

SEDIMENTARY STRUCTURES AND TEXTURES OF RIO ORINOCO CHANNEL SANDS, VENEZUELA

Chapter C

By Edwin D. McKee

CONTENTS

	Page
Abstract-----	1
Introduction-----	1
Terminology used for sedimentary structures-----	2
Sand-wave deposits of the Orinoco-----	7
Cross-stratification-----	11
Miscellaneous sedimentary structures-----	13
Depositional features-----	13
Contorted structures-----	20
Climbing megaripples-----	26
Additional sedimentary features-----	26
Texture--grain size and sorting-----	32
Grain size distribution-----	37
Sorting of sand-----	43
References-----	44

ILLUSTRATIONS

Figure 1. Localities of sand structure study along

Rio Orinoco, Venezuela----- 3

2a, b. Tabular-planar structures in trench; foresets dip downstream; bank of Rio Orinoco at Musinacio-----	5
3a-g. Tabular-planar structures exposed in trenches parallel to direction of river flow; bar formed from sand waves at Curiquima on Rio Orinoco-----	8
4a, b. Sedimentary structures at crests of sand wave deposits on bar in Rio Orinoco above Las Ventanas, 2 km above mouth of Rio Suapure-----	9
5. Profile of sand-wave deposits showing positions of crests and intercrest areas and trench locations. Section parallel to stream flow, Rio Orinoco near km 1234 at Isla Babilla Flaca-----	10
6a-d. Profile of sand-wave deposits showing positions of crests and intercrest areas and trench locations with cross-stratification patterns in each. Rio Orinoco at Musinacio-----	12
7. Trough structure with festoon pattern in sand on right bank of Rio Meta at Las Caracaras gaging station-----	14
8a, b. Festoon cross-stratification with trough structure in pebbly sand, Rio Orinoco, 1.9 km above mouth of Rio Apure, on left bank. Section "a" parallel to river; block "b" trough plunges toward river-----	15
9a, b. Trough structure with festoon pattern in trench, right bank of Rio Meta, 2 km below Las Caracaras gaging station-----	16

10a-e.	Profile of sand-wave deposits showing cross-strata patterns of trenches at crests and between crests. Rio Orinoco near Isla Babilla Flaca (km 1234), right channel-----	17
11.	Tabular-planar and wedge-planar structure in sand-wave deposits. Trench on left bank of Rio Meta at junction with Rio Orinoco-----	18
12a, b.	Wedge-planar cross-strata (a, b). Bank exposing section of sand-wave deposits near Puerto Páez on Rio Orinoco-----	19
13a-e.	Minor sedimentary structures (a-e), exposed on face of bar in center of Rio Orinoco, 2 km downstream from Puerto Ayacucho-----	21
14a, b.	Lenticular laminae and lenses or flow toes (a) of coarse sand (dark) in foresets of sand-wave deposits, including folds and low-angle faults (b). Rio Orinoco, 2 km downstream from Puerto Ayacucho, center bar-----	22
15.	Alternating coarse- and fine-grained sand laminae and lenses in sand-wave deposits, Rio Orinoco at Isla Ceiba (station 401, km 1269)-----	23
16.	Sand-flow toes at base of foresets, sand-wave deposits. Right bank of Rio Orinoco, 2 km downstream from Puerto Ayacucho. Photo by Lois Hernández-----	24
17.	Penecontemporaneous sag or fold, probably caused by loading during deposition. Right bank of Rio Orinoco near Curiquima-----	25

18. Recumbent fold, probably result of drag by sand load
during deposition of overlying foresets.
Upriver-dipping eolian foresets above sand-wave
deposits dipping down river. Rio Cuchivero
near mouth----- 27
- 19a, b. Climbing megaripple structure on large scale, face
of sand bar on right bank of Rio Orinoco, upstream
from Rio Cuchivero. Foreset dips are down river
parallel to current movement. Thickness of set
about 3 meters----- 28
- 20a, b. Flat beds and lenses of carbonaceous matter among
tabular-planar sets of sand. Rio Parguaza near
mouth, left bank----- 30
21. Organic matter (leaves and twigs) among tabular-planar
sets of cross-stratified sand-wave deposits.
Mouth of Rio Meta on left bank of Rio Orinoco at
Puerto Paéz----- 31
22. Eolian dune on surface of sand-wave deposits.
Rio Orinoco at Punta Brava, 11 km above Rio
Cuchivero----- 33
23. Barchan dune (3.4 m high) on sand bar, Rio Orinoco at
mouth of Rio Cuchivero----- 34
24. Section of trench showing cross-stratification of
eolian deposits above sand-wave deposits. Right
bank of Rio Orinoco at mouth of Rio Cuchivero----- 35

TABLES

TABLE 1. Tabular-planar and wedge-planar sand-wave deposits.

Grain-size distribution-----	36
2. The grade terms: Wentworth scale-----	38
3. Distribution by size of particles in some trough structures of Rio Orinoco-----	40
4. Percentages of grain sizes on lag deposits of sand waves and on eolian dune deposits-----	40
5. Average size and uniformity of sand grains, Rio Orinoco-----	41

ABSTRACT

A large majority of all sedimentary structures represented in sand bodies of the Rio Orinoco are tabular-planar cross-strata which, together with some wedge-planar, are the products of sand-wave deposition. Locally, in areas of river meander, where point bars are characteristically developed, trough structures forming festoon patterns are numerous. In a few localities, sets of nearly horizontal strata occur between tabular-planar sets and are interpreted to be the deposits of very fast currents of the upper flow regime; elsewhere, uncommon lenses and beds of silt, clay, or organic matter consisting of leaves and twigs, seem to be the result of quiet-water settling through gravity.

By far the most common grain size represented in the tabular-planar and wedge-planar cross-strata of the sand-wave deposits is medium grained, as determined by screen analyses. In many samples, however, moderate amounts of coarse or very coarse sand are also present. Eolian dunes on top of the sand-wave deposits are dominantly fine grained. The river channel sands were determined to be largely moderately well sorted, although in some places they were mostly well sorted, and in others, mostly moderately sorted.

INTRODUCTION

A study of the sedimentary structures and textures of Rio Orinoco channel sands in Venezuela was made during the month of March 1983, when the river was at low stage. The project was conducted as one of a series of studies on hydrology, water chemistry, and other aspects of the Rio Orinoco, most of which are described and discussed in accompanying chapters of the present publication. Work was done largely during a trip on the barge Duida from Puerto Ayacucho down river to Ciudad Guyana (fig. 1). Some preliminary

work was done in small boats upstream as far as Santa Barbara, but mostly the studies were conducted along the banks and on emergent bars accessible from the Duida.

FIGURE 1.—NEAR HERE

The sedimentary structures work was conducted contemporaneously with other river studies wherever opportunity permitted. Carl Nordin, in general charge of the program, and Robert Meade and Claire Cranston, of the U.S. Geological Survey, contributed greatly to the sedimentary studies, in addition to handling their individual assignments. Two groups of Venezuelan geologists and hydrologists participated in the detailed program of trenching, sampling, and measuring. One group, consisting of David Pérez Hernández, Antonio Ahogado, and Ricardo Smith, helped on the upper part as far downstream as Cabruta; this group was then succeeded by Alfredo DeLeon and Alfred Vilorio. Appreciative thanks for assistance is due to all of these men. For help in the work above Puerto Ayacucho, thanks are extended to Lois and Omar Hernández. Finally, for assistance and encouragement involving the entire research project, thanks are given to Dr. Abel ^SMajila, Project Coordinator.

TERMINOLOGY USED FOR SEDIMENTARY STRUCTURES

Definitions of terms adopted for use in the accompanying report are largely those used in the monograph of the Supai Group of Grand Canyon, U.S. Geological Survey Professional Paper 1173, 1982. For the convenience of the reader some of the more common terms, especially those involving quantitative designations, are presented here as a glossary. This list is not intended to be inclusive, but rather a list of selected terms that seem to be ambiguous and in a number of examples have been used in more than one way in recent literature.

FIGURE 1.--Localities of sand structure study along Rio Orinoco, Venezuela.

Cross-stratification - (Modified from McKee and Weir, 1953.)

- a. Scale as applied to foreset length:
 - 1. Small scale - less than 1/3 meter in length.
 - 2. Medium scale - approximately 1/3 - 6 meters.
 - 3. Large scale - greater than 6 meters in length.
- b. Classes of dip angles (foreset surfaces):
 - 1. High-angle strata - dip 20 degrees or more.
 - 2. Low-angle strata - dip less than 20 degrees.
- c. Basic types of cross-strata: Based primarily on the character of the lower bounding surface of each set of cross-strata and, secondarily, on the shape of each set of cross-strata.
 - 1. Tabular-planar - contain bounding surfaces that are essentially parallel (fig. 2).

FIGURE 2.--NEAR HERE

- 2. Wedge-planar - contain planar bounding surfaces that converge.
 - 3. Lenticular - contain one or more bounding surfaces that are curving and not planar.
 - 4. Trough structure - the lower bounding surface is trough-shaped; laminae filling the trough may be symmetrical or asymmetrical.
 - 5. Festoon troughs - group of troughs each having a partially dissected underlying trough or troughs with festoon pattern.
- Bedforms
- d. ~~Sand waves as defined by Friedman and Sanders (1978, p. 570) are rhythmic bedforms larger than ripples, formed by water currents in cohesionless sediments. According to Allen (1982, p. 454), they consist "of long crested parallel ridges typified by a moderate to high symmetry in cross-section and by low to mild slopes" and mostly they "are long-crested in plan, ranging from~~

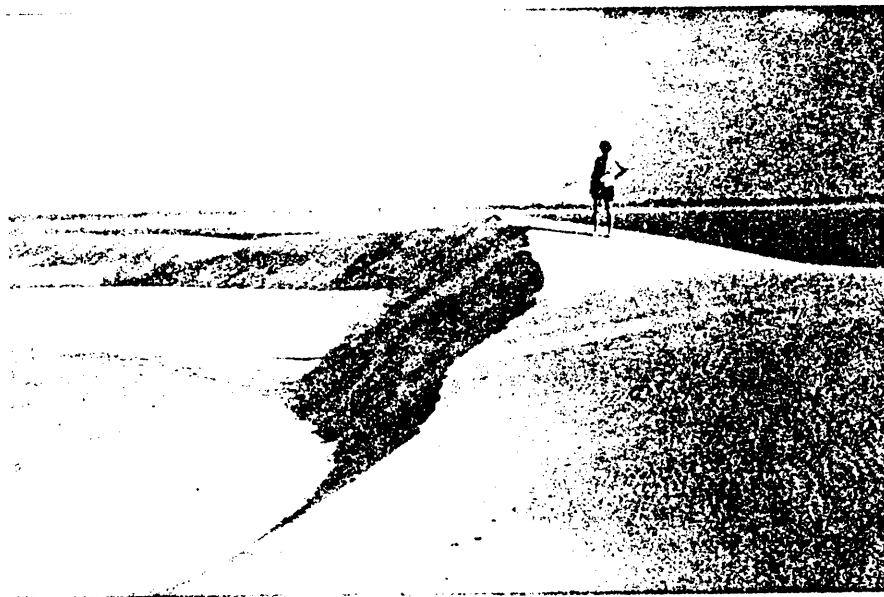


Figure 23.--Barchan dune (3.4 m high) on sand bar, Rio Orinoco at mouth of Rio Cuchivero.

