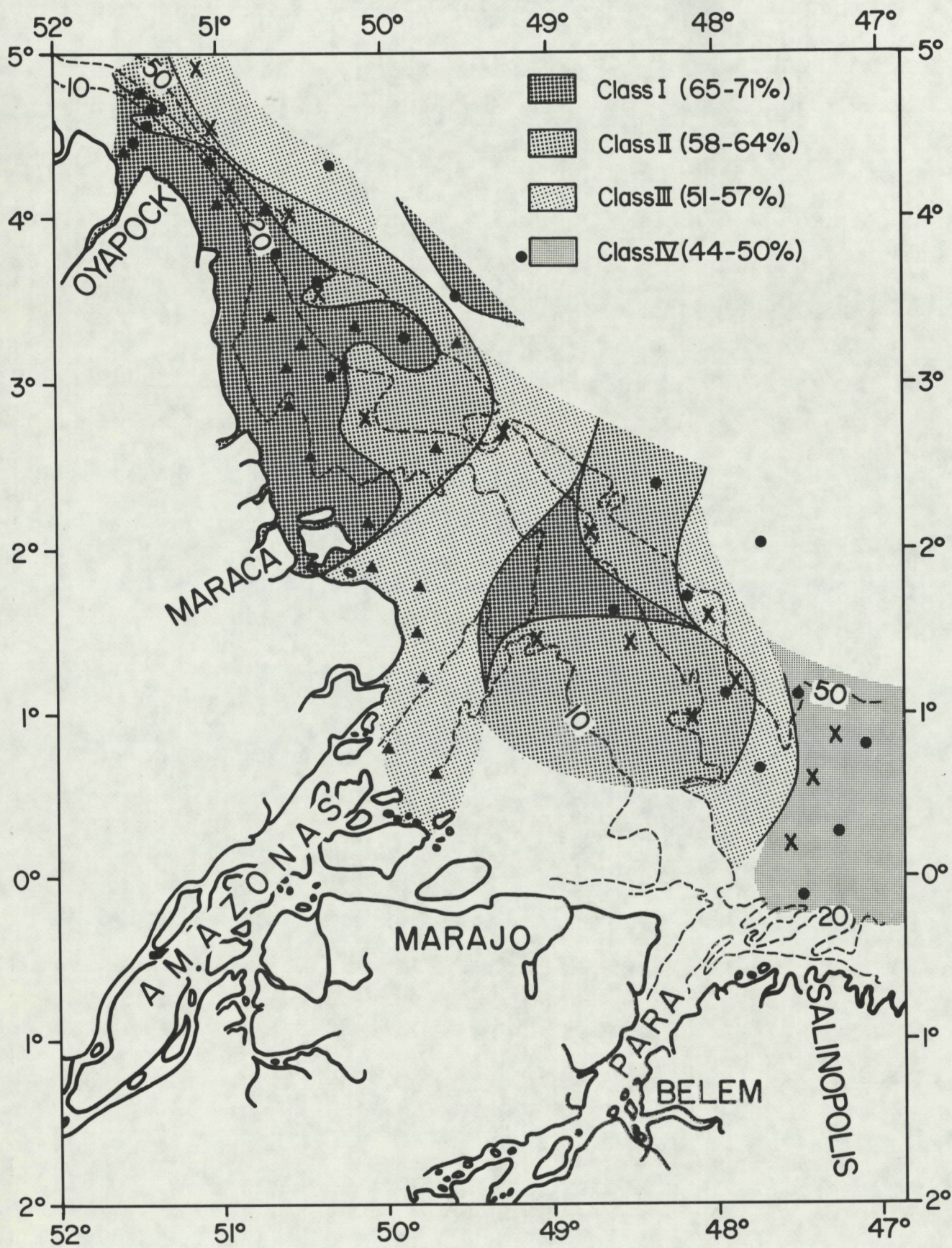


Fig. 11. Spreading of sediments, classed according to the percentages of their pore volume.

