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The Amazon River Input on the Adjacent Continental Shelf: a Review

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Abstract — New and important data covering the sedimentary model of the Amazon continental shelf were recently published abroad. These studies confirmed the presence of a subaqueous delta developed through the Amazon fluvial contribution as it was previously identified by several brazilians researchers. The sediments formed predominantly by sandy mud of fluvial origin developed a subaqueous prograding feature offshore and allongshore over a continental shelf transgressive sand blanket. The absence of a classical delta and its subaerial portion is mainly related with the high energy of the oceanic basin (waves, littoral and tidal currents). New sedimentological studies, based on superficial and cores samples from the lower Amazon and Pará rivers system to the bathymetry of ~ 100 meters, revealed the strong modern fluvial influence on the 5 to 40 meters surface of the subaqueous delta with the presence of wood fibers, lateritic aggregates and micas in the coarse fraction. The subaqueous delta front with a variable higher gradient is formed by sandy silt and silt with the presence of spicules, echinoids and other marine organisms, while a prodelta thin bed of clayey silt and clay with the dominance of marine organisms cover a basal transgressive quartzose sand with bioclastic fragments of a higher energy level sedimentation.

Resumo — Novas e importantes informações relativas ao modelo sedimentar da plataforma continental do Amazonas foram, recentemente, publicadas no exterior. Estes estudos, confirmam a presença de um delta subaquoso desenvolvido através da contribuição fluvial do Amazonas, conforme anteriormente identificado por vários pesquisadores brasileiros. Os sedimentos formados por lama arenosa de origem fluvial, desenvolvem uma feição progradante em direção de mar aberto e ao longo da costa, sobre uma cobertura arenosa transgressiva da plataforma continental. A ausência de um delta clássico e sua porção subaérea, está principalmente relacionada com a alta energia da bacia oceânica receptora, (ondas, correntes litorâneas e de marés). Novos estudos sedimentológicos, baseados em amostras superficiais e de testemunhos do sistema fluvial inferior dos rios Amazonas e Pará, até a batimetria de - 100 metros revelaram uma forte influência fluvial moderna, na superfície de cinco a quarenta metros do delta subaquoso, com presença de fibras de madeira, agregados lateríticos e micas, na fração grosseira. A frente deltaica do delta subaquoso, com elevado gradiente é formado por silte arenoso e silte, com presença de espículas, equinóides e outros organismos marinhos enquanto o prodelta formado por fina camada de silte argiloso e argila com dominância de organismos marinhos, cobre uma areia transgressiva quartzoza com fragmentos bioclásticos, de nível de energia de sedimentação elevado.

INTRODUCTION

The north Brazilian continental shelf adjacent to the Amazonas River mouth has been studied during the last decades with the objetive of stablishing its Late Quaternary sedimentary model. (Fig. 1)

Characterized by a large amount of fine sediments originated from the Amazonas river discharge (1,2 x 10^9 ton.) this region represents an extensive zone of mud accumulation feature, prograding over a basal Holocenic transgressive sandy surface, as a subaqueous delta (Martins et al, 1971, 72; Figueiredo et al, 1972).

The studies done in the region can be divided into two distinct groups. The first one is represented by pioneer studies regarding the morpho-sedimentologic characterization of the accumulative feature, using as basic elements precision depth recorder profiles, bottom and cores samples. These studies developed in the 1960's and 1970's were devoted to the northeast Amazon continental shelf up to the Orinoco river prodelta. The second group embraced recent studies using as additional tool high resolution seismic profiles and a

Figure 1 — Location map of study area.

modern laboratory procedure.

In the first group the most proeminent contributions are by: Ottmann (1959, 60), Reyne (1961), Van Andel (1967), Allersma (1968), Coutinho & Morais (1968), Nota (1969), Bandeira (1970), Eisma & Van Der Marel (1970), Mabesone & Coutinho (1970), Martins et al. (1971, 72), Diegues (1972), Zenbruscky et al.(1972), Figueiredo et al. (1972), Kowsmann & Costa (1974), Pomerancblum & Costa (1972), Santos (1972).