FIGURE 2a, b.--Tabular-planar structures in trench; foresets dip downstream;
bank of Rio Orinoco at Musinacio. Scale (a) 12 inch (30 cm) rule on
left; (b) 2 foot (.01 m) machete on right.

Bedforms

- a. Classification - A considerable amount of confusion exists concerning terminology for rhythmic bedforms developed in cohesionless sediment by water currents as stated by Miall (1977, p. 33). The size, shape, and internal structure are features most commonly used to differentiate kinds of bedforms, and three or four principal classes generally are recognized, e.g., three forms adopted for reversing tidal currents (Allen, 1979), four forms for fluvial deposits (Coleman, 1969). Furthermore, numerous names are synonymous in part or in total.
- b. Sand waves - As defined by Friedman and Sanders (1978, p. 570), these are rhythmic bedforms larger than ripples, formed by water currents in cohesionless sediments. In the classification of Coleman (1969, table VI), they are shown as having greater wave height and wave length, in general, than either megaripples or (aqueous) dunes and are characterized by long crested parallel ridges that in plan view range from relatively straight or gently curved to moderately sinuous. Because they grade in size, shape, and ripple index from typical aqueous dunes ^{from} and the still smaller megaripples, they are used as synonymous with these features by many geologists (Collinson, 1970; N. D. Smith, 1971; Karez, 1972; Sing and Kumar, 1974). Other probable synonyms of sand wave are large-scale ripples (Williams, 1971), linguoid bars (Allen, 1968), and transverse bars (N. D. Smith, 1970).

- c. Dunes (aqueous, not eolian) - As defined by Collinson (1978), aqueous dunes contrast with sand waves in having lower length-to-height ratios, crest lines that are sinuous and commonly discontinuous, and have deep scour troughs on the lee side in front of crest line saddles. The lee side scour troughs normally produce trough cross-bedding with festoon pattern. Both aqueous dunes and sand waves are highly variable in size, depending on depth of the water (Coleman, 1969, table VI). Ripple marks often are developed on their stoss surfaces. The term megaripple, as normally used, may be synonymous with aqueous dune, although Coleman (1969) considers that it represents a low-water and ^arising stage, whereas the dune characterizes a flood stage.
- d. Megaripple - In the classification of Coleman (1969, table VI), megaripples are described as small bedforms that develop "with increasing discharge and velocity" and ^{with} relatively smooth water. They have linguoid or lunate crest lines in plan view, and a ripple index much higher than in small-scale ripples. They are commonly considered a variety of aqueous dune.
- e. Crest of fluvial sand wave is the hinge line or junction of the stoss surface and the foreset beds. It forms a low ridge normal to current direction which, in plan view, generally is relatively straight or gently curved to moderately sinuous.

~~relatively straight or gently curved in a single direction to moderately sinuous."~~

~~e. Crest of sand wave is a ridge normally formed at the downstream terminus of a sand wave; it develops normal to the direction of stream current and may be straight or relatively sinuous.~~

~~f. Megaripple or aqueous dune is a bedform developed through down-current migration of crescentic sand waves and may occur in meandering river systems, braided streams or nearshore sand bodies; crest forms differ as in ordinary small ripple marks.~~

f g. Point bar deposits are the sediments accumulated on the inside of bends in the wave-like loops of meandering rivers. They characteristically have trough structures.

g h. Flow regimes are classified as lower and upper by Simons, Richardson, and Nordin (1965, p. 36). Bedforms in the lower flow regime are listed as ripples, ripples on dunes, and dunes; the mode of sediment transport is in discrete steps and the relation between bed and water surface is "out of phase." In the upper flow regime, bedforms consist of plane beds, antidunes and chutes and pools; mode of transport is continuous; the bed and water surface relations are "in phase."

h X. Sand-flow toes: This term as applied by Ahlbrandt and Fryberger (1982, p. 26-27) refers to the leading edge of avalanche sand deposits where they taper down to a point, commonly near the base of a flow. The name was originally applied to eolian foresets, but what seem to be typical flow-toes were recognized in sand-wave deposits of the Rio Orinoco in numerous places.

SAND-WAVE DEPOSITS OF THE ORINOCO

Deposits of sand waves on the Rio Orinoco were examined on islands and banks at fourteen localities along the river between Puerto Ayacucho in the southwest and Musinacio to the northeast (fig. 1)--a distance of approximately 650 km. The morphology of these deposits, as seen at a low stage of the river, consists of relatively flat sheets of sand crossed by low, largely straight sand crests oriented at right angles to the direction of river flow. Each crest apparently was formed at the downstream end of a sequence of sand-wave deposits. In most areas, the approach surface was nearly horizontal, but sloped gently downriver with stream gradient. This crest was asymmetrical with its steep side facing downriver. Commonly its form was accentuated either by an accompanying trough or furrow in front, or it formed the lower end of a bar.

The size of individual sand-wave deposits differed greatly from one locality to another. The largest of those measured along Rio Orinoco showed terminal ridges or crests separated by distances greater than 300 m. At Curiquima, one was 320 m (fig. 3); upstream from Rio Suapure, one measured 310 m (fig. 4). Minimum crest-to-crest distances were less than 100 m at several localities, i.e., near Isla Babilla Flaca, 69 m, 78 m, 90 m (fig. 5); and downstream from Puerto Ayacucho, 78 m and 90 m. The heights of individual ridges or crests, above the generally flat surface of inter-ridge spaces, likewise differed greatly from one locality to another but commonly ranged up to 2.4 or more meters.

FIGURES 3, 4, 5.--NEAR HERE

FIGURE 3a-g.--Tabular-planar structures exposed in trenches parallel to direction of river flow; bar formed from sand waves at Curiquima on Rio Orinoco.

FIGURE 4a, b.--Sedimentary structures at crests of sand-wave deposits on bar in Rio Orinoco above Las Ventanas, 2 km above mouth of Rio Suapure.

FIGURE 5.--Profile of sand-wave deposits showing positions of crests and intercrest areas and trench locations. Section parallel to stream flow, Rio Orinoco near km 1234 at Isla Babilla Flaca.

CROSS-STRATIFICATION

Characteristics of the cross-stratification in sand bodies of the Rio Orinoco channel were determined largely by trenching at various selected localities on bars and banks of the main river channel. Trenches were dug in T- or L-shaped forms to expose the stratification in three dimensions. These trenches were of various sizes up to 3 meters in length and one or more meters deep, depending on features to be determined in each situation. In some localities, trenches were located both on the crest of a sand wave deposit and at three or more equally-spaced intervals within the area between crests (figs. 3, 6).

FIGURE 6.--NEAR HERE

Of the three principal types of cross-stratification generally recognized, the tabular-planar type (fig. 2) is by far the most common in the Orinoco sand deposits, represented both in medium and rarely in large scale. Many trench sections show 4 or 5 tabular sets with foresets dipping downstream at angles between 18° and 30° and separated by near-horizontal bounding planes. In crests at the downstream ends of sand-waves, numerous small sets of cross-strata commonly combine into one or two large sets as at Curiquima (fig. 3), near the mouth of Rio Suapure (fig. 4) and especially at Musinacio (fig. 6). In such places, single sets attain thicknesses of almost 2 meters--equal to the entire coset thickness in the adjoining intercrest areas upstream.

Trough-type cross-strata forming festoon patterns in sections normal to trough axes were recorded at several localities. Two of these were at Puerto Páez near the mouth of the Rio Meta (fig. 7) and on the Rio Orinoco, 2 km above the mouth of Rio Apure (fig. 8). In all places, the trough structures were relatively wide and shallow (fig. 9a, b); some were filled

FIGURE 9a, b.--Trough structure with festoon pattern in trench, right bank of Rio Meta, 2 km below Las Caracaras gaging station. Scale is 12 inches (30.5 cm).

FIGURE 8a, b.--Festoon cross-stratification with trough structure in pebbly sand, Rio Orinoco, 1.9 km above mouth of Rio Apure, on left bank. Section "a" parallel to river; block "b" trough plunges toward river.

FIGURE 7.--Trough structure with festoon pattern in sand on right bank of Rio Meta at Las Caracaras gaging station.

FIGURE 6a-d.--Profile of sand-wave deposits showing positions of crests and intercrest areas and trench locations with cross-stratification patterns in each. Rio Orinoco at Musinacio.

symmetrically and others asymmetrically with sand laminae, suggesting that the depositing currents were well above the trough rims at the time of sediment filling as has been shown experimentally (McKee, 1957, p. 132). A few scattered pebbles, with diameters as much as 50 millimeters were in the low parts of some channel fills. The examples of trough bedding are believed to have formed under point-bar conditions of sedimentation at low stages of the Rio Orinoco. Such an environment is known to favor the development of this structure (Frazier and Osanik, 1961; Bernard et al., 1970).

FIGURES 7, 8, 9a, b.--NEAR HERE

A third type of cross-stratification--the wedge-planar (McKee, 1962, p. 563, 571, 585; 1982, p. 299)--was observed at some localities along the Orinoco, although it was much less common than tabular-planar. Examples are illustrated from Isla Babilla Flaca, near km 1234 (fig. 10) and at Puerto Páez at the mouth of Rio Meta (figs. 11, 12). The explanation for why the planar-bounding planes are sloping in this type of cross stratification, rather than horizontal as in tabular-planar, is not known, but a likely explanation seems to be fluctuations or changes in water level that control the surface of sand-wave deposits during sedimentation.

FIGURE 10, 11, 12.--NEAR HERE

MISCELLANEOUS SEDIMENTARY STRUCTURES

Depositional Features

A widespread and characteristic feature of stratification in a majority of sand-wave deposits along the Rio Orinoco is an alternation of coarse- and fine-grain sizes in the foreset bedding of tabular-planar sets. Because differences in the grain size of different strata are conspicuously shown by the light and dark shades of yellow and yellowish-brown sand, the

FIGURE 12a, b.--Wedge-planar cross-strata. Bank exposing section of sand-wave deposits near Puerto Páez on Rio Orinoco. Scale is 12 inches

FIGURE 11.--Tabular-planar and wedge-planar structure in sand-wave deposits. Trench on left bank of Rio Meta junction with Rio Orinoco.

FIGURE 10a-e.--Profile of sand-wave deposits showing cross-strata patterns of trenches at crests and between crests. Rio Orinoco near Isla Babilla Flaca (km 1234), right channel.