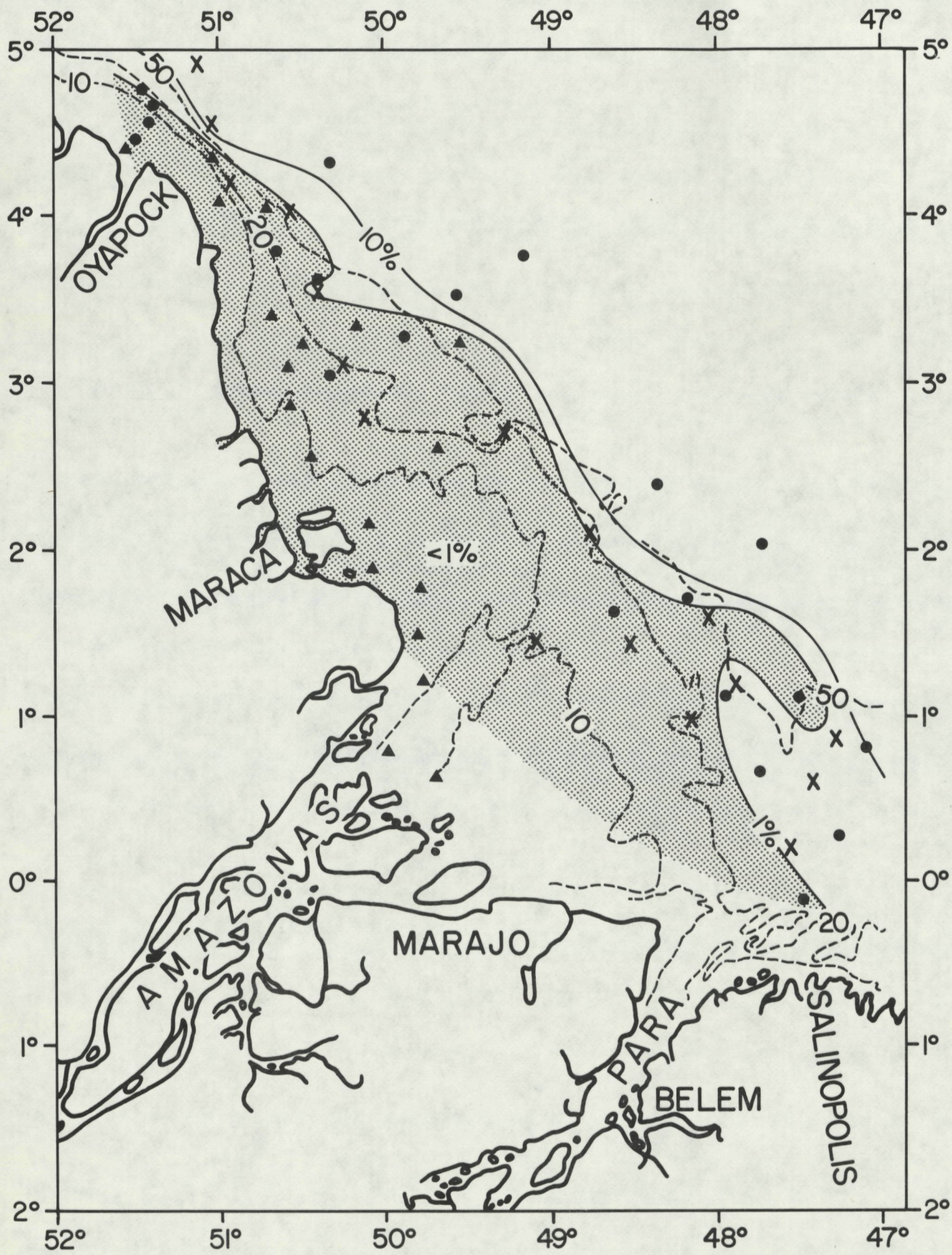


Fig. 12. Carbonate content of the sediments, isopleths of 1% and 10% indicated.

