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Textural characteristics of organic matter in several subenvironments of the Orinoco Upper Delta

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Abstract

Four subenvironments (oxbow lake, back swamp/flood basin, crevasse splay, natural levee) from the Orinoco Upper Delta plain were sampled for quantitative analysis of organic matter. Each subenvironment has been characterized on the basis of two main criteria: organic matter composition and textural characteristics.

The Oxbow lake model has two main subdivisions related to the influence of the dry and rainy seasons on the organic assemblages. The rainy season assemblages are rich in light-coloured organic matter, with abundant fungal and insect remains, are usually coarse grained, and have a highly variable particle shape. The dry season assemblages are relatively poor, the organic matter is darker and the finest grain size is scarcely represented.

The *Montrichardia* backswamp/flood basin model is also related to the flood – and the dry periods of the basin. Dry periods in the flood basin are characterized by very poor organic matter assemblages consisting of fine grains of woody and humic gels. The flood stages are characterized by a very high content of organic remains of variable composition.

The crevasse splay model assemblage is characterized by a strong bimodal distribution of the grain size, and by fluctuations in the amount of organic matter preserved at different levels of the fan.

The natural levee model assemblage is highly variable in the organic matter content and composition, and shows a wide range of particle grain sizes varying from medium sand to clay.

Introduction

This paper reports the results of a quantitative study of textural and compositional characteristics of the organic assemblages recovered from recent sedimentary environments of the Orinoco Upper Delta plain. The aim of this study was to improve the models for environmental interpretation currently used in palynology, by introducing quantitative data generated through digital image analysis of the kerogen concentrates.

The Orinoco Delta is an excellent example of a large fluvial/wave-dominated tropical delta; it is located in Eastern Venezuela (Fig. 1), and covers an area of 20642 km^2 (Van Andel 1967).

The sampling was carried out at the onset of the rainy season (1987), and was done in the Orinoco upper deltaic plain, close to the transition towards the lower deltaic plain, in a region that Muller (1959) called the 'middle delta plain'. All sampled subenvironments: oxbow lake, crevasse splay, *Montrichardia* back swamp/flood basin and natural

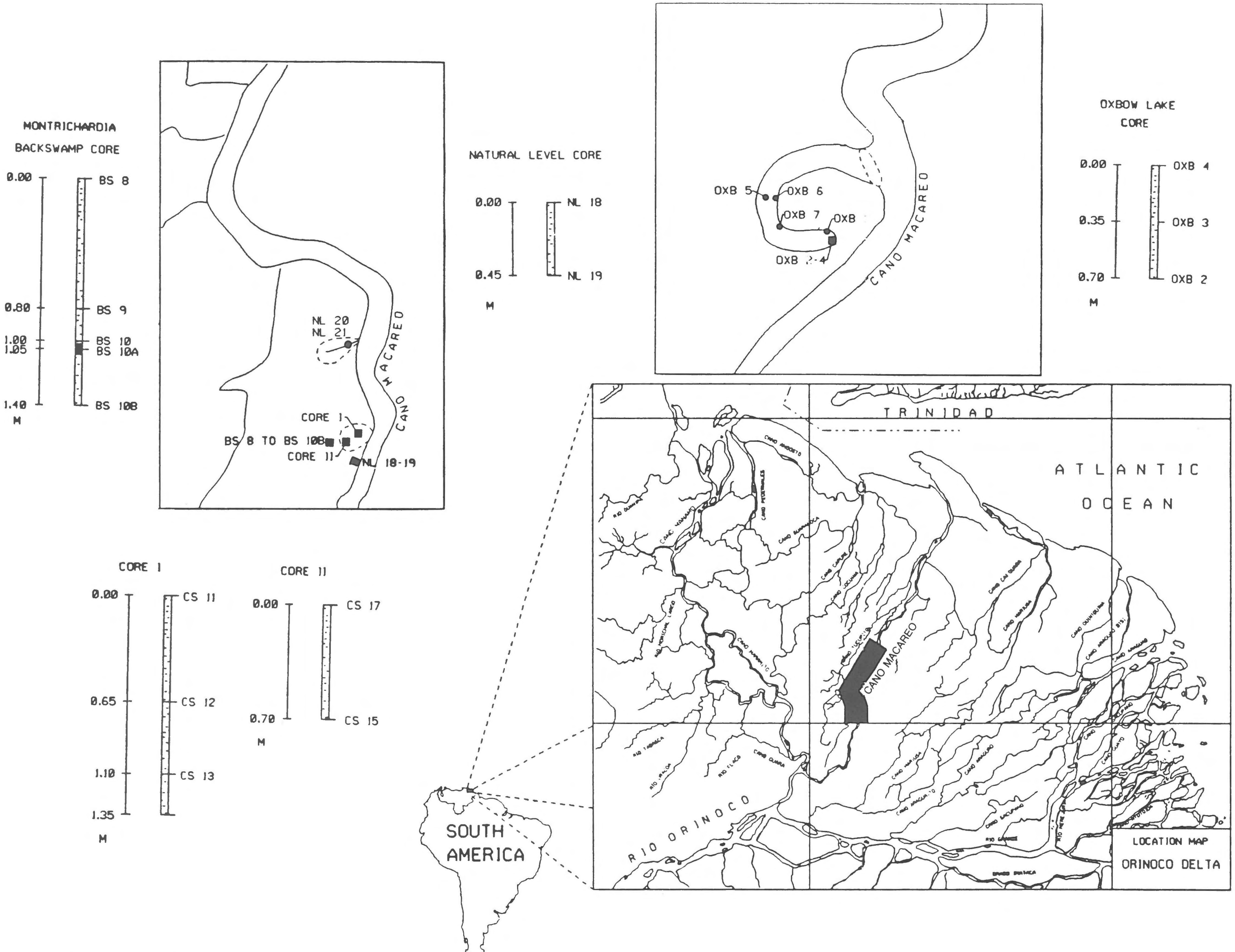


Fig. 1. Sample location map.

levee, were located in the Caño Macareo, a 213 km long and up to 1 km wide distributary channel, with a depth in excess of 35 m.

Methods

Samples were prepared using the standard palynological method (HF, HCl, $ZnBr_2$) and analysed for organic matter composition and quantitative textural characterization. The textural characterization as used here is based on the measurement and calculation of the particle size and shape.

All measurements were done with the help of ADIE™, a digital image processing system. This system is based on an IBM PC AT microcomputer, with a frame grabber (PC VISION PLUS), a B/W TV camera directly installed on the microscope, and a laser printer. ADIE™ measures the area, the perimeter, the length and breadth, and automatically calculates the relative elongation and relative irregularity of organic particles.

Particle size is expressed by means of grain size histograms and cummulative curves. Grain size of organic particles is based on the determination of the 'phi diameter' currently used in sedimentological granulometric analysis. Due to the bidimensional nature of the digital image measurements, the calculations of the 'phi diameter' are based on the conversion of the particle into a circle (Lorente 1986, 1989), using the measured particle area as the area of a perfectly circular particle that represents it. Subsequently the 'particle calculated diameter' is calculated:

'Particle measured area' = 'Circular particle area'
'Particle measured area' = πr^2, hence
$r = \sqrt{\text{'Particle measured area'}/\pi}$
'Particle calculated diameter' = 2r
'Phi diameter' = $-\log_2$ 'Particle calculated diameter'

Using the phi diameter, two different types of grain size distribution histograms and cummulative curves are generated, one is based on the $\sum$(number of particles) and the other one on the $\sum$(particle areas).