FIGURE 13a-e.--Minor sedimentary structures (a-e), exposed on face of bar in center of Rio Orinoco, 2 km downstream from Puerto Ayacucho.

lensing character of individual laminae or groups of laminae (figs. 13B, 14, 15) and the development of flow toes in the sand (figs. 3a, b, 4, 6c, 16) are readily apparent. Likewise the characteristic structure of climbing ripples, considered evidence of an excess sand supply (McKee, 1965, p. 81), was noted at several localities along the banks.

FIGURE 13, 14, 15, 16.--NEAR HERE

Contorted Structures

In addition to those structures formed at the time of and during deposition, others of a penecontemporaneous variety result from local folding, faulting, and contortion on a small scale. These may be classified into three principal types according to genesis. They consist of (1) those structures, both tensional and compressional, resulting from avalanching, (2) structures caused by loading as from the accumulating weight of deposits settling from above, and (3) overturned folds that result from the drag or friction of large sand masses moving across a beveled surface at the top of a series of foreset beds.

Structures typical of each of the principal deformational processes were recorded in stratification of the Orinoco, though some of them probably were in deposits not of sand waves. In sections of a sand bar about 2 km downstream from Puerto Ayacucho, small examples of sags from loading (figs. 13a, 17), of shattered and contorted folds (fig. 13c), and of irregular lensing (fig. 13b) were noted in laminae of coarse sand among the fine sand laminae. These were formed on foresets, probably the result of avalanching. Small convolute structures such as commonly develop in the upper layers of loose sand as a result of sediment loading (McKee, 1967, p. 840) were also observed in this locality (fig. 13e).

FIGURE 17.--NEAR HERE

FIGURE 18.--Recumbent fold, probably result of drag by sand load during deposition of overlying foresets. Upriver-dipping eolian foresets above sand-wave deposits dipping down river. Rio Cuchivero near mouth.

FIGURE 17.--Penecontemporaneous sag or fold, probably caused by loading during deposition. Right bank of Rio Orinoco near Curiquima.

FIGURE 16.--Sand-flow toes at base of foresets, sand-wave deposits. Right bank of Rio Orinoco, 2 km downstream from Puerto Ayacucho. Photo by [illegible]. Scale is 6 inches (15 cm).

FIGURE 15.--Alternating coarse- and fine-grained sand laminae and lenses in sand-wave deposits, Rio Orinoco at Isla Ceiba (station 401, km 1269).

FIGURE 14a, b.--Lenticular laminae and lenses or flow toes of coarse sand (dark) in foresets of sand-wave deposits, including folds and low-angle faults. Rio Orinoco, 2 km downstream from Puerto Ayacucho, center bar. Scale is 6 inches (15 cm).

FIGURE 19a, b.--Climbing megaripple structure, face of sand bar on right bank of Rio Orinoco, upstream from Rio Cuchivero. Foreset dips are down river parallel to current movement. Thickness of set about 3 meters.

Near the mouth of Rio Cuchivero, the beveled lower part of a typical recumbent fold, of the type that forms from drag by a mass of sand moving across foreset tops (McKee, 1962, p. 553) was recorded (fig. 18). This feature is considered good evidence of flood conditions where water is transporting a heavy load of sediment across the sand surface.

FIGURE 18.--NEAR HERE

Climbing Megaripples

On a large sand bar along the right bank of the Orinoco, near the mouth of Rio Cuchivero, an exceptionally fine example of climbing megaripple structure on a large scale was exposed by erosion (fig. 19a, b). Two sets of 27° -dipping foresets were recorded in the bank above river level and the corresponding low-angle beds (topsets) of the upcurrent side of each megaripple formed nearly horizontal planes. This structure clearly illustrates the rapid rate of sedimentation involved and the large amount of sand carried by the stream at the time of deposition.

FIGURE 19a, b.--NEAR HERE

Additional Sedimentary Features

Relatively few features affecting the remarkably uniform, primary stratification and cross-stratification of the Orinoco channel deposits have been noted despite trenching at many localities. Other than the penecontemporaneous structures already described, most exceptions to the uniformity consist of (1) incorporated organic materials, (2) partial destruction of laminae by boring or burrowing animals or from plant growth, and (3) reworking of water-deposited sediments by subsequent current action

Organic materials, largely in the form of leaves, twigs, and other debris trapped in pockets or trough-like depressions adjacent to sand-wave deposits have accumulated as lenses or irregular beds. Such deposits were observed at various localities along the Orinoco, but apparently are not common in the channel sands. On the left bank of the Rio Parguaza near its mouth, thin beds and small lenses of black carbonaceous matter, partially decomposed leaves, were noted between sets of tabular-planar sand in which foresets dipped uniformly between 22 and 25 degrees (fig. 20a, b). At Rio Meta near Puerto Paéz, some relatively thick black beds, consisting largely of twigs and plant debris, likewise were conspicuous between sand-wave deposits consisting of tabular-planar cross-beds of yellowish sand (fig. 21). Dips of foresets in these sands ranged from 20 to 28 degrees downstream.

FIGURE 20a, b, and 21.--NEAR HERE

Partial destruction through biturbation of stratification patterns among sand-wave deposits of the Rio Orinoco seems to be a relatively uncommon feature, especially when compared with many other environments of sand deposition. The general scarcity of burrowing and boring organisms probably is the result of impermanence of river sand bars. Constant changes in river discharge and in velocity and direction of current flow make habitats for many organisms unstable. At Isla Babilla Flaca, near km 1234, however, numerous vertical and high-angle tubes, about 1 cm in diameter, were recorded penetrating foresets that dipped at 19 and 20 degrees (fig. 10d) throughout a limited area. Elsewhere along the river, little evidence of laminae disruption by organisms was noted.

The reworking of sand-wave deposits by wind was a conspicuous feature on many of the large bars and some of the small ones. Eolian dunes of

barchanoid type were developed on top of the otherwise flat surfaces of sand-wave deposits. Examples were near Cabruta, at Punta Brava, 11 km above Rio Cuchivero (fig. 22), and at the mouth of Rio Cuchivero where they were 3.4 m high (fig. 23). In general, the foresets of eolian dunes were considerably longer^{VI} ~~than~~ those of sandwaves, and therefore, formed thicker sets of tabular-planar type, and they commonly exhibited large curving tangents with their flat basal bounding surfaces. Furthermore, the direction of dip in most eolian foresets was opposite to that of underlying sand-wave deposits, as wind commonly blew upriver, whereas water-formed foresets dipped downriver (fig. 24).

FIGURE 22, 23, 24.--NEAR HERE

TEXTURE--GRAIN SIZE AND SORTING

The lower part of the Rio Orinoco drainage system, like that of most other large rivers, can be divided into two principal parts on the basis of depositional processes involved and types of sediment accumulated. One of these parts, the active channel, is roughly from 1 to 4 km in width, depending largely on the amount of outcropping rock that confines its course in any particular area. The other part is the overbank portion commonly known as the flood plain, which in places is as much as 25 km wide including the channel in its middle.

Detrital sediment that is being deposited in the active channel of the Orinoco consists preponderantly of sand-sized particles and includes extremely little mud (silt or clay) in general (table 1). Very fine-grained sediment is largely transported to the delta at the river's mouth, or is accumulated over the flood plain on each side of the river where it settles in quiet water.

TABLE 1.--NEAR HERE

FIGURE 24.--Section of trench showing cross-stratification of eolian deposits above sand-wave deposits. Right bank of Rio Orinoco at mouth of Rio Cuchivero.

FIGURE 23.--Barchan dune (3.4 m high) on sand bar, Rio Orinoco at mouth of Rio Cuchivero.

FIGURE 22.--Eolian dune on surface of sand-wave deposits. Rio Orinoco at Punta Brava, 11 km above Rio Cuchivero.

FIGURE 21.--Organic matter (leaves and twigs) among tabular-planar sets of cross-stratified sand-wave deposits. Mouth of Rio Meta on left bank of Rio Orinoco at Puerto Paéz.

FIGURE 20a, b.--Flat beds and lenses of carbonaceous matter among tabular-planar sets of sand. Rio Parguaza near mouth, left bank.

Table 1.--Tabular-planar and wedge-planar sand-wave deposits. Grain-size distribution.
[Numbers underlined are dominant size; * = wedge-planar]

Locality	P e r c e n t						Silt and clay
	Granule	Very coarse	Coarse	Sand Medium	Fine	Very fine	
Trapichote	.0	.0	.67	<u>67.88</u>	25.54	4.70	.010
Puerto Ayacucho	.20	.30	5.15	<u>62.01</u>	25.69	5.46	.010
Rio Meta*	11.16	<u>37.39</u>	24.78	20.73	4.64	1.01	.003
Rio Meta*	.49	1.58	9.37	<u>71.01</u>	15.48	1.68	.004
Rio Meta*	13.50	<u>34.91</u>	26.16	21.78	2.68	.85	.001
Rio Meta*	3.87	8.76	22.47	<u>56.15</u>	7.57	.84	.003
Isla Babilla Flaca	14.39	<u>50.81</u>	28.50	4.63	.22	.89	.010
Isla Babilla Flaca	6.25	33.70	<u>53.71</u>	6.20	.0	.0	.001
Isla Babilla Flaca	3.64	11.50	<u>63.48</u>	21.06	.16	.0	.001
Isla Babilla Flaca	5.44	<u>43.17</u>	42.21	8.92	.0	.17	.001
Isla Babilla Flaca	3.92	13.46	52.52	29.63	.12	.11	.002
Isla Babilla Flaca	.99	1.65	17.13	<u>77.76</u>	1.15	.83	.005
Isla Babilla Flaca*	21.73	<u>48.05</u>	24.59	5.02	.30	.21	.000
Isla Babilla Flaca*	.98	1.88	26.93	<u>68.01</u>	1.05	.84	.003
Rio Parguaza	.30	.19	6.51	<u>70.42</u>	17.55	4.54	.004
Rio Parguaza	.30	.46	8.48	<u>71.95</u>	12.88	4.70	.010
Santa Maria	.0	.24	.11	.12	38.92	<u>55.19</u>	.050
Curiquima	.16	1.14	13.15	<u>82.53</u>	2.92	.0	.000
Curiquima	3.80	18.62	<u>38.52</u>	32.55	3.80	2.35	.004
Curiquima	.0	.50	8.85	<u>69.70</u>	17.83	2.62	.005
Curiquima	.91	11.78	<u>51.36</u>	32.48	2.71	.61	.002
Curiquima	.45	.45	9.25	<u>81.94</u>	7.01	.75	.002
Cabruta*	.11	.11	2.22	<u>36.16</u>	6.60	3.22	.030
Cabruta*	.42	.53	11.39	<u>80.38</u>	2.01	3.69	.020
Rio Cuchivero	.47	.95	.62	16.83	<u>60.53</u>	18.24	.020
Rio Cuchivero	.0	.0	.0	16.16	<u>76.67</u>	7.72	.005
Musinacio	7.91	<u>45.67</u>	38.34	7.20	.61	.25	.001
Musinacio	.13	1.56	12.21	<u>74.41</u>	10.99	.44	.003
Musinacio	.34	1.01	2.43	<u>80.07</u>	16.16	.61	.002
Musinacio	21.72	<u>47.72</u>	14.97	13.31	1.89	.21	.001
Musinacio	.10	.19	2.50	<u>80.08</u>	16.36	.66	.001

The extensive sand deposits of the Orinoco channel, although including all size grades, are dominantly within the range of medium sand (1/4-1/2 mm) on the Wentworth scale. A common feature, however, in places where coarse and very coarse sand (1/2-2 mm) is also present, is a sorting into alternating laminae of the two grade sizes on the foresets of tabular-planar units. This alternation seems to be very characteristic in many localities and probably should be considered a diagnostic feature of sand-wave strata on the Rio Orinoco, although its cause is not clear.