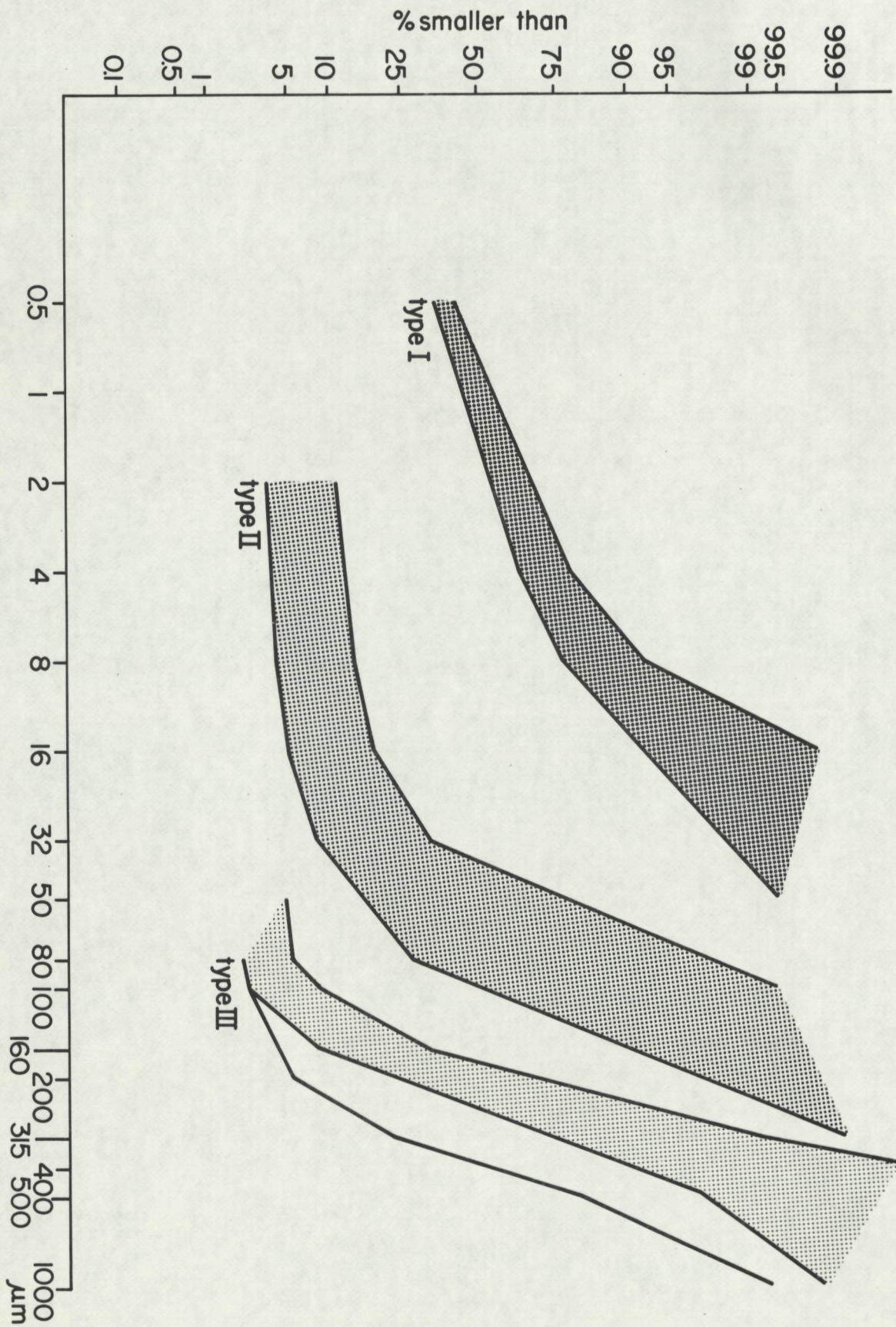


Fig. 13. Cumulative curves showing the grain size frequency distribution of sediment types.