Particle shape is expressed by means of relative elongation and relative irregularity histograms. Relative elongation is based on the relation length/breadth, and represents the degree of elongation of the particle (see Table 1). The results are expressed in the form of histograms, with class values ranging from 1.00 (perfectly equidimensional) to >10.00 (filiform particles).

Relative irregularity is based on the relation between the measured perimeter of the particle and its minimal possible perimeter. The calculation of the minimal possible perimeter is based on the conversion of the particle into a circle as is done for the 'phi diameter' (Lorente 1986, 1989). Then the 'particle minimal perimeter' will be the perimeter of the calculated circular ($P_{calculated}$) particle. So if

$r = \sqrt{\text{'Particle measured area'}/\pi}$ = then
$P_{calculated} = 2\pi r$ and thus
$P_{calculated} = 2\pi \sqrt{\text{'Particle measured area'}/\pi} =$
$P_{calculated} = 2\sqrt{\text{'Particle measured area'} \cdot \pi}$

The results are expressed in the form of histograms, with class values ranging as follows:

1.00–1.50	Regular
1.60–2.00	Irregular
2.10–3.00	Very Irregular

The organic matter composition was described according to the classification published by Lorente (1986) as shown in Table 2.

The Oxbow Lake subenvironement

General remarks

The Oxbow Lake is the part of a meander belt that marks the transition between the upper and lower delta plain. This particular lake was formed during the last 20 years (navigation beacons signs are still left), maps of Van Andel (1967) showing the meander as active. The sedimentation rate is about 0.85 m/a. Hecht (in press) calculated this very high rate from the maximum reported water depth in the active channel (35 m) and the maximum measured water depth in the lake (18 m). The same author reports sedimentation rates close to 0.9 m/a near the open end of the lake. The sedimentation in this environment is restricted to the low-water (dry) season.

Vegetation on the lake banks is dominated by the natural levee inhabitant *Inga spuria.* Floating macroflora is represented by: herbs, *Eichornia crassipes* and *Azolla* sp.

Samples were taken in the lake bed by means of a grab sampler and a hand coring device. Several localities were sampled as shown in the location map (Fig. 1). Samples OXB 1, OXB 5, OXB 6 and OXB 7 were taken on the lake bed and represent the onset of the rainy season sedimentation. Samples OXB 4, OXB 3 and OXB 2 were taken from a 0.70 m thick core of homogeneous grey clay drilled near the closed end of the lake (Fig. 1). This core probably represents the sedimentation during the last low-water season.

Sample description

Sample OXB 1. This sample was taken close to the lake inner bank, at about 1 m water depth, it consists of grey clay with plant remains.

The organic matter in the coarse fraction is mainly epidermal/cuticular material, together with insect and fungal remains. The fine fraction is dominated by biodegraded terrestrial structural material and small fragments of humic gels and 'charcoal'. The organic fraction recovered was fairly scanty.

The textural characteristics are:

1. *Particle size:* more than 60% of the particles are in the medium to fine silt range, the coarser particles are in the medium to very fine sand range with a deficit of fine sand, the smaller ones in the very fine silt to clay-size ranges.
2. *Particle shape:* the relative elongation varies from equidimensional to tabloid shaped small particles, and from elongate to strongly elongate tabloid shaped coarser particles. The relative irregularity tends to be in the irregular values (1.4 to 2.4).

Sample OXB 5: This sample was taken on the lake bed, at the maximum depth (about 18 m). It consists of grey clay with abundant plant remains.

The organic matter assemblage is very similar to the assemblage in sample OXB 1, but it had a higher concentration of humic gels.

The textural characteristics are:

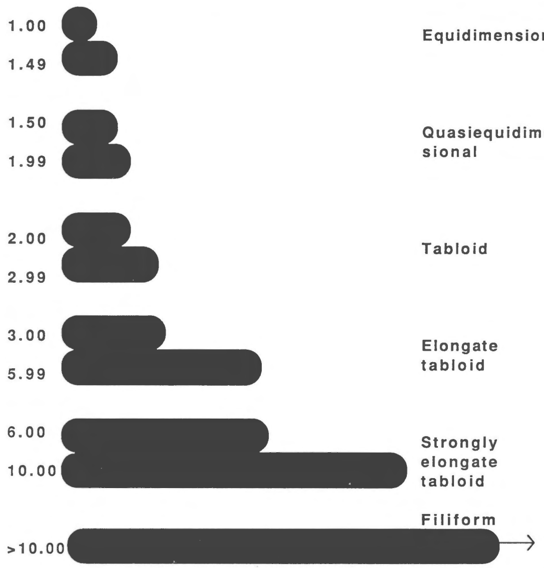
1. *Particle size:* more than 80% of the particles are in the medium to fine silt range, the coarser particles in the fine sand to coarse silt range with a deficit of the very fine sand. The smaller particles range from very fine silt to clay;
2. *Particle shape:* the elongation varies from an equidimensional/tabloid shape of the small particles, to an elongate/strongly elongate tabloid shape of the coarser particles. The particle relative irregularity tends to be in the 'irregular' range 1.4 to 2.4, although the total range of values extends from 1.4 to 3.0.

Sample OXB 6. This sample was taken at the point-bar border of the former meander and consists of grey clay with few macroscopic remains of leaves.

The organic matter assemblage is similar to the assemblage in sample OXB 5. The organic fraction recovered was fairly substantial.

The textural characteristics are very similar to those of sample OXB 1; both samples were from the same lake bank.

Table 1. Relative elongation



Sample OXB 7. This sample was taken in the lake bed, near the former point bar border, at the middle point from the centre to the closed end of the lake, and consists of grey clay with abundant leaves and twigs.

The organic matter in the coarse fraction is mainly epidermal/cuticular/woody and contains resinous material together with insect and fungal remains. The fine fraction is dominated by partially biodegraded epidermal/cuticular material, woody, fungal and humic gel remains. The organic fraction recovered was fairly large.

Textural characteristics (Fig. 2b):

1. *Particle size:* more than 70% of the particles are in the medium to fine silt range. This sample contains an unusual amount of coarser material in the medium sand size range. The smaller particles are in the very fine silt to clay size ranges.
2. *Particle shape:* elongation varies from the equidimensional/tabloid shape of small particles to the elongate/strongly elongate tabloid shaped coarser particles. Particle irregularity tends to be in the 'irregular' values (1.4 to 2.5), but very irregular particles are also present (up to 4.0), although in very low concentrations.

Core sampling description

All lithological samples taken from the oxbow lake core (Fig. 1) consist of homogeneous, unconsolidated grey clay. Sample OXB 4 was taken at the core top. Sample OXB 3 was taken 0.35 m below the water/bottom interface. Sample OXB 2 was taken at 0.70 m below the water/bottom interface. According to the calculated sedimentation rate OXB 3 and OXB 2 must have been deposited during the last low-water season.

Sample OXB 4. The organic matter assemblage is very similar to that in sample OXB 5, but contains a higher concentration of humic gels and 'charcoal' material in the fine fraction. The organic fraction recovered was fairly substantial.

The textural characteristics are very similar to those in sample OXB 1.