Grain Size Distribution

Grain-size determinations were made from mechanical analyses of 55 sand samples from 17 localities. The samples were considered representative of tabular- and wedge-planar structures, trough- or festoon-type structures, surface lag deposits, eolian dune deposits, and tongues or sand flow toes of relatively coarse sand. Size classification is according to the Wentworth scale as given in table 2.

TABLE 2.--NEAR HERE

Because a large majority of sand deposits in the lower reaches of the Rio Orinoco are the product of sand waves and mostly have either a tabular- or a wedge-planar structure, samples from them are considered separately from those of other types in this discussion of grain size. The 31 samples and 10 localities represented in table 1 illustrate that more than half of the sediment deposited as sand waves is in the medium-size class. In contrast, only three samples are in the fine and very fine classes, and only 7 and 4 samples, respectively, are in the coarse and very coarse classes (table 1).

Table 2.—The grade terms

Limiting dimensions	The pieces	The aggregate	The indurated rock
mm			
256	Boulder	Boulder gravel	Boulder conglomerate
64	Cobble	Cobble gravel	Cobble conglomerate
4	Pebble	Pebble gravel	Pebble conglomerate
2	Granule	Granule gravel	Granule conglomerate
1	Very coarse sand grain	Very coarse sand	Very coarse sandstone
1/2	Coarse sand grain	Coarse sand	Coarse sandstone
1/4	Medium sand grain	Medium sand	Medium sandstone
1/8	Fine sand grain	Fine sand	Fine sandstone
1/16	Very fine sand grain	Very fine sand	Very fine sandstone
⁵ / ₁₆	Silt particle	Silt	Siltstone
1/256	Clay particle	Clay	Claystone

A second structure that occurs locally along the Rio Orinoco is the trough type that forms a distinctive festoon pattern. As illustrated in table 3, this structure, which generally is considered the result of point-bar development in areas where a stream meanders, is inconsistent in its grain size and commonly includes scattered granules and pebbles, especially near the trough bottoms. No one grain size seems to be dominant among the sands of these festoons.

Particles of very coarse sand and of granule- and pebble-size constitute a conspicuous though relatively minor part of many sand-wave deposits along Rio Orinoco. They occur mostly as scattered grains, interpreted as lags, on bar surfaces, although in some vertical faces they form lenses (fig. 15) or concentrations filling irregular depressions. The percentages of size grades in lag samples from three representative localities along the river are shown in table 4 and illustrate typical coarse fractions.

At the opposite extreme in grain size are the sands of eolian dunes that commonly develop on the surfaces of sand bars (figs. 22, 23). These wind-blown sands apparently were derived largely from the underlying sand-wave deposits and are composed mostly of fine grains ($1/8$ - $1/4$ mm) and to a lesser extent of medium grains ($1/4$ - $1/2$ mm). Relatively few of either coarser or finer sizes are present as shown in table 4. Thus, sorting (table 5) is very good--even better than in the sand-wave deposits.

TABLES 3, 4, 5.--NEAR HERE

In numerous sand-flow deposits that form bars and banks along the Rio Orinoco, a prominent feature in many vertical sections, is the presence of thin tongues of relatively coarse sand in the foresets of tabular-planar units. These strata commonly dip at 20 to 28 degrees and terminate near their bases as pointed sand-flow toes (figs. 3a, 3b, 4, 10d-e, 16).

Table 3.--Distribution by size of particles in some trough structures of Rio Orinoco

Locality	Pebble	Granule	P e r c e n t					Silt and Clay	Figure
			Very coarse	Sand Coarse	Medium	Fine	Very fine		
Puerto Ayacucho	.0	.0	.39	4.58	40.32	44.40	9.58	.01	-
Rio Meta: Las Caracaras (pebbly)	.0	1.84	20.68	51.19	22.56	2.88	0.50	.003	6, 8
Rio Apure	0.17	.66	.33	.67	45.85	50.00	1.99	.003	7
Rio Apure	.09	.57	3.02	14.92	58.17	22.29	.75	.002	7

Table 4.--Percentages of grain sizes on lag deposits of sand waves and on eolian dune deposits

Locality	Pebble	Granule	P e r c e n t					Silt and Clay	
			Very coarse	Sand Coarse	Medium	Fine	Very fine		
Isla Ceiba	14.30	38.79	12.45	12.18	12.85	8.51	.79	.001	Lag deposits
Trapichote	11.42	51.58	27.87	5.79	2.72	.96	.0	.000	
Rio Meta	6.80	28.77	22.46	13.87	15.12	8.81	3.49	.010	
Punta Brava	.0	.0	.0	.13	40.29	57.36	1.96	.003	Eolian dunes
Rio Cuchivero	.0	.35	.35	.18	30.50	62.36	6.38	.002	

Table 5.--Average size and uniformity of sand grains, Rio Orinoco
[Tabular-planar--Tab.-plan.; Eolian dune--Dune; Lens--Lens;
Wedge-planar--Wedge-plan.; Non stratified--Non strat.;
Flow toes--Fl. toes; Trough--Tr. festoon; Horizontal--Horiz.]

Locality	Structure type	Mean grain size (Phi units)	Size class	Graphic standard deviation	Sorting coefficient
Trapichote	Tab.-plan.	1.8387	med. sand	0.5687	mod. well sorted
Trapichote	Non strat.	-0.0771	v. coarse sand	1.6019	poorly sorted
P. Ayacucho	Tab.-plan.	1.8378	med. sand	0.5911	mod. well sorted
P. Ayacucho	Non strat.	2.7680	fine sand	0.7568	mod. sorted
P. Ayacucho	Tr. festoon	2.1167	fine sand	0.7022	mod. well sorted
P. Ayacucho	Lens	0.2514	coarse sand	1.1080	poorly sorted
Ceiba Id.	Tab.-plan.	1.1366	med. sand	0.6469	mod. well sorted
Rio Meta	Tr. festoon	1.2790	med. sand	0.3778	well sorted
Rio Meta	Wedge-plan.	1.5831	med. sand	0.5245	mod. well sorted
Rio Meta	Wedge-plan.	0.1495	coarse sand	1.0461	poorly sorted
Rio Meta	Wedge-plan.	1.1000	med. sand	0.8529	mod. sorted
Rio Meta	Tr. festoon	0.5517	coarse sand	0.7456	mod. sorted
Rio Meta	Tr. festoon	2.3254	fine sand	0.4128	well sorted
Babilla Flaca	Tab.-plan.	-0.2580	v. coarse sand	0.7520	mod. sorted
Babilla Flaca	Tab.-plan.	0.0981	coarse sand	0.6456	mod. well sorted
Babilla Flaca	Tab.-plan.	0.5796	coarse sand	0.5897	mod. well sorted
Babilla Flaca	Tab.-plan.	0.0539	coarse sand	0.6731	mod. well sorted
Babilla Flaca	Tab.-plan.	0.6653	coarse sand	0.6004	mod. well sorted
Babilla Flaca	Tab.-plan.	1.2690	med. sand	0.3870	well sorted
Babilla Flaca	Wedge-plan.	-0.3786	v. coarse sand	0.7787	mod. sorted
Babilla Flaca	Wedge-plan.	1.1716	med. sand	0.4557	well sorted
Rio Apure	Tr. festoon	1.9386	med. sand	0.4121	well sorted
Rio Apure	Lens	1.7317	med. sand	0.3330	v. well sorted

Table 5.--Average size and uniformity of sand grains, Rio Orinoco (continued)

Locality	Structure type	Mean grain size (Phi units)	Size class	Graphic standard deviation	Sorting coefficient
Rio Apure	Tr. festoon	1.5319	med. sand	0.6381	mod. well sorted
Rio Apure	Tr. festoon	2.0017	fine sand	0.4086	well sorted
Rio Apure	Wedge-plan.	2.1608	fine sand	1.1868	poorly sorted
Parguaza	Tab.-plan.	1.6976	med. sand	0.5631	mod. well sorted
Parguaza	Tab.-plan.	1.5998	med. sand	0.6081	mod. well sorted
Santa Maria	Tab.-plan.	3.1831	v. fine sand	0.4502	well sorted
Curiquima	Tab.-plan.	0.6534	coarse sand	0.8955	mod. sorted
Curiquima	Tab.-plan.	1.6308	med. sand	0.5158	mod. well sorted
Curiquima	Tab.-plan.	1.2385	med. sand	0.2988	v. well sorted
Curiquima	Fl. toes	0.5071	coarse sand	0.9000	mod. sorted
Curiquima	Tab.-plan.	1.3616	med. sand	0.3585	well sorted
Curiquima	Horiz.	1.6244	med. sand	2.6264	v. poorly sorted
Cuchivero	Tab.-plan.	2.5509	fine sand	0.6229	mod. well sorted
Cuchivero	Dune	2.2589	fine sand	0.4828	well sorted
Cuchivero	Dune	2.0874	fine sand	0.3127	v. well sorted
Cuchivero	Tab.-plan.	2.3884	fine sand	0.4024	well sorted
Cabruta	Wedge-plan.	6.9925	med. silt	5.4975	well sorted
Cabruta	Wedge-plan.	1.3980	med. sand	0.5362	mod. well sorted
Musinacio	Tab.-plan.	-0.0266	v. coarse sand	0.7272	mod. sorted
Musinacio	Tab.-plan.	1.4907	med. sand	0.4735	well sorted
Musinacio	Tab.-plan.	1.7040	med. sand	0.3362	v. well sorted
Musinacio	Tab.-plan.	1.6875	med. sand	0.3528	well sorted
Musinacio	Fl. toes	0.9484	coarse sand	0.7403	mod. sorted
Musinacio	Fl. toes	1.3730	med. sand	0.7583	mod. sorted

Mechanical analyses of 7 samples of these tongues and flow toes from 7 localities show that in 5 of the samples, the dominant grade size of sand was very coarse (1-2 mm). In all samples of associated matrix, the sand size was less, mostly medium grade. This common textural feature in the tabular-planar structures seems to be distinctive in many sand-flow deposits of the Rio Orinoco but the cause has not been determined.