The modern studies are mainly represented by the papers of Nittrouer et al. (1983), Rine and Ginsburg (1985); Nittrouer and DeMaster (1986), which in a special volume discussed the sedimentary processes of the continental shelf. Lately the same results were presented during the XXX Brazilian Geological Congress by Nittrourer et al.(1988), Kuehl et al.(1988) and DeMaster et al.(1988).

This paper is a result of a class exercise and seminar developed during the CECO/UFRGS Marine Sedimentation graduate course. From data and samples of the Centro de Estudos de Geologia Costeira e Oceânica — CECO, new and additional sedimentological information is furnished with the purpose of stablishing a better undertanding of the relationship between mechanical and mineralogical compositions of the sediments of the subaqueous delta and the Amazon solid discharge.

MORPHOLOGY AND SEDIMENTOLOGY

The Holocene Amazon fluvial discharge contribution is exhibited trough the presence of three sedimentation levels, delineating a subaqueous delta.

The first level that extended up to the 40 meters isobath is formed by muds sometimes interbedded with sand. It is a planar surface showing low gradient and forming the topset part of the subaqueous feature.

The surface between 40 and 60 meters shows a much steeper gradient with mud and fine sand forming the subaqueous delta front, while the prodeltaic zone is represented by a thin layer of homogeneous mud covering a Holocene transgressive sand blanket (Martins et al. 1971,72 e Martins, 1974).

The modern studies linked with Nittrouer and DeMaster (1986) confirmed through seismic profiles the presence of the subaqueous feature including its modern counterpart as it was previously described by Martins (1974), and added several new pieces of information about the three sedimentation levels.

Summarizing, it is confirmed through these last studies the correctness of the older research papers made by Brazilian sedimentalogists (not mentioned in the Nittrouer group papers) in which they say that the Amazon is responsible for the construction of a subaqueous feature along the inner and middle shelf with a development through hundreds of kilometers offshore and allongshore from its mouth.

This prograding seaward and upward feature shows a deltaic stratification, but differs from other classical deltaic models by the absence of a subaerial portion.

The feature is the result of a large amount of solid discharge in an open oceanic basin with high energy represented by the presence of waves, strong tides and longshore currents.

According to McCave (1972), deposition of mud can occur along the continental shelf in several bathymetric situations, as modern or relict sediments, the last ones related with the sea level fluctuations during the Quaternary.

The Amazon situation seems to be adjusted to the mud occurrence linked with large amounts of solid discharge that is responsible for a wedge shape accumulation.

This peculiar emplacement promotes a parcial deposition along the adjacent continental shelf, forming a subaqueous deposition feature while another part of the mud is transported through littoral drift, parallel to the coastline in northeast direction furnishing fine material to the Amapa State and Guianas continental shelf (Martins et al. 1971, 72; Reyne, 1968; Nota, 1969; Eisma and Van Der Marel, 1970; Martins, 1974). According to Rine and Ginsburg (1985), the muddy coast of the Guianas is, in fact, an attenuated delta of the Amazon river. McCave (1972) indicates that the deposition of mud can occur in shallow waters zones when the sediment suspension load is high (100 mg/l or more). In the case of the Amazon mud composed of clay silts and silty clays it seems to be the main reason for its deposition (330 mg/l) according Martins (1974) and from 100 to 500 mg/1 as described by Nittrouer et al. 1986).

PROFILES LOCATION AND ANALYSIS

The studied area of this research comprises an Amazon coastal strip, from the Rio Pará mouth, between 1º50'S to 3º50'S of latitude and 46º30'W to 50º40'W of longitude.

Based on the available data on bathymetry, bottom and cores samples, three profiles were chosen, normal to the coastline, with a northeast-southwest direction and the following location: (Fig. 2)

Profile A - A'

Between 0º30'N and 50º09'W and 3º35'N and 49º12'W (Amazon river mouth).

Thirteen bottom samples and cores located from 1 to 100 meters depth were analysed.

Profile B - B'

Located between 0º10'N - 40º27'W and 2º55'N - 48º05'W (Amazon river mouth in the Mexiana Island vicinity), with eleven bottom samples and cores taken from 1 to 100 meters of depth.