Sample OXB 3. The coarser fraction is depleted in organic matter, which is mainly represented by dark woody and 'charcoal' fragments; this fraction is probably more resistant to oxidation. The medium and fine fractions are dominated by humic gels, woody, charcoal, epidermal, sporomorphic, resinous and fungal remains. The very fine fraction is also depleted in organic substance. The organic fraction was recovered in fairly ample quantities.

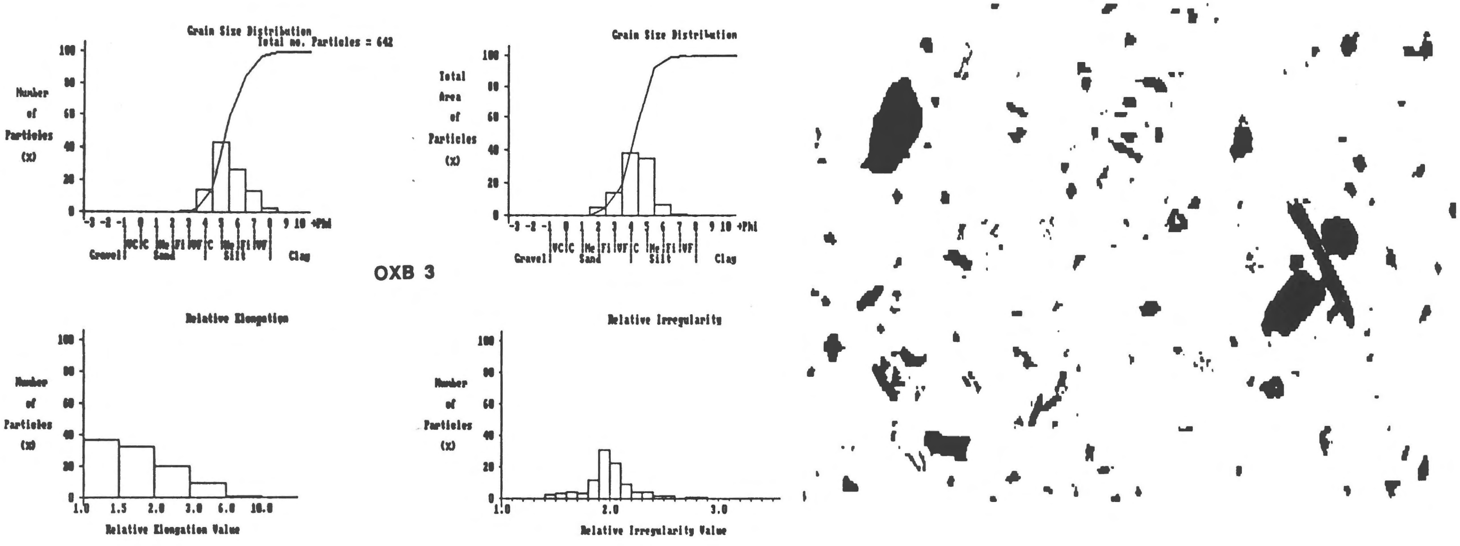
The textural characteristics are different from the samples taken at the water/bottom interface (Fig. 2a):

1. *Particle size:* the histogram shows an almost normal distribution, with its maximum at the coarse to fine silt size-range;
2. *Particle shape:* the elongation values are concentrated in the equidimensional/tabloid shape. The particle irregularity is concentrated in the 'irregular' (1.5 to 2.9) range, with most values in the 1.9 to 2.2 range.

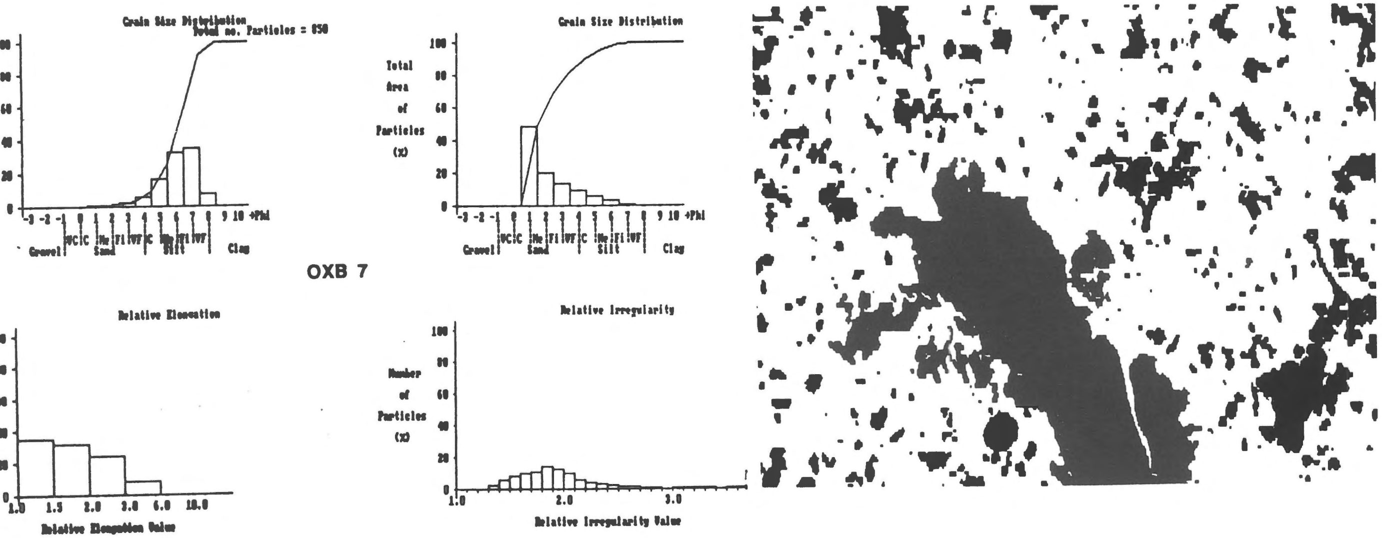
Table 2. Organic matter classification (fluorescent palynomacerals *italicised*)

Aquatic		Terrestrial	
Structureless	Structured	Structureless	Structured
		'Humic' gels	*Exinic*
Algal masses	*Colonial algae*	– pure	– *cuticular*
		– with *inclusions*	– *sporomorphic*
Bacterial masses	*Single cell algae*		– fungal remains
		Resins	– *animal exoskeleton remains*
		'Charcoal'	Epidermal
		Degraded plant material	Woody