Sorting of Sand

The degree of uniformity in channel sands of the Rio Orinoco was determined on the basis of 47 samples, distributed from Trapichote above Puerto Ayacucho, downriver as far as Musinacio (fig. 1). Using the graphic standard deviation method recommended by Folk (1968, p. 46), sand samples were assigned to classes of sorting as follows:

<0.350--very well sorted	0.70-1.00--moderately sorted
0.350--well sorted	1.00-2.00--poorly sorted
0.500--moderately well sorted	2.00-4.00--very poorly sorted

A tabulation of samples representing the principal structure types in the Orinoco sands illustrates several features (table 5). First, tabular-planar cross-strata which dominate the sand-wave deposits are more than 50 percent in the moderately well sorted class and about 25 percent in the well sorted class. Secondly, sands with wedge-planar structures which are much less common, range from poorly sorted to well sorted with nearly equal amounts in each class. Finally, the trough or festoon type, although variable, is mostly in the well sorted class.

Deposits that accumulated as pockets or lenses of relatively coarse sand or that formed flow toes among foreset beds are largely moderately to poorly sorted. At the other extreme in size, the eolian dune sands, probably because they were derived mostly from sand-wave deposits, are well to very well sorted.

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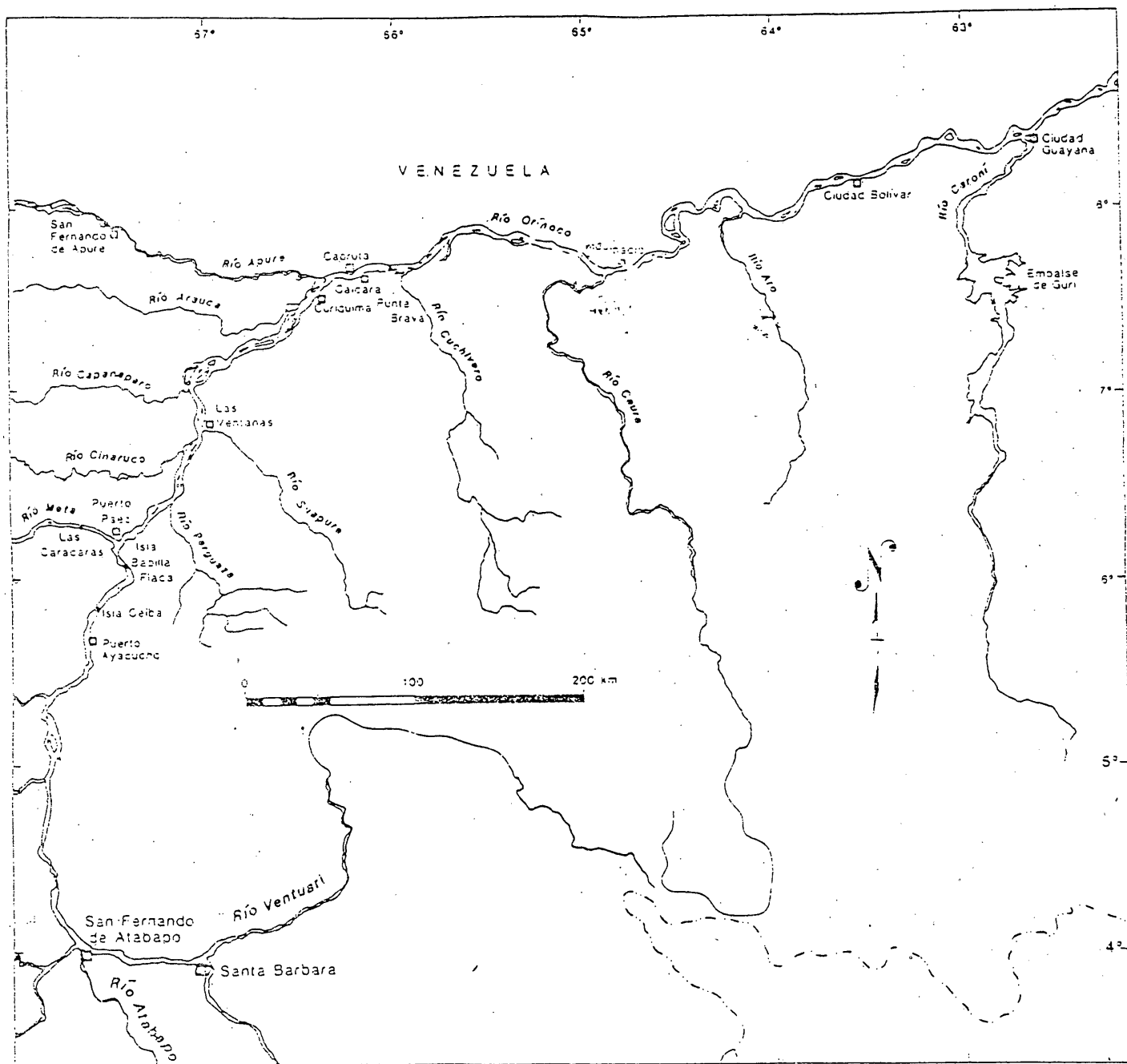


Figure 1.--Localities of sand structure study along Rio Orinoco, Venezuela.

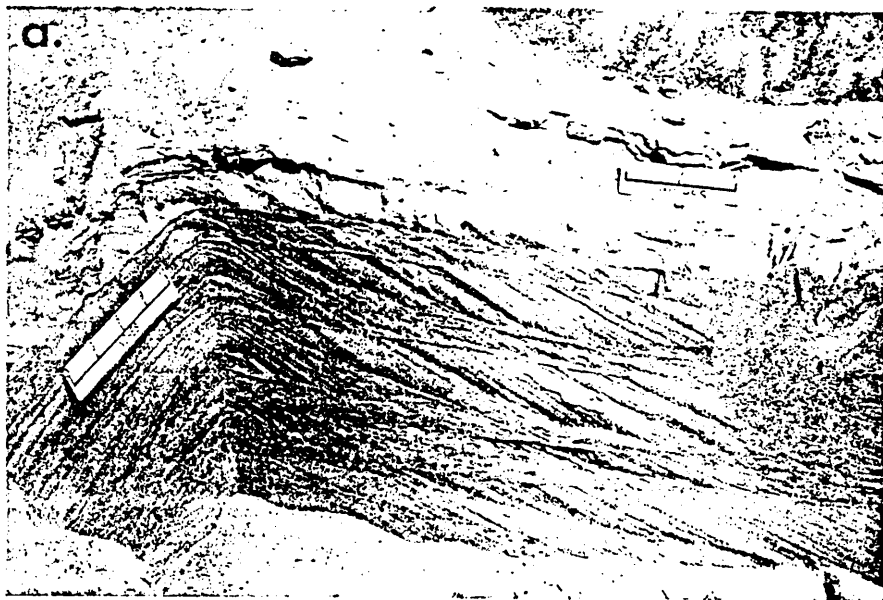
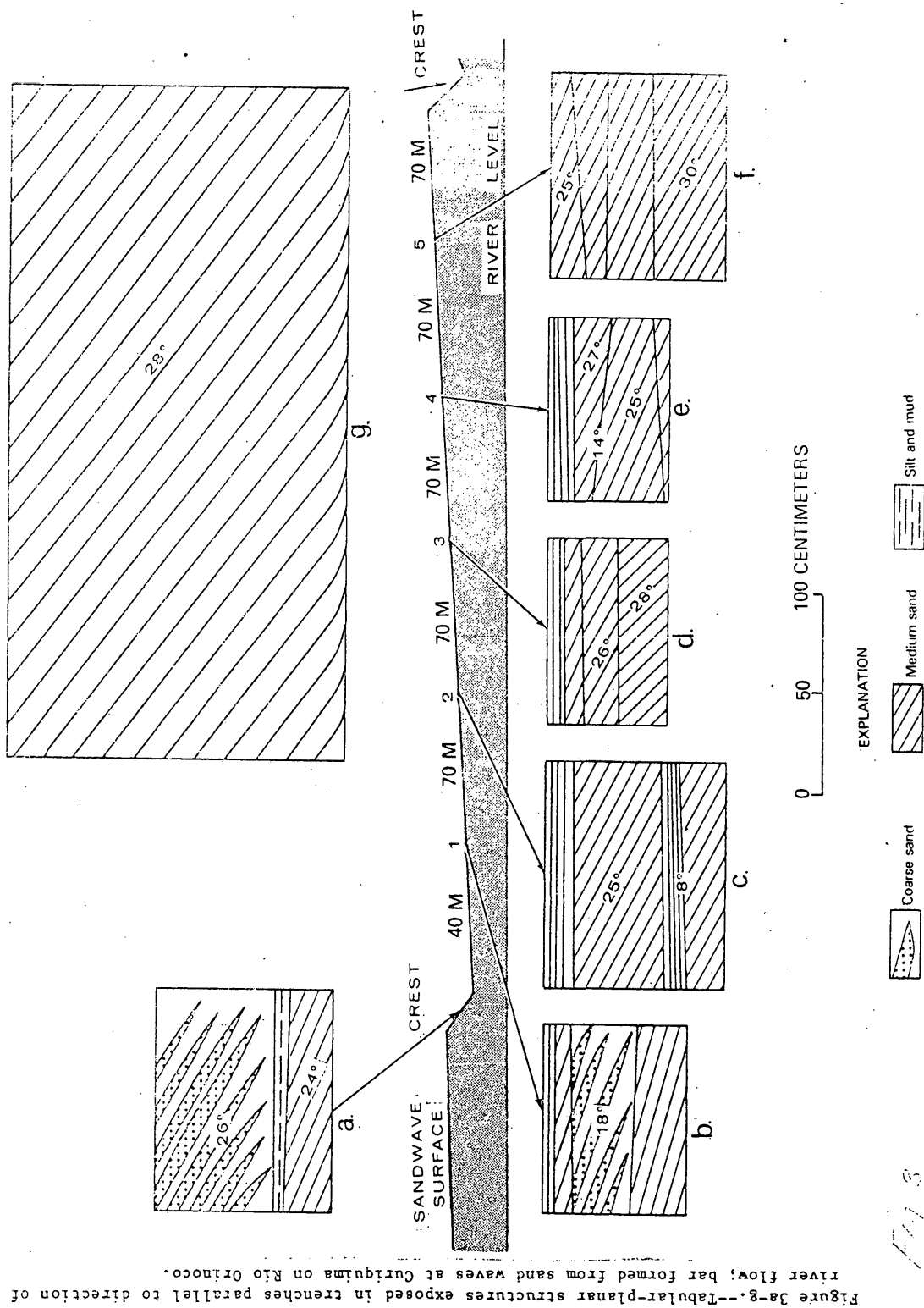


Figure 2a, b.--Tabular-planar structures in trench; foresets dip downstream; bank of Rio Orinoco at Musinacio.