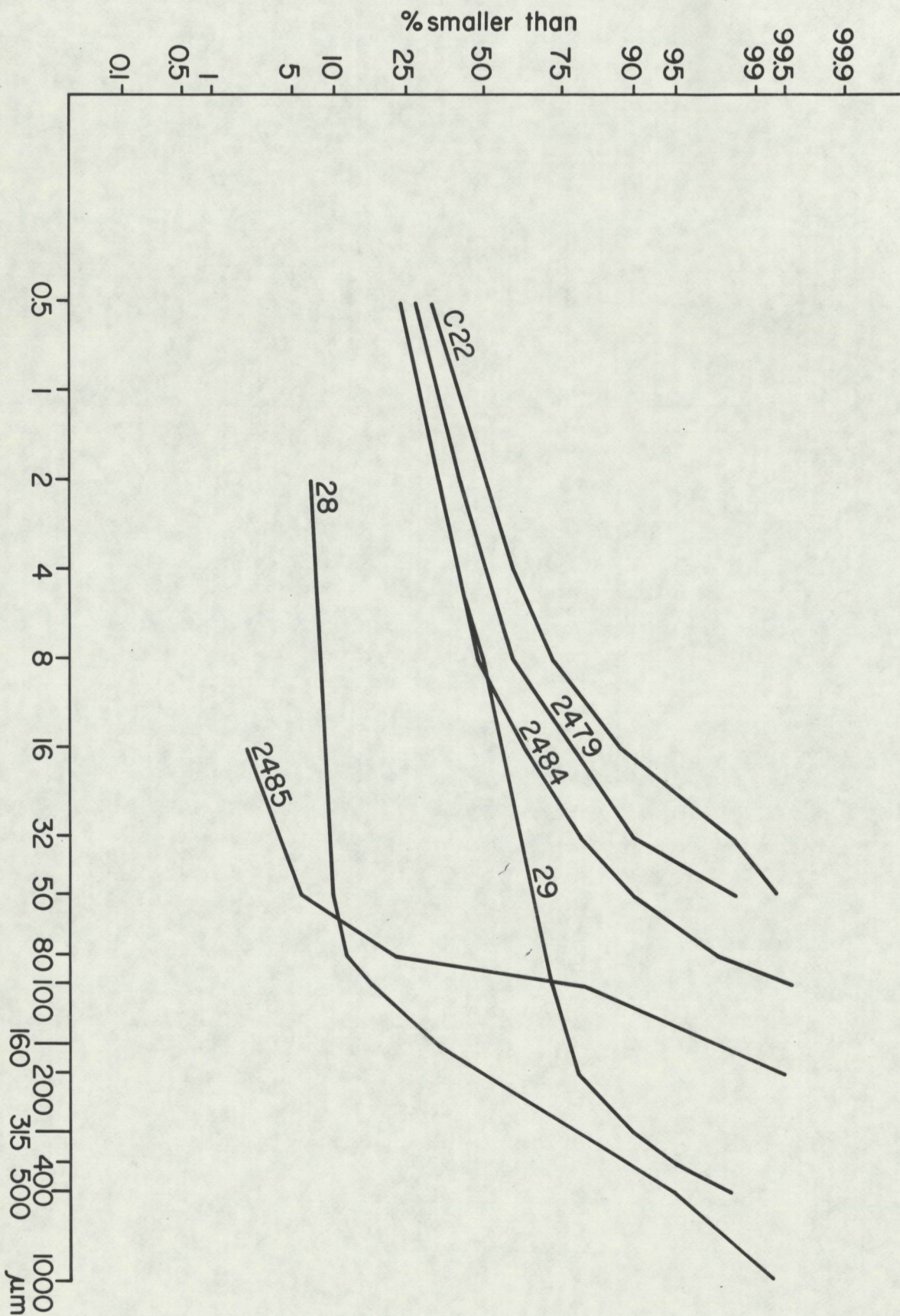


Fig. 14. Cumulative curves showing the grain size frequency distribution of sediments that are mixtures of different types (cf. Fig. 14); numbers refer to stations of sampling (see Fig. 11).