a

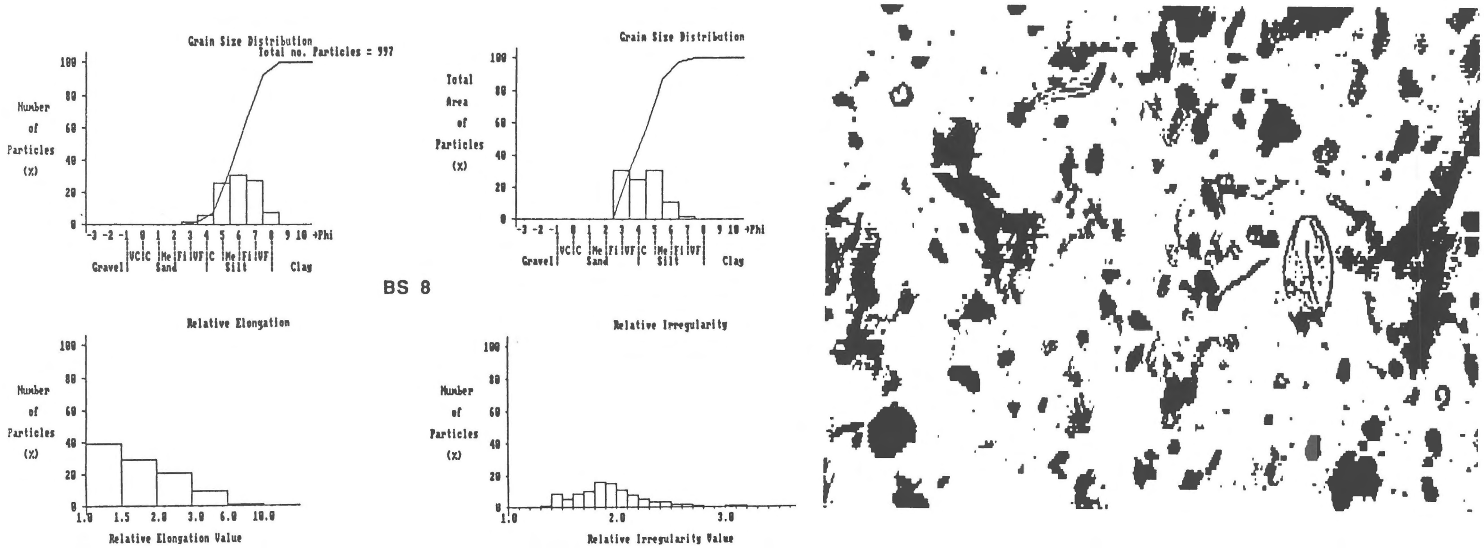


b

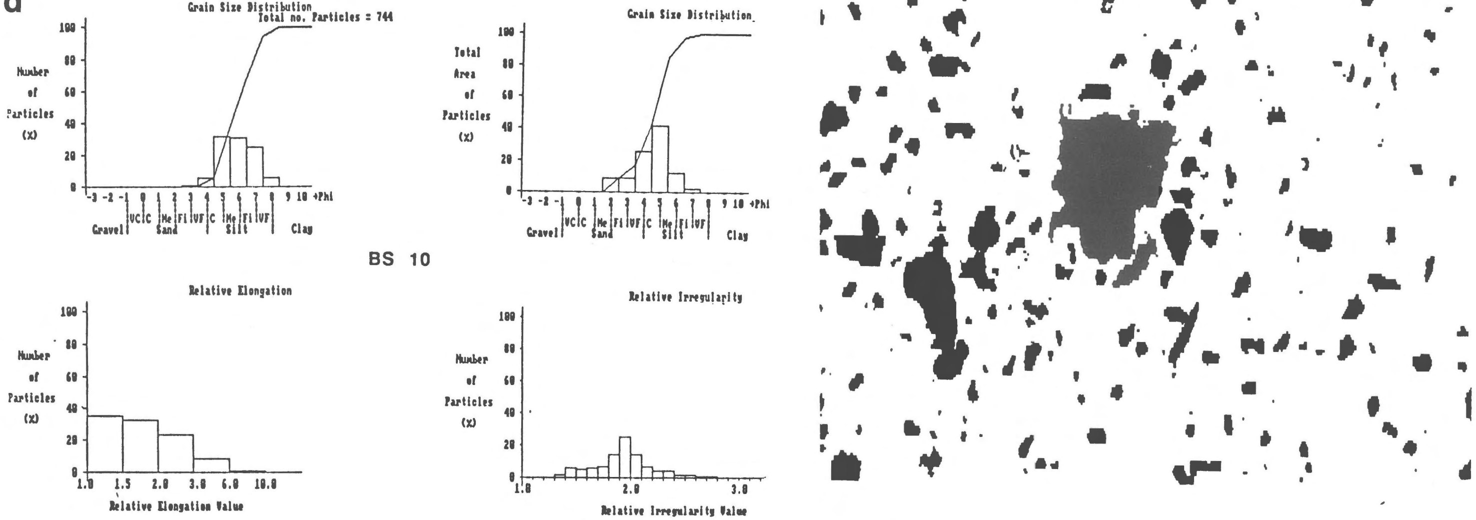


Figs 2a, b. Grain size, relative elongation and relative irregularity histograms. Samples: OXB 3, OXB 7.