RIO ORINOCO AT CURIQUIMA



SUAPURE

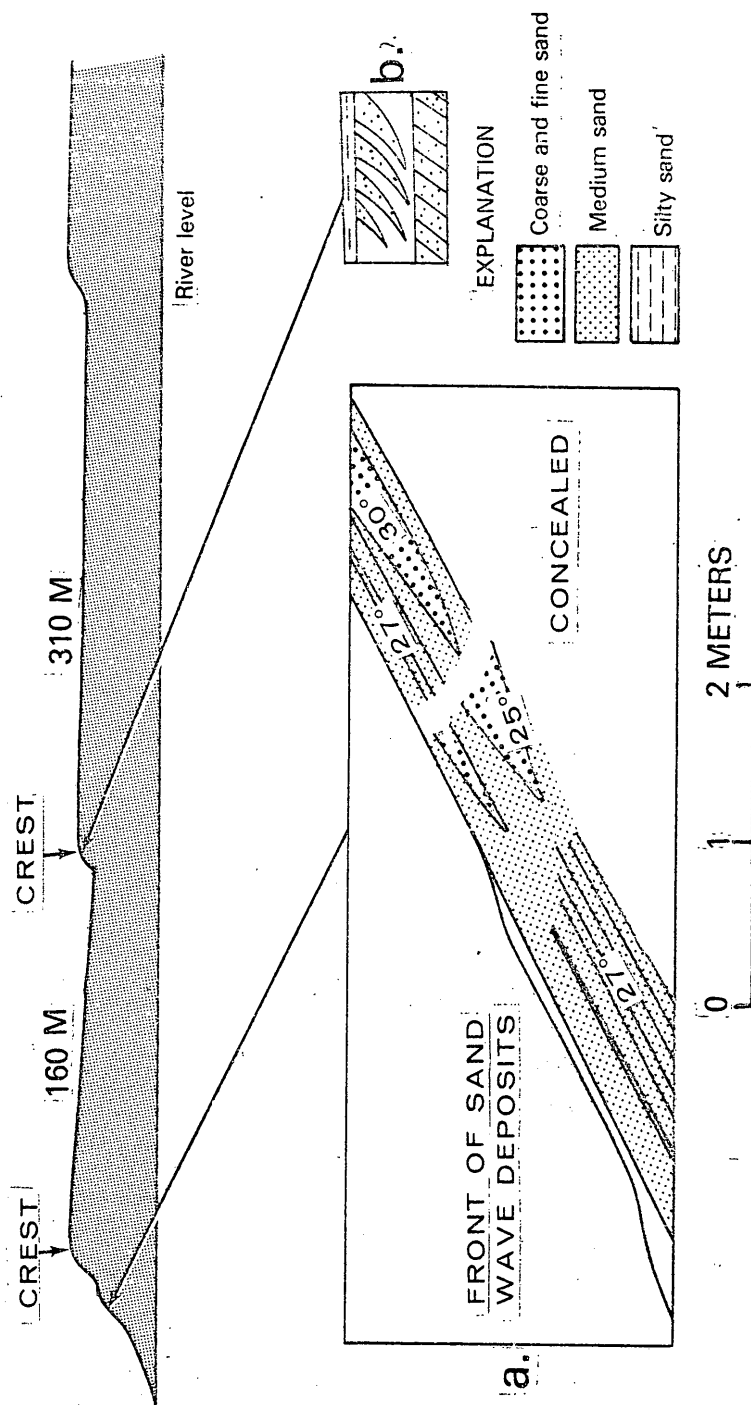


Figure 4a, b.--Sedimentary structures at crests of sand wave deposits on bar in Rio Orinoco above Las Ventanas, 2 km above mouth of Rio Suapure.

Fig. 4a, b

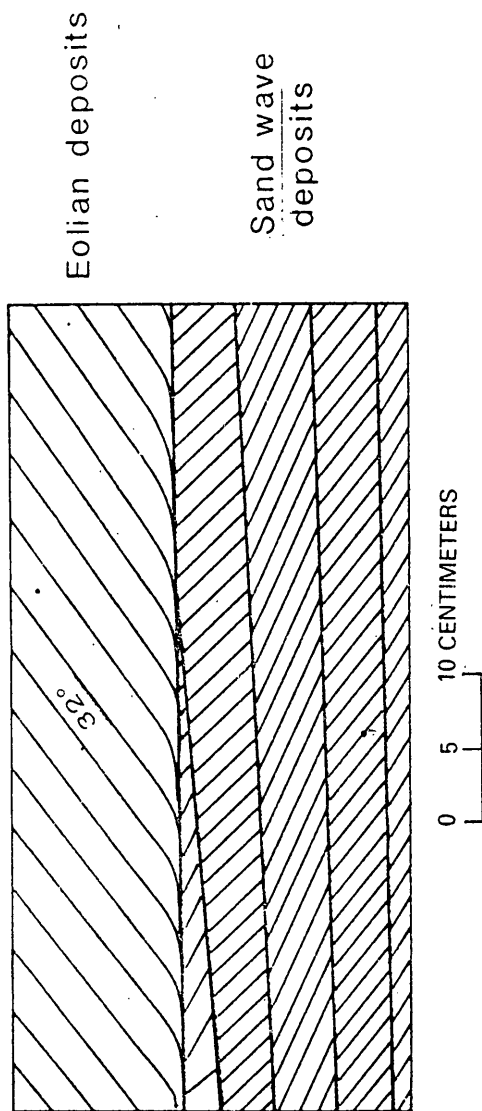


Figure 24.--Section of trench showing cross-stratification of eolian deposits above sand-wave deposits. Right bank of Rio Orinoco at mouth of Rio Cuchivero.

Fig. 24

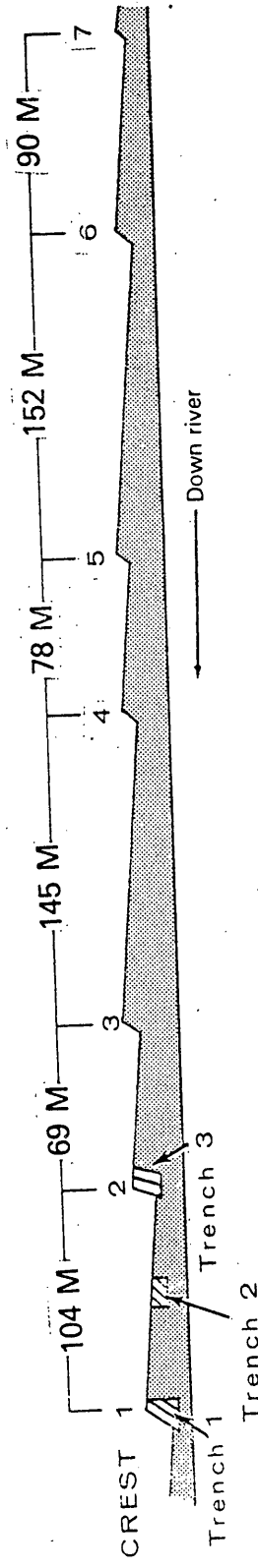


Figure 5.--Profile of sand-wave deposits showing positions of crests and interest areas and trench locations. Section parallel to stream flow, Rio Orinoco near km 1234 at Isla Babilla Flaca.

SUAPURE

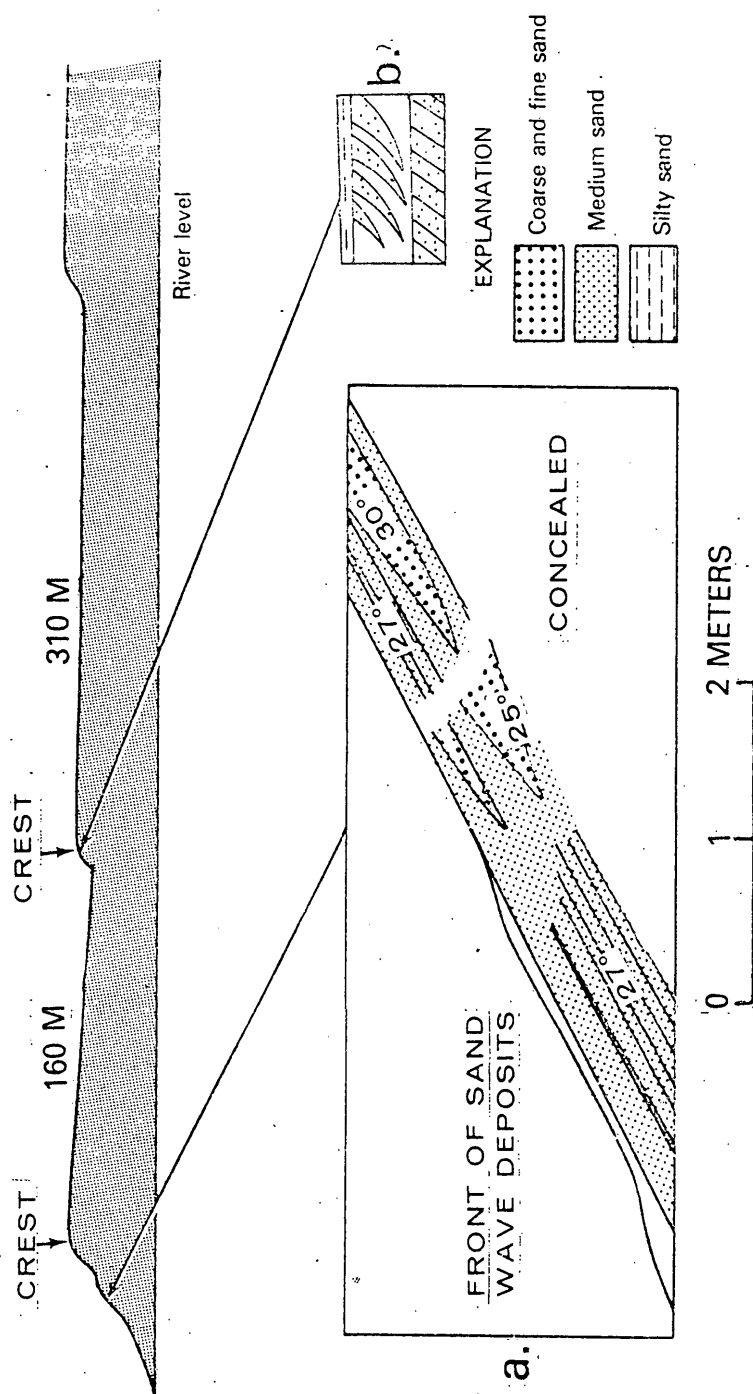


Figure 4a, b.--Sedimentary structures at crests of sand wave deposits on bar in Rio Orinoco above Las Ventanas, 2 km above mouth of Rio Suapure.