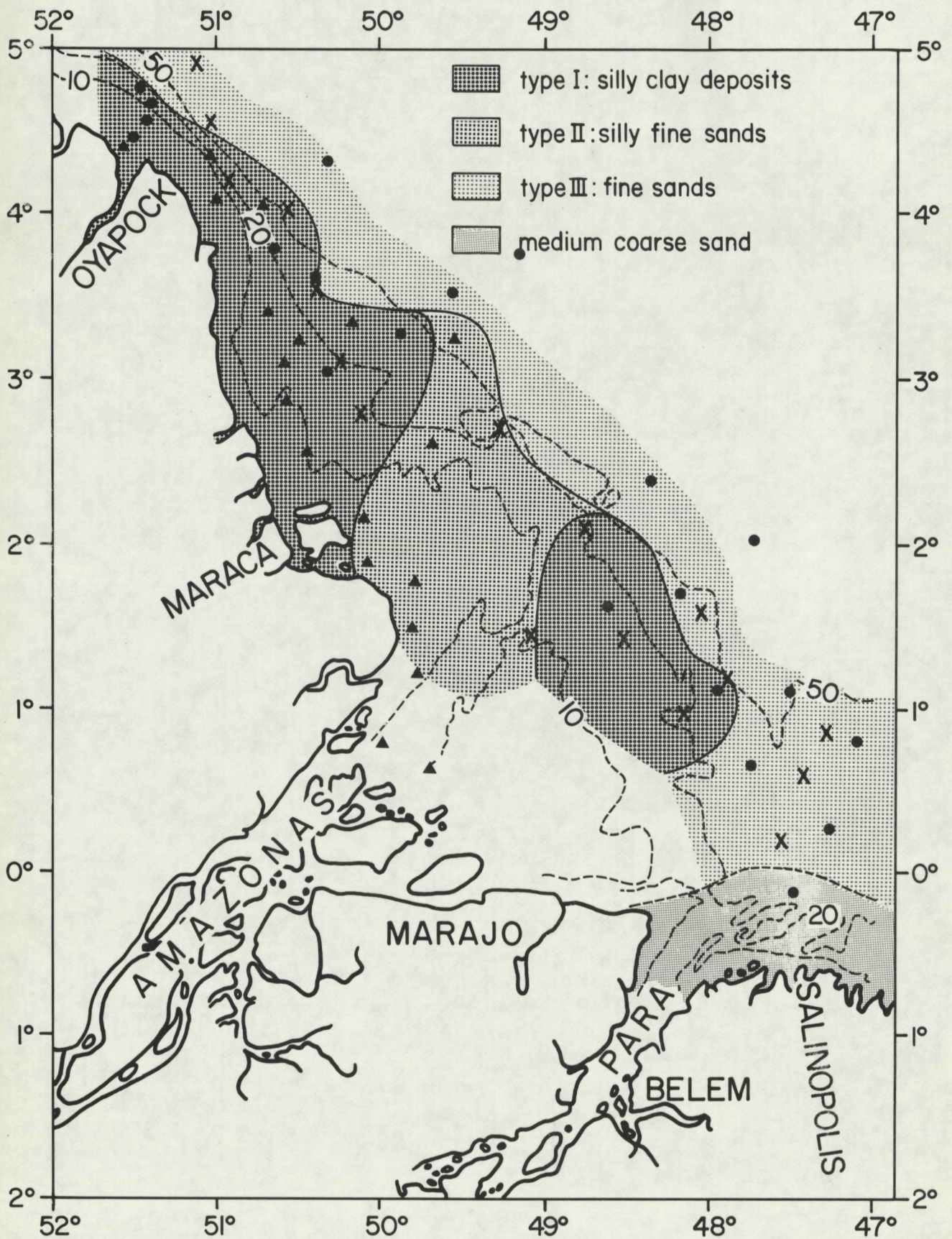


Fig. 15. Distribution pattern of sediments classed in correspondence with grain-size characteristic.