c

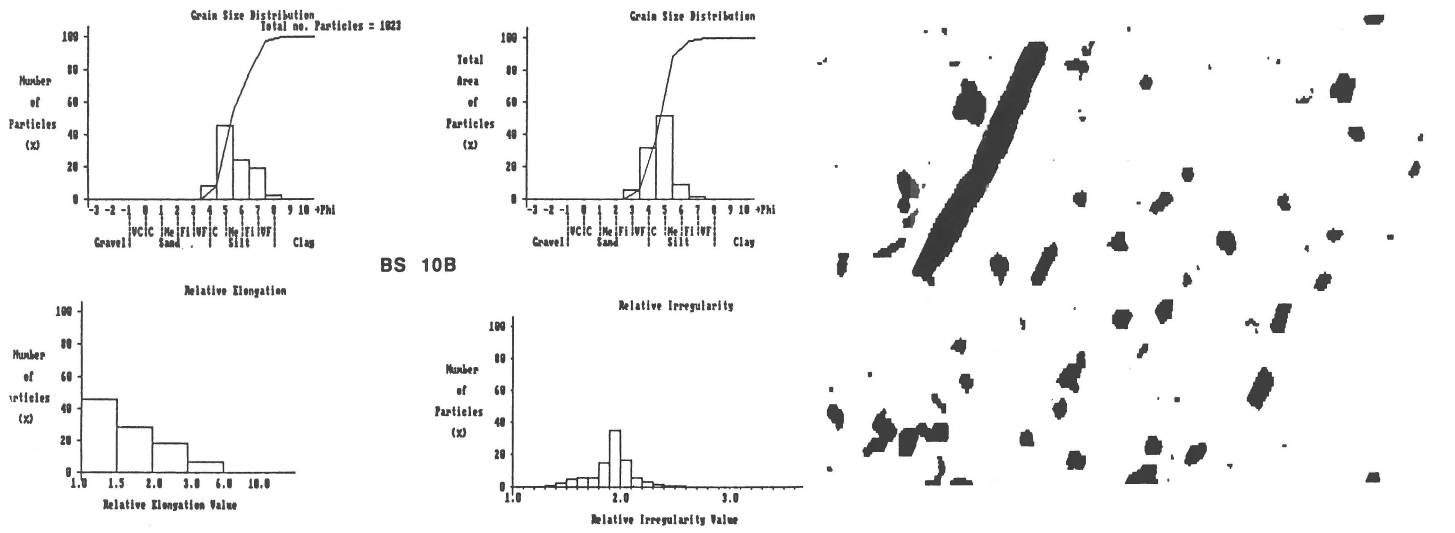


d

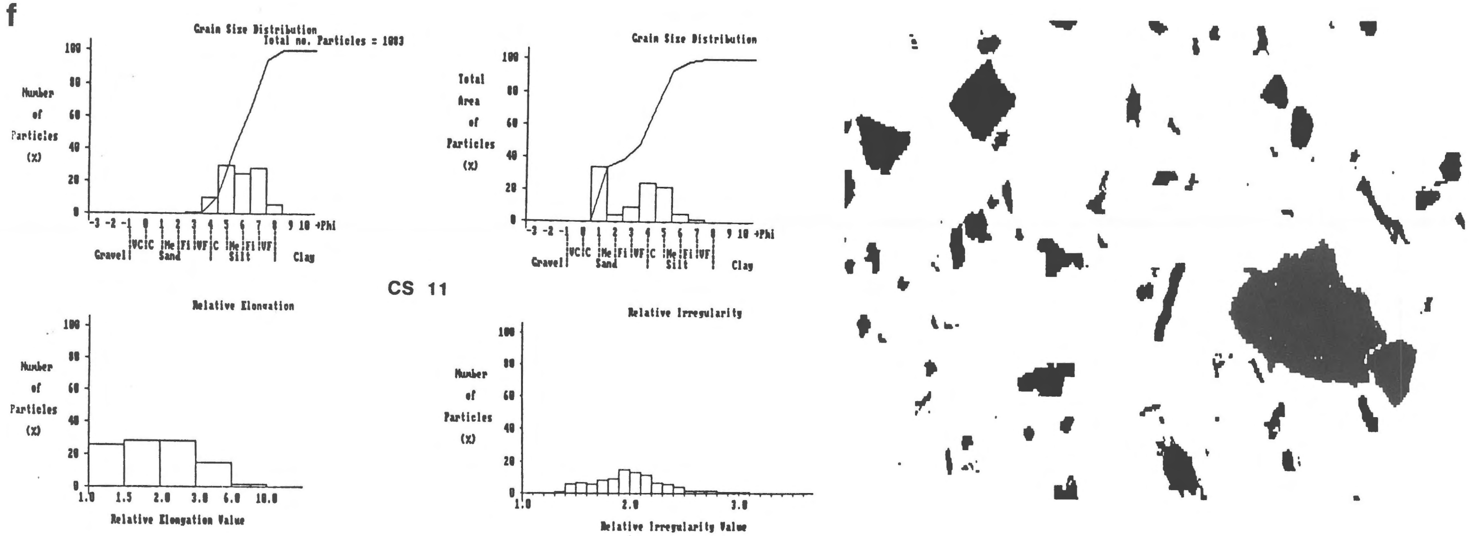


Figs 2c, d. Grain size, relative elongation and relative irregularity histograms. Samples: BS 8, BS 10.

e

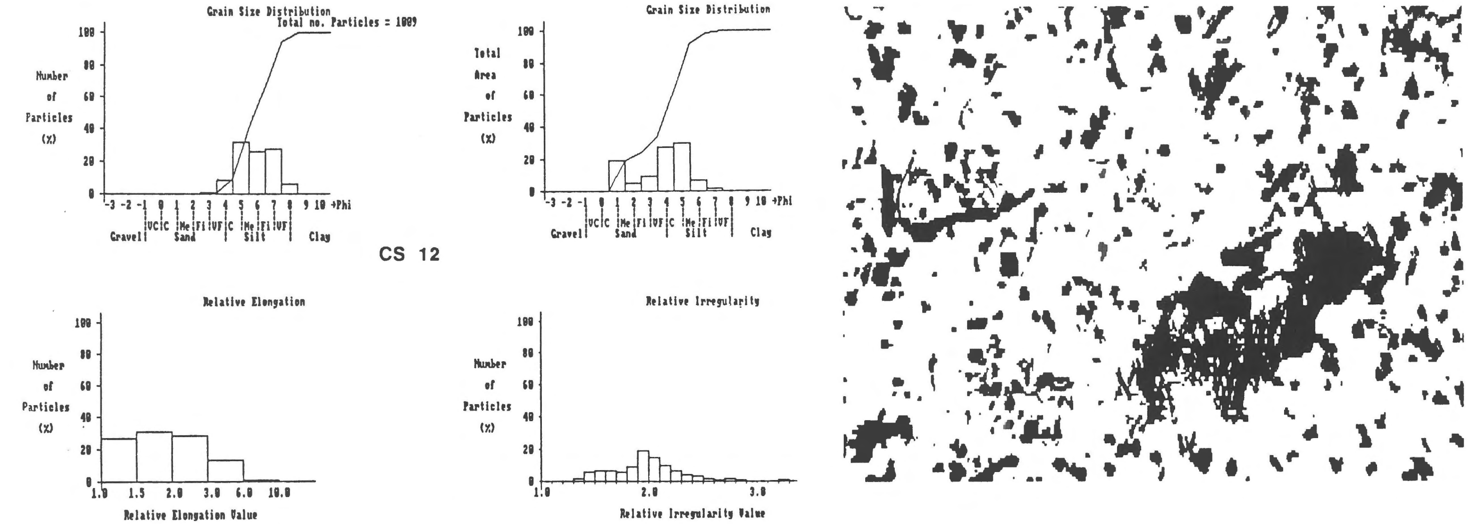


f

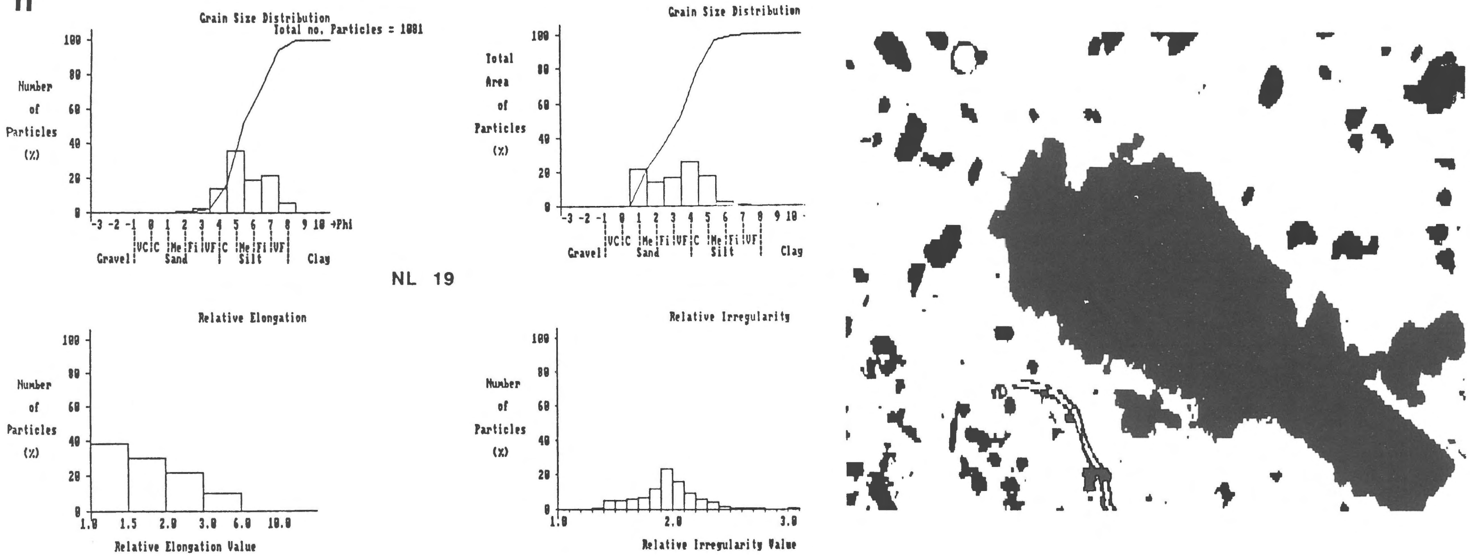


Figs 2e, f. Grain size, relative elongation and relative irregularity histograms. Samples: BS 10B, CS 11.

g



h



Figs 2g, h. Grain size, relative elongation and relative irregularity histograms. Samples: CS 12 and NL 19.