Profile C - C'

Emplaced between 1º01'S - 48º30'W to 1º45'N - 46º31'W (Rio Pará mouth) with eleven bottom samples and cores obtained from a depth of 5 to 100 meters.

Additional bottom samples and cores, outside the three profiles, were also used with the objetive of obtaining a detailed sedimentary information of the three depositional surfaces.

The bottom samples and cores used are from GEO-

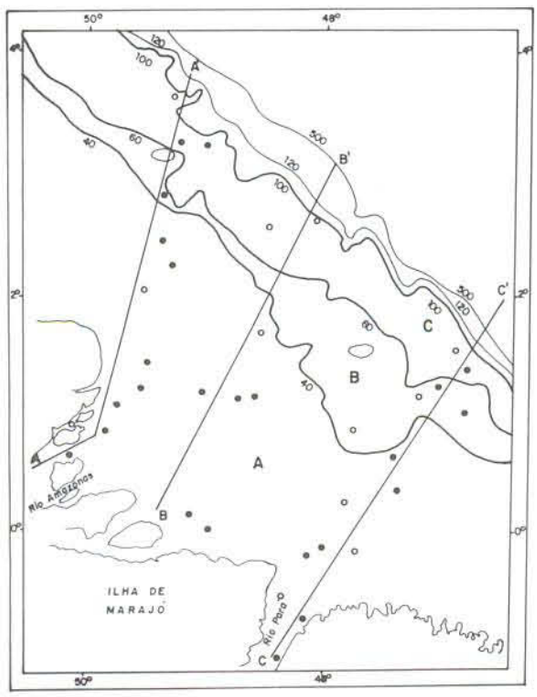

Figure 2 — Profiles, samples sites and relative distribution of depositional zones of the amazon subaqueous delta. O core and bottom samples.

A. Fine to very fine sand and coarse silt (MZϕ3,38-5,24), good to poorly sorted (σ ϕ 0,32-2,10). Wood fibers, lateritic fragments and micas indicate strong modern fluvial influence. Montmorillonite is the dominant clay mineral. Inner sand shows cut and fill structures, while an alternation of sand and mud beds appears in the medium and outer parts of this portion of the subaqueous delta.

B. Medium to fine silt (Mzϕ6,00-7,00) poorly to very poorly sorted (σ ϕ2,00-3,00). Marine organisms are dominant in the coarse fraction (spicules, equinoides, shell fragments, foraminifers). Bioturbation is responsible to the dominance of mottled structures identified in a large number of cores.

C. Very fine silt and clay (Mzϕ8,00-10,00) poorly to very poorly sorted (σ ϕ 1,16-3,65). Foraminifers and shell ash are present predominantly in the coarse fraction. Lamination occurs in some cores. A mixture of mud and relict quartzose and bioclastic coarse and medium sand is found in the outer portion of the prodelta.

MAR I, GEOMAR II, GEOMAR III, REMAC, Brazilian Navy hydrographic and other small missions, and filed in CECO/UFRGS.

From this material and using special criteria involving mainly textural, mineralogical and bottom morphology aspects, a study was developed with the purpose of obtaining new information about the Amazon subaqueous delta.

The choice criterium of the samples was its location in relation with the 5-40, 40-60 and 60-100 meters surfaces, that permits the study of sediments from Amazon and Pará river mouths, subaqueous delta plataform, front and prodelta.

MECHANICAL AND MINERALOGICAL COMPOSITION

a) 0 to 40 meters level

In the sequence of the contribution of the Amazon fluvial drainage, this surface strongly controlled by a continental influence is formed by fine to very fine sand and sandy silt, showing the coarser componentes of the entire feature.

There is a grain size decrease in offshore direction (Mzϕ3,28 to 5,24) followed by a decrease in the sorting grade (σ ϕ 0,32 to 2,10).

This behavior is intimately related with the progressive sand depletion (100 to 34%) and an increase in the mud content (silt an clay) . The fluctuation of the sand content is extremely heterogeneous through the length of the cores denoting an alternation of sandy and muddy layers. (Martins, 1974).

The coarse fraction composition indicates a dominance of quartz grains, followed by heavy minerals (4%), wood fibers (3-4 %), lateritic fragments and micas (2%), which charaterizes the strong fluvial influence on the sediments of this level.