Table I

Salinity, watertemperature and suspended matter concentration near
the Amazon's River mouth in September - October 1970.

Station number	Latitude N	Longitude W	Water- depth (m)	Sampling- depth (m)	Salinity ‰	Suspended mater (ppm)	Tempera- ture °C
6	04°18.8'	050°17.1'	89	surface	20.9	1.3	28.4
				5	21.0	0.2	28.4
				10	35.35	0.4	28.1
				15	35.53	n.d.	28.0
				20	35.63	n.d.	27.8
				40	35.64	trace	26.7
				75	35.80	tr.	26.1
7	03°03.5'	050°17.4'	20	surface	20.9	5.5	27.8
				5	21.0	7.2	27.8
				8	24.0	30.2	27.6
				10	29.1	35.4	27.4
				16	31.6	69.7	27.0
8	03°17.5'	049°52.1'	60	surface	34.61	n.d.	27.2
				5	34.61	n.d.	27.2
				10	34.64	1.2	27.2
				15	36.15	1.3	27.2
				20	36.12	n.d.	26.7
				50	36.20	6.5	26.4
9	03°33.2'	049°32.3'	88	surface	36.60	1.4	29.0
				5	36.45	n.d.	28.0
				10	36.45	n.d.	27.9
				25	36.45	1.1	27.8
				50	36.35	0.5	27.0
				75	36.25	0.2	26.1
				86	n.d.	tr.	n.d.
10	03°46.7'	049°08.2'	111	surface	36.21	0.3	27.9
				5	36.25	n.d.	27.8
				20	36.17	n.d.	27.4
				40	36.17	tr.	27.0
				80	36.15	0.1	25.8
				108	n.d.	0.5	n.d.

Table I (continued)

Salinity, watertemperature and suspended matter concentration near
the Amazon's River mouth in September - October 1970.

Station number	Latitude N	Longitude W	Water-depth (m)	Sampling-depth (m)	Salinity ‰	Suspended matter (ppm)	Temperature °C
17	02°01.5'	047°43.0'	77	surface	36.45	0.1	27.1
				10	36.42	n.d.	27.2
				25	36.43	tr.	27.2
				30	36.45	n.d.	27.2
				50	36.40	0.1	27.0
				75	36.34	tr.	25.8
18	01°43.0'	048°10.5'	47	surface	36.10	1.0	n.d.
				25	n.d.	2.2	n.d.
				45	n.d.	2.2	n.d.
24	00°48.5'	047°05.0'	44	surface	36.19	0.1	27.5
				10	36.18	n.d.	27.5
				20	36.09	tr.	27.6
				30	36.00	n.d.	27.8
				40	36.01	tr.	27.8
26	00°08.5'	047°28.0'	24	surface	36.77	0.5	28.0
				10	36.72	0.4	28.2
				20	36.67	0.2	28.2
28	00°39.5'	047°43.0'	40	surface	36.35	0.3	28.0
				10	36.33	n.d.	28.0
				20	36.28	1.1	27.8
				30	36.23	n.d.	27.9
				38	36.20	2.5	28.0
29	01°37.0'	047°43.0'	51	surface	36.22	0.5	27.9
				10	36.22	n.d.	27.9
				25	36.21	1.8	27.7
				40	36.25	n.d.	27.7
				45	36.23	1.0	27.7
30	01°37.0'	048°38.0'	19	surface	36.55	26.4	28.2
				5	36.50	n.d.	28.3
				10	36.50	26.2	28.4
				15	36.50	58.3	28.4