Sample OXB 2. This sample is almost identical to OXB 3 in its organic matter composition. The coarser fraction is relatively more abundant than in OXB 3, and mainly represented by dark woody and 'charcoal' fragments; some fragments of epidermal material are also present. The medium and fine fractions are dominated by humic gels, woody, charcoal, epidermal, sporomorphic, resinous and fungal remains. The very fine fraction is depleted. The organic fraction recovered was fairly substantial.

Textural characteristics are very similar to those of sample OXB 3.

The *Montrichardia* backswamp and flood basin subenvironments

General remarks

In the upper delta plain there are different types of backswamps/flood basins, depending on the type of vegetation cover present and on its topography. In caño Macareo *Montrichardia* swamps are very common. *Montrichardia* is up to 5 m high and grows in dense stands.

A core was taken in a *Montrichardia* swamp, very near to the crevasse splay and the natural levee that was also sampled for this study. The core was located in an area about 200 m from the river channel, near the end of a crevasse splay fan and six samples were taken from it (Fig. 1).

Three different 'lithological' levels were found from base to top: a grey plastic clay (sample BS 10B); a very thin peat layer (sample BS 10A) and a grey clay with oxidation spots and plant remains, mainly roots (samples BS 10, BS 9 and BS 8). The position and description of samples can be summarised as follows:

BS 8: core top, grey clay with oxidation spots and macroscopic plant remains;
BS 9: 0.8 m below the core top; grey clay with oxidation spots and macroscopic plant remains;
BS 10: 1.0 m below the core top, just on top of a thin peat layer, grey clay with oxidation spots and macroscopic plant remains;
BS 10A: 1.05 m below the core top, very thin peat layer;
BS 10B: 1.40 m below the core top, homogeneous, grey plastic clay.

Sample description

Sample BS 8. The organic matter in the coarse fraction consists mainly of woody and epidermal/cuticular material, with some coaly ('charcoal') material present, probably originating from a recently burned vegetation. The fine fraction is dominated by humic gels, woody and degraded material. The organic fraction recovered was fairly substantial.

Textural characteristics (Fig. 2c):

1. *Particle size:* more than 75% of the particles are in the coarse to fine silt range. The coarser particles are in the fine sand to coarse silt range, with a slight depletion in the very fine sand values. The smaller particles are in the very fine silt to clay ranges.
2. *Particle shape:* the particle elongation varies from equidimensional to filiform shapes. More than 80% of the particles are in the equidimensional to tabloid range. The relative irregularity tends to be in the 'irregular' values (1.5 to 2.1).

Sample BS 9. The organic matter in the coarse fraction contains mainly woody and epidermal/cuticular material. The fine fraction is dominated by humic gels, resins, woody and degraded material. Fungal remains are also abundant. The organic fraction recovered was fairly rich.

Textural characteristics:

1. *Particle size:* the coarser particles are in the size range of medium to fine sand, with a maximum in the very fine sand values. The smaller particles are in the very fine silt to clay range. The highest amount of particles (about 40%) is in the very fine silt range.
2. *Particle shape:* the relative elongation varies from equidimensional to strongly filiform values. More than 80% of the particles are in the

equidimensional to tabloid range. The relative irregularity tends to be in the 'irregular' values (1.5 to 2.0), but the irregularity values are widespread up to the range of 3.3 times the length of the equiareal circle, indicating the presence of very irregular particles.

Sample BS 10. The organic matter in the coarsest fraction is represented by rare large fragments of epidermal/cuticular tissues; woody and coaly ('charcoal') remains are relatively abundant but in a smaller size range. The fine fraction is dominated by degraded terrestrial material and fungal remains. There is a change in the general organic matter composition in this sample, when compared with the upper section, showing a higher amount of relatively dark material. The organic fraction recovered was fairly rich.

The textural characteristics (Fig. 2d) are:

1. *Particle size:* more than 70% of the particles are in the size range of coarse to fine silt. The coarser particles are in the fine sand to coarse silt range but these particles are relatively rare in this sample. The smaller particles are in the very fine silt to clay size ranges. This sample is moderately well sorted, better sorted than the samples from higher levels in the section.
2. *Particle shape:* the elongation varies from equidimensional to strongly elongate tabloids. More than 80% of the particles are in the equidimensional to tabloid range. The particle irregularity tends to be in the 'irregular' ranges 1.4 to 2.1.

Sample BS 10A. The organic assemblage is similar to that in sample BS 10, but is very rich in organic matter. This sample has a higher amount of relatively dark material than sample BS 10. The organic fraction recovered was very large.

The textural characteristics are very similar to those of sample BS 10.

Sample BS 10B. The organic assemblage is mainly composed of woody and coaly ('charcoal') material. There is a change in the general composition of the organic assemblage, with a tendency towards higher amounts of dark material. Delicate tissues are absent, and the sample is characterized by a high concentration of dense and thick microscopical plant remains. The organic fraction recovered was fairly poor.

Textural characteristics (Fig. 2e) are:

1. *Particle size:* more than 80% of the particles are in the coarse to medium silt range. The coarser particles are in the very fine sand range, but they are relatively rare in the sample. Most particles are in the coarse to medium silt ranges. The smaller particles are in the very fine silt to clay ranges. This sample is well sorted.
2. *Particle shape:* the relative elongation varies from equidimensional to strongly elongate tabloids. More than 80% of the particles are in the equidimensional to tabloid range, although the elongate tabloids are present in significant amounts. The relative irregularity tends to be in the 'irregular' range (1.4 to 2.1), with most values in the 1.8 to 2.1 range.

The crevasse splay subenvironment

General remarks

In the upper delta there are many crevasse splay fans of different size. This study deals with two of these features (Fig. 1): one small fan with an area of about 10.000 m^2 and a sediment thickness of 1.10 m in the central part and 0.70 m near the end border, and one major crevasse feature with the main channel inundated throughout the rainy season.

In the small crevasse splay two cores were taken (Fig. 1). In both cores, below the crevasse splay sediments, a sand layer of unknown thickness was found, probably belonging to the river sand bar deposits.

The first core was drilled in the central area of the crevasse fan, the second core was drilled near the transition from the crevasse fan to the backswamp and this last one yielded only 0.70 m of fine sediments on top of the underlying sand layer. The sample position is shown in Fig. 1.

From the first core the following samples were recovered:

- Sample CS 11, from the core top, consists of 0.54 m of grey-mottled, silty clay with *Montrichardia* sp. fibres;
- Sample CS 12, from the top of a mottled sandy/silty grey clay 0.56 m thick, with a higher organic content than sample CS 11;
- Sample CS 13, from the base of the mottled sandy/silty grey clay.