The collected samples taken far from the river mouths show fluvio-marine characteristics accompanied by a grain size and sorting decrease and the presence of marine organisms mixed with-wood fibers, laterite fragments and micas in a lower percentage.

The gradient of this surface is low, usually 1: 2.000 and the sandy cores taken in the vicinity of the Amazon and Pará Rivers showed depositional features like cut and fill, while the more distal layers show an alternation of muddy and sandy layers (Martins, 1974). The last ones are extended in offshore direction up to the bathymetry of 40 meters and in the northeast reaching the Amapa continental shelf exhibiting the most extensive part of the subaqueous delta.

According to Martins, (1974) montmorillonite is the predominant clay mineral and this level shows an active fluvial and fluvio-marine sedimentation, with dominance of mud and sand attired by drifting wave shoals ascribed to the actual hydrodynamic conditions present in the region.

b) 40 to 60 meters level

The transition slope located between the topset an the prodelta, morphologically identified by Martins et al, (1971, 72) Figueiredo et alii (1972) and through the subsurface seismic reflectors (Nittrouer et al, 1968), has variable gradient, but more expressive than the first level.

Medium to fine silt (Mzϕ 6,00 to 7,00), very poor sorted (σ ϕ 2,00 to 3,00) is the dominant sediment on the slope. Identified sedimentary structures show a dominance of disturbed laminations by benthic organisms exhibiting several classical mottled layers.

Another important property of the sediments of this level is the size decrease and the disapearance of the fluvial indicators, with the appearance in the coarse fraction of marine organisms, mainly represented by spicules, echinoids and shell fragments (shell ash).

c) 60 to 100 meters level

This level is formed by a thin mud layer, covering

an original coastal plain sandy surface that was developed during the Wisconsin lowstand of the sealevel and reworked during the Holocene transgression and redeposited as a transgressive sand blanket.

This old surface is formed by relict-palimpsest sediments (quartzose and bioclastic sands) carpet by younger muds (very fine silt and clays) showing a medium diameter between 8,00 to 10,00 ϕ, very poor sorting and is considered the prodelta of the subaqueous feature.

In offshore direction the contact between the muddy sequence with the basal transgressive sands is transitional. Several drowned channels and features like sandwaves and sandridges are common along the sandy zone. This irregular mud-sand contact could be watched through the three profiles, observing that the thin mud layer seldom reaches the 100 meters depth and is more or less confined to the 70 to 80 depths.

From this point relict-palimpsest sands infiltered by mud occur in variable proportions but always less than 7% of mud and changing gradually to clean sand with bioclastic material near the shelf border.

DISCUSSION

The study the Holocene fluvial contribution to the morphology, structure and sedimentology of the Amazon continental shelf represents an important element in the analysis of the Late Quaternary geological history of the region.

According to Emery, (1968) near 75% of the sedimentary cover of the world continental shelf is relict, and the same proportion was approximately found on the Brazilian continental shelf (MARTINS et al, 1971). This is true if we consider palimpsest (relict reworked) sediments (Swift et al. 1971).

The modern contribution entailed with regions of inner shelf is related with the fine sediment escape joined with large fluvial discharge, coastal erosion or organic activity (calcareous sediments mainly).

Diagenic or authigenic components and volcaniclastic are peculiar to some regions or occur in special conditions and are accessory when compared with the other large groups.

Specifically in relation with the first group - the escape from the continent and the accumulation of fine sediments on continental shelves - this is accomplished on special conditions as was discussed by Van Andel (1967), Allerma (1968), McCave (1972) and Drake (1976).

McCave (1972) for instance pointed out the fact that the location and the accumulation rate are controlled by the relation of the suplying of fine material ($<$ 0,026 mm) usually represented by the nepheloid layer and the ability of the marine transportation, through the sum waves and currents action.

From the different situations of mud accumulation, the schematic explanation represented in Figure 3, where the balance between concentration and wave and current activity is in favor of concentration. The advective transport is important, as was discussed by Martins (1974) that added the high concentration of the suspended load brought by the Amazon river, to explain the mud deposition.