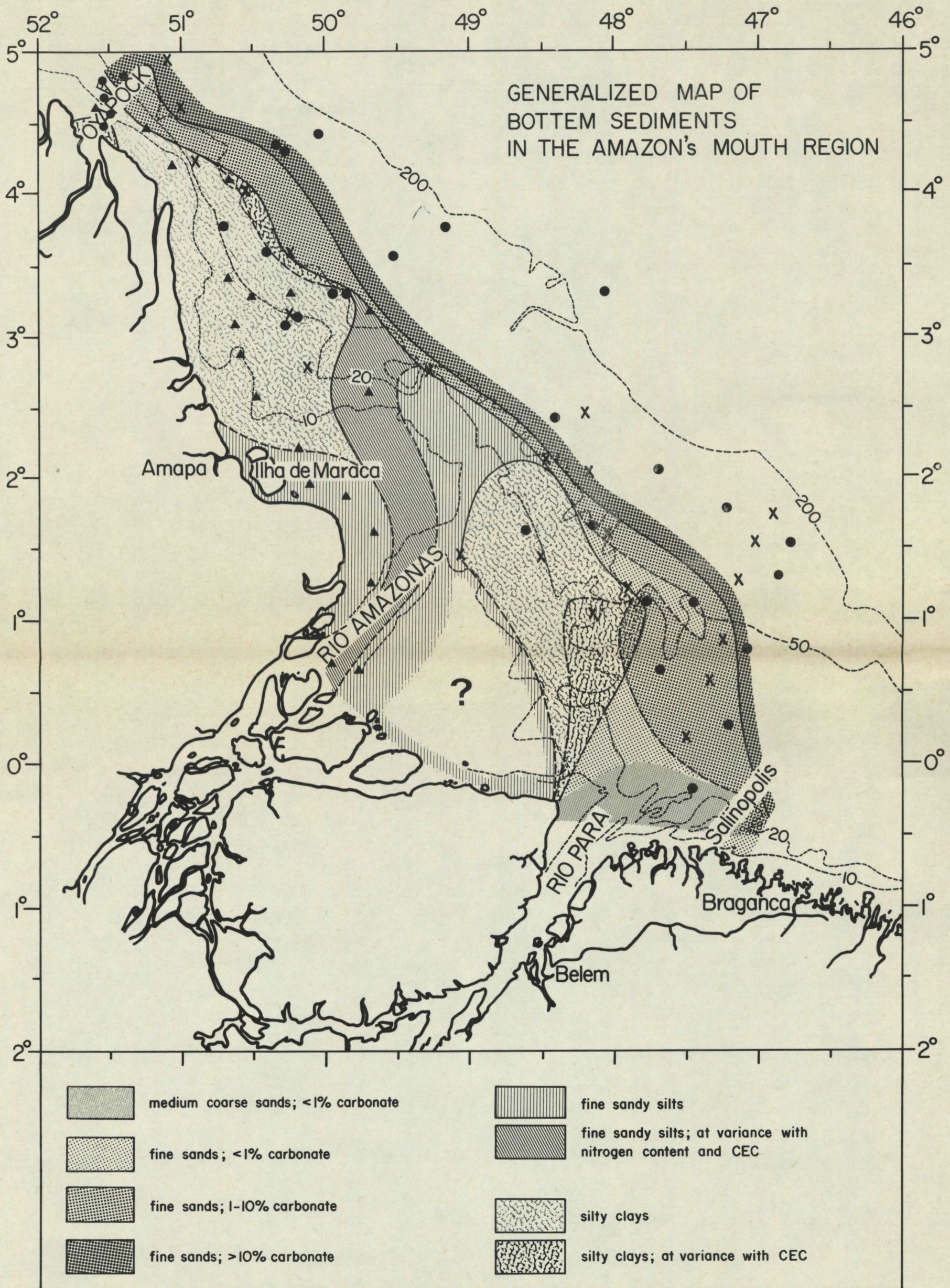


Fig. 16. ("Enclosure 1"). Generalized map of bottom sediments in the Amazon's mouth region.