From the second core the following samples were recovered:

- Sample CS 17, taken at the core top, consists of 0.70 m of grey-mottled, silty clay with *Montrichardia* sp. fibres;
- Sample CS 15, taken at the base of the mottled sandy/silty grey clay, 0.70 m below sample CS 17.

The major crevasse splay samples were taken on a cut-off in sandy sediments of the main crevasse channel.

Sample NL 20 consists of a yellowish sand, and was taken at 50 cm below the crevasse fan top. Sample NL 21 also is a yellowish sand, situated about one meter below sample NL 20 and very near the water level.

Sample description

Sample CS 11. The organic matter is of a terrestrial type, cuticle/epidermal, woody and humic gel material. Some fungal remains are present, but in low concentrations. The organic fraction recovered was fairly poor.

The textural characteristics (Fig. 2f) are:

1. *Particle size:* the grain size histogram based on the number of particles shows a platykurtic distribution, with grain sizes from medium sand to clay. The sum of the areas grain size histogram is characterized by a bimodal distribution. This distribution is determined by a strong deficit in fine and very fine sand, and might be related with the hydraulic characteristics of the water flow.
2. *Particle shape:* the relative elongation varies from equidimensional to strongly elongate tabloids, but more than 80% of the particles are in the range of equidimensional to tabloid shapes. The relative elongation histogram is flat (platykurtic distribution). The relative irregularity varies from 'irregular to very irregular' 1.4 to 3.1, most values laying in the range of 1.5 to 2.5.

Sample CS 12. The organic matter is of a terrestrial type: cuticle/epidermal, woody and humic gel material. Some fungal remains are present in low concentrations. The organic fraction recovered was fairly rich.

Textural characteristics (Fig. 2g) are:

1. *Particle size:* the grain size histogram, based on the number of particles, shows a platykurtic distribution, with grain-sizes ranging from medium sand to clay. The bimodal grain-size histogram, based on the sum of areas, is a common feature in all the grain size distribution graphs of the crevasse splay samples, with the exception of sample CS 17 located very near the backswamp limit. The bimodal shape results from a strong depletion in the values of fine and very fine sand.
2. *Particle shape:* the relative elongation varies from equidimensional to strongly elongate tabloids, but more than 80% of the particles are in the equidimensional to tabloid range. The relative elongation histogram is relatively flat. The relative irregularity values vary from 1.3 to 3.3, with few particles in the 3.3 range, and most values in the 'irregular' range 1.5 to 2.5.

Sample CS 13. The organic assemblage of this sample is identical to the assemblage in sample CS 12.

Sample CS 17. The organic matter is of a terrestrial type: mainly cuticle/epidermal, woody and humic gel material with some fungal remains in low concentrations. The organic fraction recovered was fairly rich.

The textural characteristics are:

1. *Particle size:* the grain size histogram, based on the number of particles, is characterized by a relatively flat distribution, with a grain size range from fine sand to clay. The grain size histogram, based on the sum of areas, is unimodal.

2. *Particle shape:* the relative elongation histogram is flat and shows a platykurtic distribution. The values are from equidimensional to strongly elongate tabloids, with more than 80% of the particles in the equidimensional to tabloid range. The relative irregularity values are from 1.4 to 3.2, with most particles in the range of 1.4 to 2.6.

Sample NL 20. This sample was taken in the main crevasse splay channel and the organic assemblage is very similar to that in samples CS 11–CS 13.

Sample NL 21. This sample was taken about one metre below sample NL 20, and almost at the water level. No organic matter was recovered.

The natural levee subenvironment

General remarks

Natural levees are present only in the upper deltaic plain. The lack of natural levees, in combination with the presence or absence of the mangrove vegetation, marks the boundary between the upper and lower delta plain.

The levees in the Orinoco Delta, according to Pfefferkorn et al. (in press) 'consist of silt to clay with grey to beige colour'. These levees are covered by dense vegetation, mainly of *Inga spuria* (Leguminosae tree).

According to Hecht (in press) 'the height of natural levees is 5 m at Boca Macareo at lower water stage, but levees are not present in the lower delta plain about 40 km before the distributary reaches the ocean'. In the upper delta plain 'the main sediment types are bank deposits, i.e. natural levees and crevasse splays deposited during high flood stages' . . . 'various sections show interfingering of sand barback swamp- and flood basin sediments with levee deposits'.

In the natural levee sampled for this study, a 0.42 m long core was taken very near the described small crevasse splay. The recovered sediments consist of very dirty mottled silty sands with root remains.

Sample NL 18 was taken at the core top and sample NL 19 was taken 0.40 m below the top (Fig. 1), both samples consist of silty mottled sand.

Sample description

Sample NL 18. The organic matter is terrestrial, with a high proportion of dark material (woody, humic gels and coaly fragments), but there are also relatively numerous epidermal/cuticle remains, mainly in the coarser fractions. The organic matter recovery was fairly rich.

The textural characteristics are:

1. *Particle size:* particle grain sizes vary from very fine sand to clay, with most of the particles in the silt size range. The organic matter is moderately sorted. Very fine silt is clearly the dominant grain size.
2. *Particle shape:* almost 70% of the particles have an equidimensional to quasidimensional shape, the relative elongation histogram shows a step-like distribution. The relative irregularity varies from 1.4 to 2.8, but most particles are in the 'irregular' 1.5 to 2.2 range.

Sample NL 19. The organic assemblage is very similar to that of sample NL 18, but the organic fraction recovered was poorer.

The textural characteristics (Fig. 2h) are:

1. *Particle size:* the assemblage in general consists of coarser particles than NL 18, with grain sizes in the range of medium sand to clay. Although about 40% of the particles fall in the medium silt range, the sum of areas histogram is relatively flat in the medium sand to medium silt range.
2. *Particle shape:* the histogram of relative elongation shows a step-like form similar to that of sample NL 18; about 70% of the particles are in the equidimensional to quasidimensional range and 90% of tabloid shapes are included. The relative irregularity values are concentrated in the 'irregular' range of 1.5 to 2.4, although values may rarely reach 3.1.

Discussion of subenvironment models

The Oxbow Lake subenvironment characterization

The characteristics of the organic matter assemblages present in this high rate sedimentation environment, are directly related to the area of the lake and to the season (low and high water) during which the sedimentation took place. This is shown by the different characteristics of the organic assemblages recovered from the bottom surface and from the core, as discussed below.

Oxbow Lake, rainy season
There are relatively minor variations in composition and texture of the organic assemblages recovered from the sediments that were simultaneously deposited at the bottom of the Oxbow Lake during the onset of the rainy season. These variations are related to the distance from the source vegetation or the relative position of the sample within the lake.

Generally, the assemblages are very rich in organic remains, with epidermal, woody and humic gels in the coarser fraction, and humic gels, together with biodegraded materials, in the finer fraction. Insects and fungal remains are very abundant in all fractions. From the textural point of view the grain-size values vary from those of medium sand to clay, although most particles are in the silt range. Particles are highly variable in relative elongation from equidimensional to filiform shapes, but the grains have relatively simple outlines.

Samples located on the former point bar side, are very similar, OXB 1, OXB 4 and OXB 6 are almost identical in organic matter composition and texture. The nearest vegetation in the water surface (main source of organic matter) was represented in these cases by a floating flora (herbs such as *Paspalum* sp., *Cyperus* sp., *Azolla* sp. and *Eichornia crassipes*). The differences observed with respect to sample OXB 7 are related to the influence of the nearby levee vegetation (*Inga spuria* trees), reflected in the higher amount of coarser material.