Fig. 4a, b

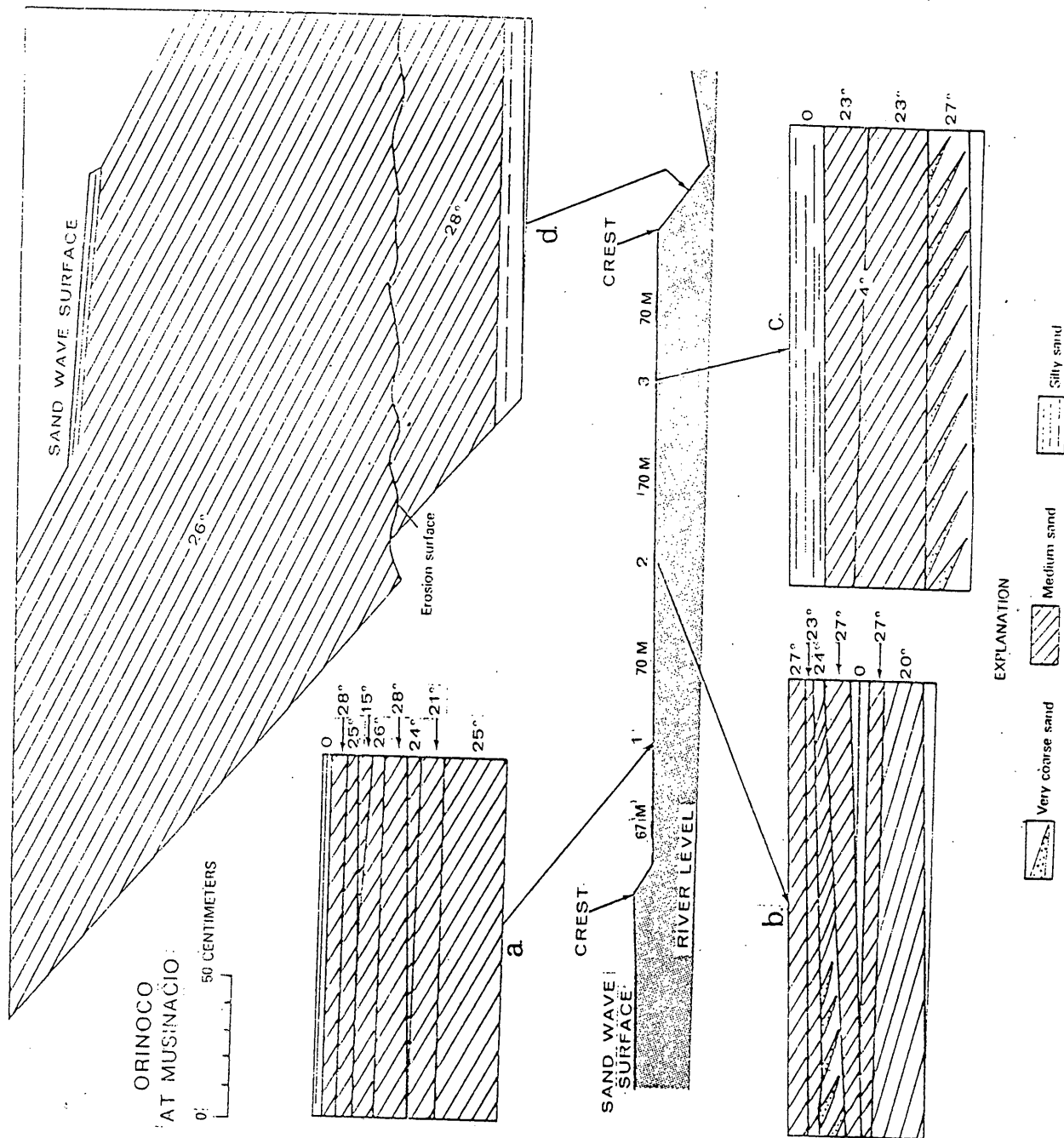


Figure 6a-d.--Profile of sand-wave deposits showing positions of crests and interest areas and trench locations with cross-stratification patterns in each. Rio Orinoco at Musinacio.

RIO META (Right bank)
 2 KILOMETERS LAS CARACARAS GAGING STATION

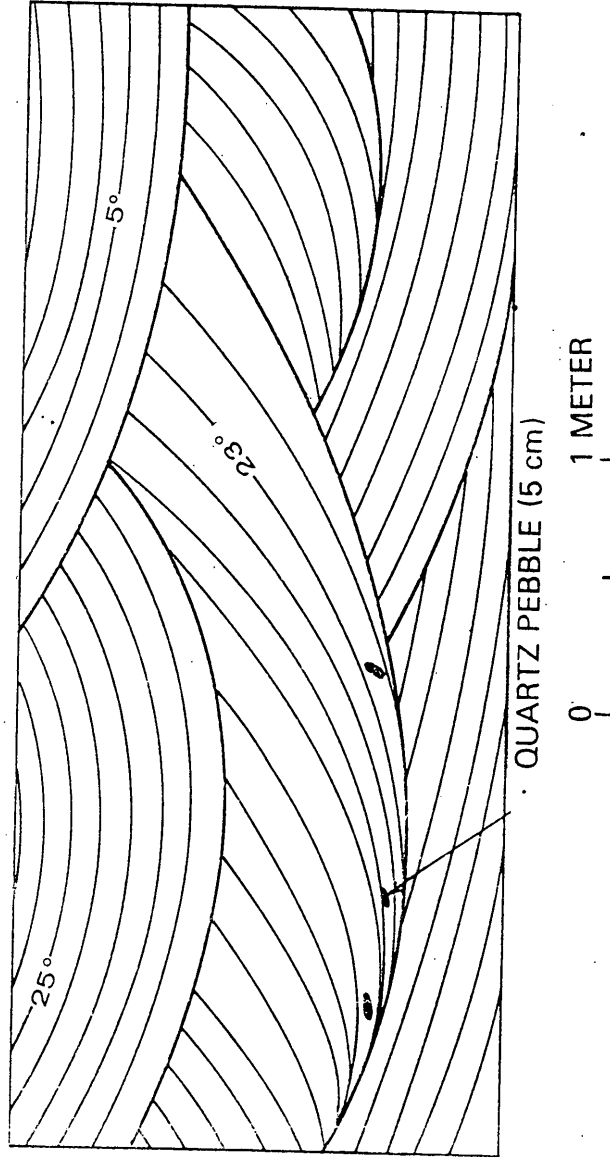


Figure 7.--Trough structure with festoon pattern in sand on right bank of Rio Meta at Las Caracaras gaging station.

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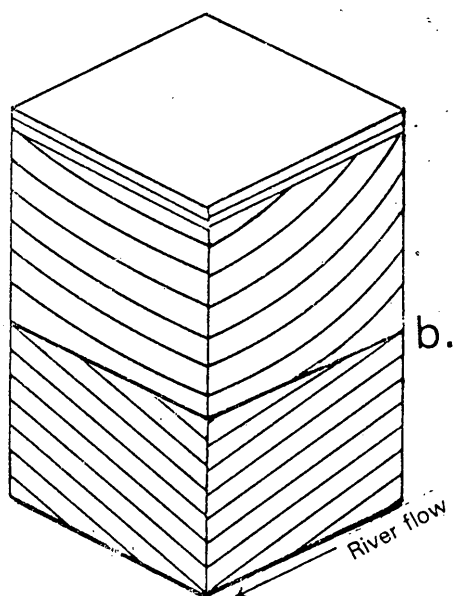
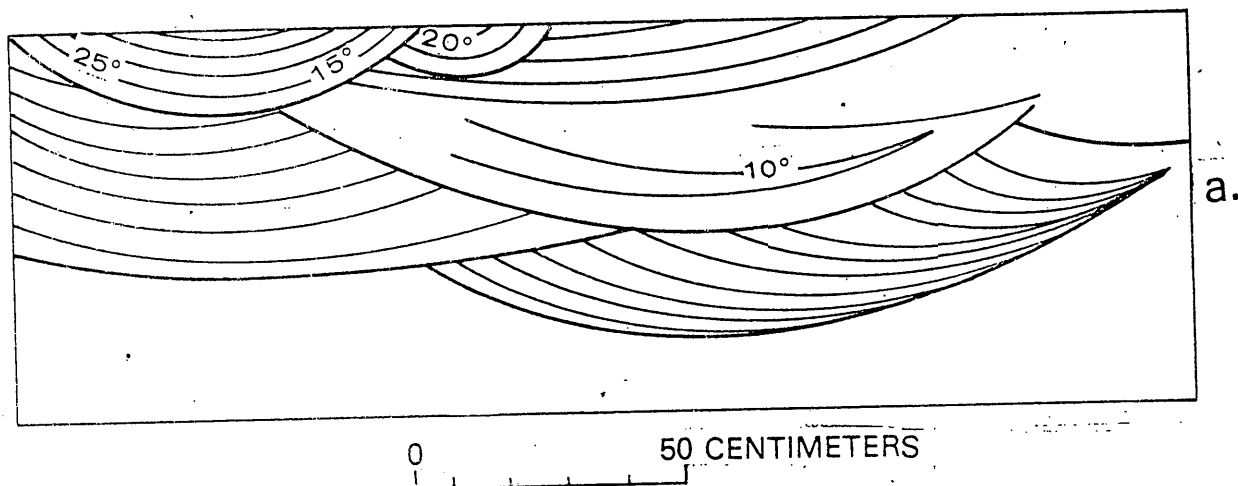


Figure 8a, b.--Festoon cross-stratification with trough structure in pebbly sand, Rio Orinoco, 1.9 km above mouth of Rio Apure, on left bank. Section "a" parallel to river; block "b" trough plunges toward river.