As was mentioned, above the concentration of the suspension load on the Amazon continental shelf has a variability of 100 to 500 mg/l (Martins, 1974; Nittrouer, 1986), which is adequate to create the essential conditions to aply the McCave's model.

Consequently, the sedimentary contribution develope after the Holocene transgression composed of fine sediments of Amazon origin was quite important in the modern evolution of the subaqueous delta (Martins, 1974).

More recently, when analysing the Quaternary

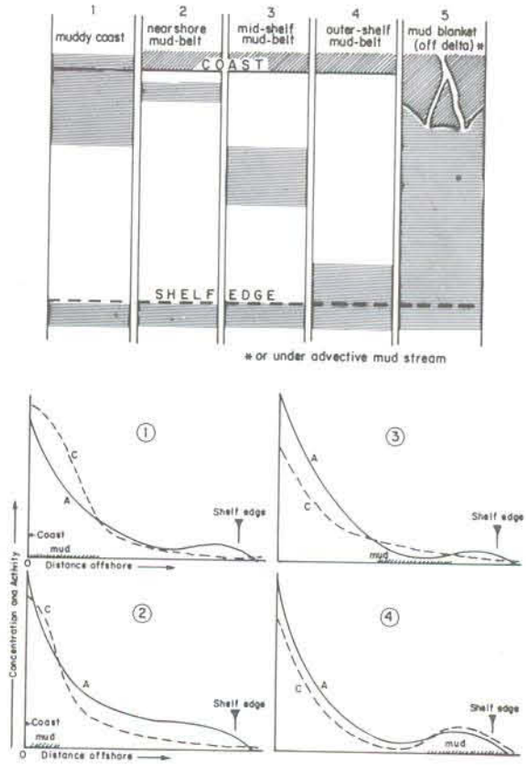

Figure 3 — Cases of sites shelf mud accumulation and the relation between concentration and wave, tide, longshore currents energy, according McCave (1972).

sedimentary cover of the Brazilian continental shelf, Martins (1987), showed some classical terrigenous sedimentary models, discarding some theories (Barreto et al. 1975; Milliman et al. 1975) that the sabaqueous delta is a relict feature. Some of them were based on an absence of an appropriate understanding of the transport mechanism existing in the area.

So in despite of the influence of the sealevel fluctuations on the feature development, the modern contribution plays a very important role in the morphology and sediments development.

Specifically discussing the age of the Amazon mud accumulation regarding Pleistocene and Holocene contributions and the influence of the sealevel fluctuations, there are some similar peculiarities with the behavior

of the mud furnished through the Rio de La Plata (Urien et al. 1978; Martins, 1987) in terms of proximal and distal muds.

Nittrouer et al.(1986) also agrees thet the Amazon subaqueous delt shows portions of different ages.

Therefore, the new elements recently published brought new data and contributed to the correct sedimentary knowledge of the region. The present review indicates the rightness of the pioneer studies describing the morphology and sedimentation of the Amazon continental shelf and in special the modern contribution developed through the fluvial discharge.

FINAL REMARKS

Reviewing the geological and geophysical information published regarding the Amazon continental shelf, and adding new results about the mechanical and mineralogical composition from superficial and cores samples from the region we can reach some conclusions:

a) The presence of a subaqueous delta in the continental shelf adjacent to the Amazon-Pará river System was confirmed by the 1971 to 1986 studies.

b) The absence of a classical deltaic model and its subaerial portion is mainly due to the strong energy level of the receiving oceanic basin and represented by wave, littoral and tidal currents.

c) The development of an offshore and allongshore transport, discussed in some previous studies, built a progradacional seaward and upward feature.

d) The modern contribution of the Amazon and Pará rivers, opposite to the conclusions of some published papers, have a real contribution to the subaqueous delta.

e) The recent published papers brought a large and consistent amount of new information and widen the knowledge of the Amazon continental shelf sedimentation model, but forgot to indicate some important sedimentological results and contributions published in the 1970's.

f) The present contribution shows some more information regarding the mechanical and mineralogical composition, the fining seaward sequence of the Amazon-Pará sediments and the coarse fraction analysis that shows a fluvial, a fluvio-marine and a marine sequence of the model, and that the modern sedimentation is active on the subaqueous delta.

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