The centre of the lake is represented by OXB 5. From the textural point of view this sample is quite similar to OXB 1 and OXB 6, but the coarsest fraction is depleted in the number of particles, probably as a result of transport selection of the material from both sides of the lake (one border with the levee tree *Inga spuria* and the other with floating flora), leaving a smaller amount of coarse material available.

Oxbow Lake, dry season
Samples from below the present bottom are very different in organic matter composition and texture when compared with samples from the water/bottom interface (sample OXB 4 is considered as a water/bottom interface sample).

These 'dry season' samples are characterized by the concentration of darker and thicker materials (woody, humic gel and 'charcoal' materials). In textural terms, the samples are depleted in fines and grain distribution graphs show almost normal distributions. Particles tend to show equidimensional to tabloid shapes with regular grain borders.

Probably climatic conditions, such as atmospheric humidity and temperature, together with the type and length of transport of the organic materials during the low water season might explain the differences between the characteristics of the organic matter assemblages observed in the Oxbow Lake.

The back swamp subenvironment characterization

The characteristics of the organic assemblage in this subenvironment are related to the variations in the nature of the swamp and the change of seasons.

There is also a relationship between the changes in 'lithology' and the changes in organic matter. The three different 'lithological' levels found in the core (Fig. 1) are linked to the three main organic assemblages observed; from base to top:

- Level A: grey clay with oxidation spots and plant remains, mainly roots, 1 m thick, represented by samples BS 10, BS 9 and BS 8;
- Level B: peat, 0.05 m layer, represented by sample BS 10A;
- Level C: grey plastic clay, 0.35 m recovered, represented by sample BS 10B.

Montrichardia Backswamp, Assemblage A

This assemblage is present throughout Level A. This 1 m thick clay deposit, probably represents sedimentation conditions similar to those prevailing today at the *Montrichardia* back swamp.

Samples located in that layer are very similar in organic matter composition. The observed differences are probably artificially induced by human activities in the area, through the cutting and burning of part of the swamp vegetation, to allow the transit of domestic animals. This burning most probably contributes to the high amount of 'charcoal' in the surface sample.

The organic fraction recovered in both samples is fairly rich, with a coarse fraction represented by epidermal/cuticular and woody material. The fine fraction is dominated by humic gels, woody and degraded material.

From the textural point of view there are some differences between the samples, specially in the grain size distributions. Sample BS 8 is better sorted and has in general a smaller grain size. With respect to the shape of fragments, those are quite similar in all kind of shapes, from equidimensional to filiform, but contain relatively simple fragments with a low irregularity value.

Flood basin deposits, Assemblage B (wet conditions)

This assemblage is present in the base of Level A and in Level B (samples BS 10 and BS 10A). Sedimentation probably took place when the back swamp was covered with a layer of water or was a small flood-basin lake.

Organic matter in the coarsest fraction is represented by large epidermal/cuticular remains (fine sand size range). In the very fine sands and silts, the main components are woody and coaly 'charcoal' particles. In the finest fraction there are fungal remains and degraded material. Generally, the organic assemblage is dark in colour. Organic particle sizes vary from fine sand to clay. The samples are moderately well sorted, but mostly better than in assemblage A.

The particle shape lies mainly in the equidimensional to tabloid range and shows low irregularity values.

Flood basin, Assemblage C (dry conditions)

This assemblage is present in Level C (sample BS 10B). This is a very particular assemblage of organic matter, probably representing a period of slow sedimentation and highly oxidising conditions, a dry interval in the flood basin.

The organic matter is mainly composed of woody and coaly material, no delicate tissues are present. The particle size is mainly in the coarse to medium silt range and the distribution is well sorted.

The crevasse splay subenvironment characterization

Samples from this high sedimentation rate subenvironment are very similar in compositional and textural characteristics. The only differences are in the amount of organic matter (sample CS 11 is poor, and sample NL 21 has no organic matter), while the coarser fraction is absent in sample CS 17 which is located very near the transition from the crevasse splay to the backswamp. This probably indicates that here characteristics of the two subenvironments are shared.

Generally, the organic matter is of the terrestrial type, cuticle/epidermal, woody and humic gel materials, with fungal remains present but in low concentrations. There are very few medium sand particles and most of the particles range from the medium to very fine silt size.

The organic fraction is fairly rich. Grain-size histograms, based on the number of particles, have a characteristic, relatively flat distribution, with particles in the medium/fine sand to clay range. In most grain size histograms (based on the sum of areas) the bimodal distribution is very distinctive of this subenvironment; it is caused by a strong depletion in the fine or very fine sand sizes. The shape distribution is also very similar. Particle-relative-elongation histograms show a relatively flat distribution, with values from equidimensional to strongly elongate tabloids, but with more than 80% of the particles in the range of equidimensional to tabloid shapes. The relative irregularity varies from 1.4 to 3.2, with most values in the 1.4 to 2.5 range.

The natural levee subenvironment characterization

The organic assemblages recovered from this subenvironment are compositionally characterized by organic matter of a terrestrial type with high concentrations of dark material (woody, humic gels and coaly), and strong variations in the organic compound. The particle size varies from medium sand to clay, with most particles in the silt size range. The particle edges tend to be very simple and grains are mainly equidimensional to tabloid in shape.

Conclusions

– Every subenvironment in the Orinoco Upper Delta plain has its own organic assemblages and textural parameter distributions.

The Oxbow Lake rainy season assemblages are rich in light-coloured organic matter, with abundant fungal and insect remains; they are usually coarse-grained, and exhibit a highly variable particle shape. The dry season organic assemblages are poorer and the organic matter is darker, material representing the finest particle size is scarce.

The *Montrichardia* backswamp/flood basin assemblages are also related to the flood and dry periods of the basin. Dry periods in the flood basin are characterized by very poor organic matter assemblages consisting of woody and humic gel material, well-sorted with most particles in the coarse to medium silt size-range. The flood stages are characterized by a very high content of organic remains of variable composition and a wide range of particle sizes and shapes.

The crevasse splay assemblage is characterized by a strong bimodal particle size distribution, and by fluctuations in the amount of organic matter preserved at different levels of the fan. The composition of the organic remains is constantly represented by cuticle, epidermal, woody and humic gel material.

The natural levee organic assemblage is highly variable in the abundance of organic matter, but in general has a high concentration of dark terrestrial material. Poorly sorted distributions show a wide range of grain sizes varying from medium sand to clay.

The observed differences indicate that in a given major environmental framework (e.g. the Orinoco Upper Delta), the quantitative study of organic assemblages allows detailed subenvironmental interpretation.

– Changes in the sediments are reflected in the composition and/or texture of organic matter assemblages, as shown in the variations described in the *Montrichardia* backswamp core, where different lithological levels are related to changes in the textural and compositional characteristics of the organic assemblages recovered.

– Changes in the characteristics of organic matter assemblages are not always reflected in the sediment texture or colour, because organic matter assemblages are very sensitive to any change in the physico-chemical conditions of the sedimentary environment or to changes in the energy of the transporting current. This can be clearly shown in the Oxbow Lake, where two different organic assemblages were recovered from a continuous homogeneous grey clay core. These changes are apparently related to changes from the dry to the rainy season sedimentation.

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