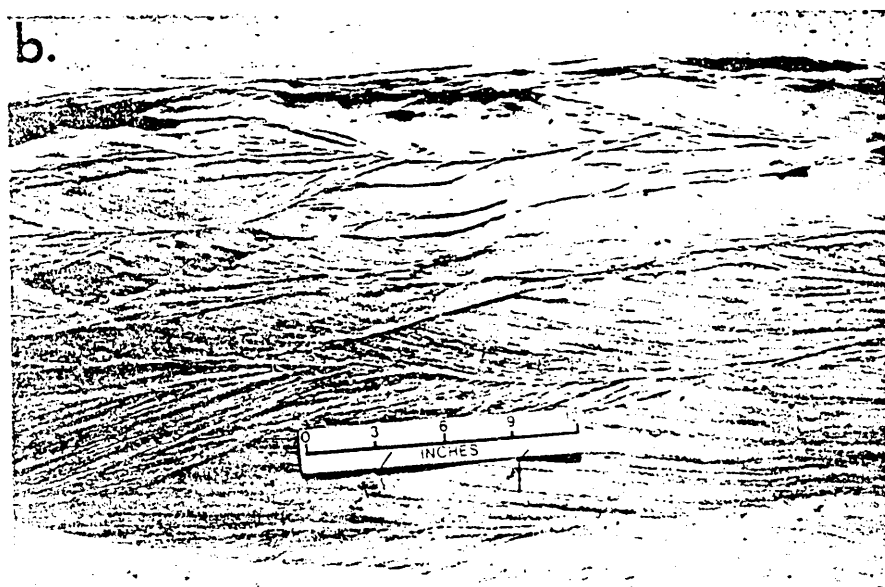
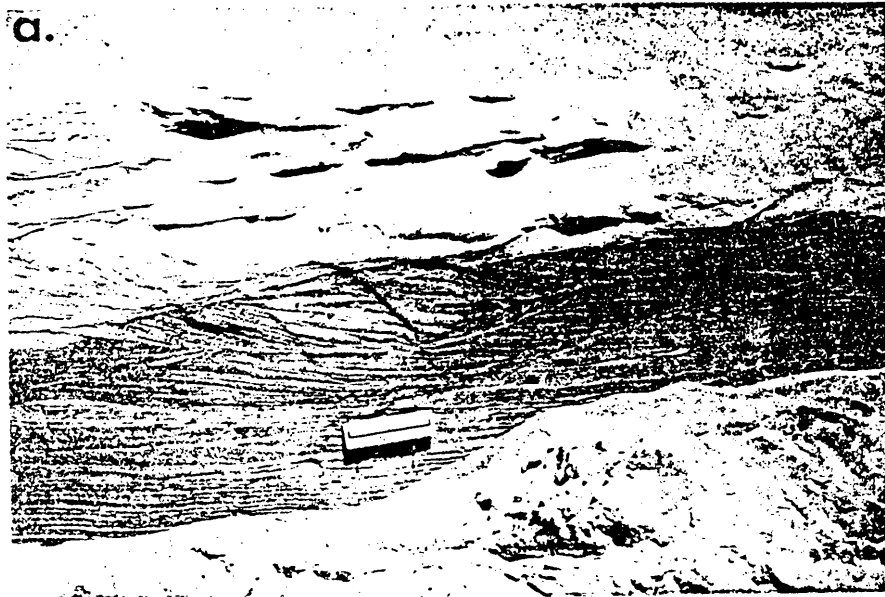
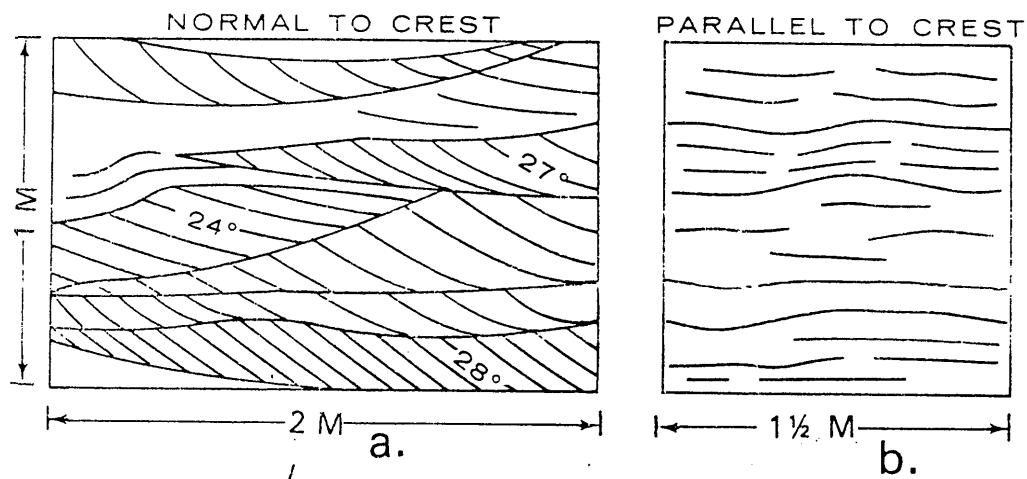
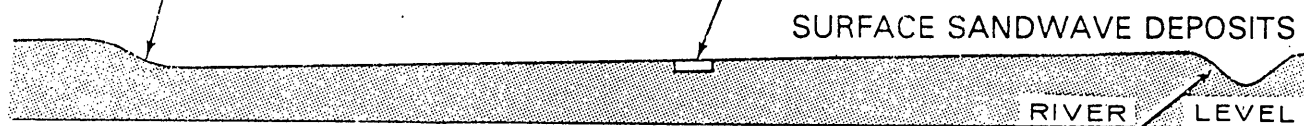
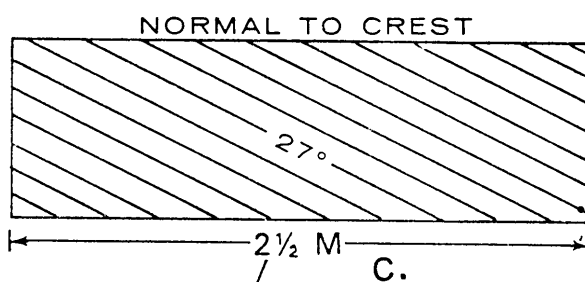


Figure 9a, b.--Trough structure with festoon pattern in trench,
right bank of Rio Meta, 2 km below Las Caracaras
gaging station.

SANDWAVE CREST, TRENCH Z

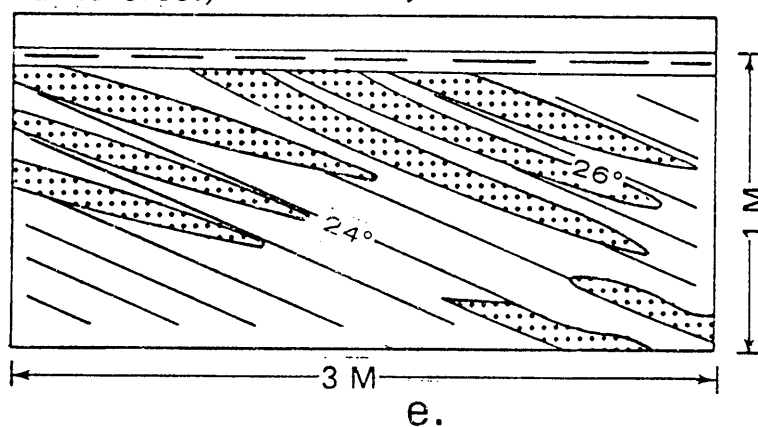
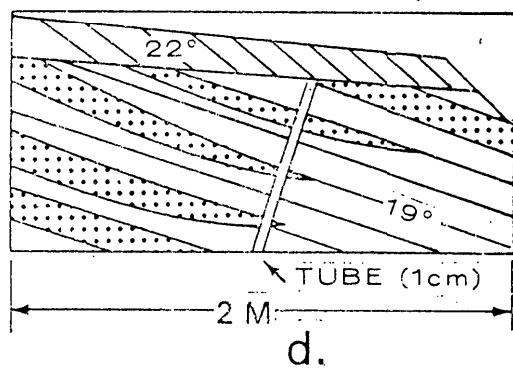


SANDWAVE INTERCREST, TRENCHES Y-Z

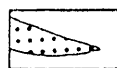


SANDWAVE CREST, TRENCH Y

(Sections normal to crest)



EXPLANATION



Very coarse sand



Medium sand

Figure 10a-e.--Profile of sand-wave deposits showing cross-strata patterns of trenches at crests and between crests. Rio Orinoco near Isla Babilla Flaca (km 1234), right channel.

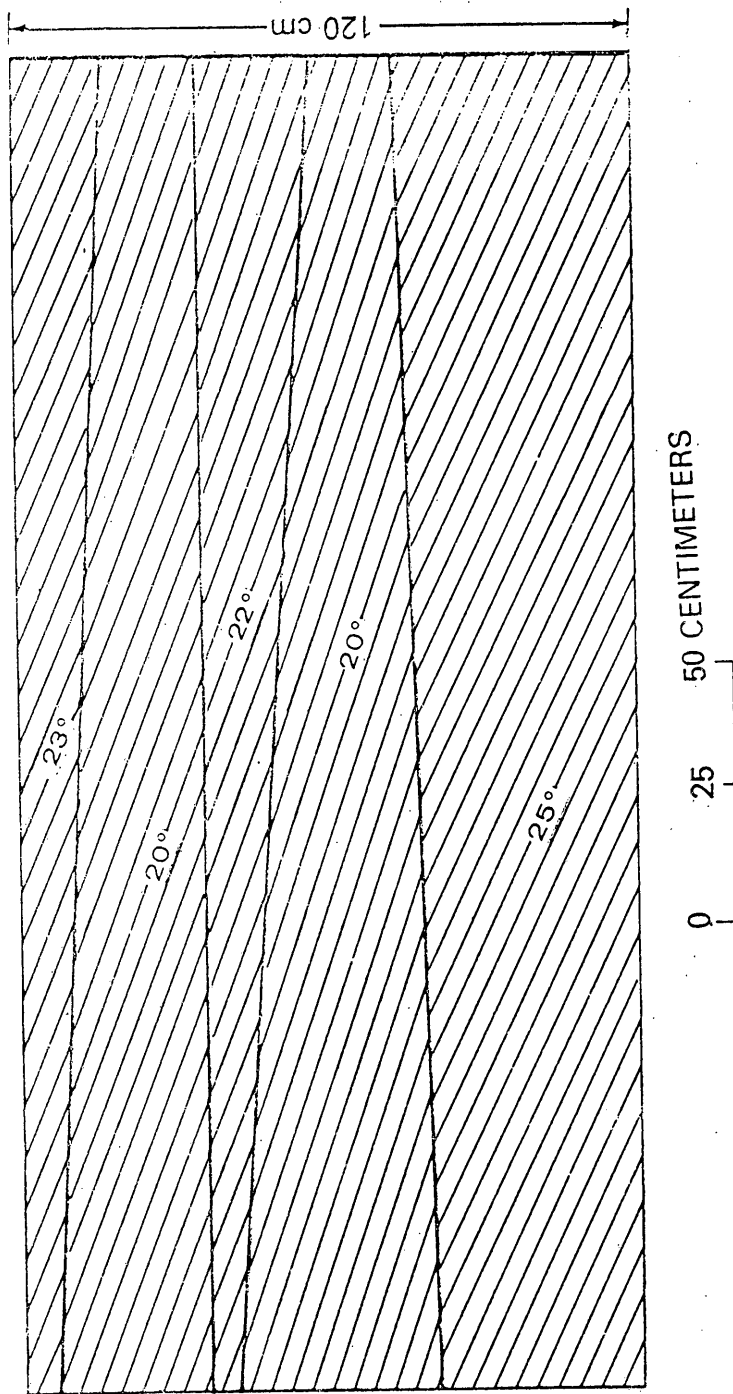


Figure 11.--Tabular-planar and wedge-planar structure in sand-wave deposits. Trench on left bank of Rio Meta at junction with Rio Orinoco.

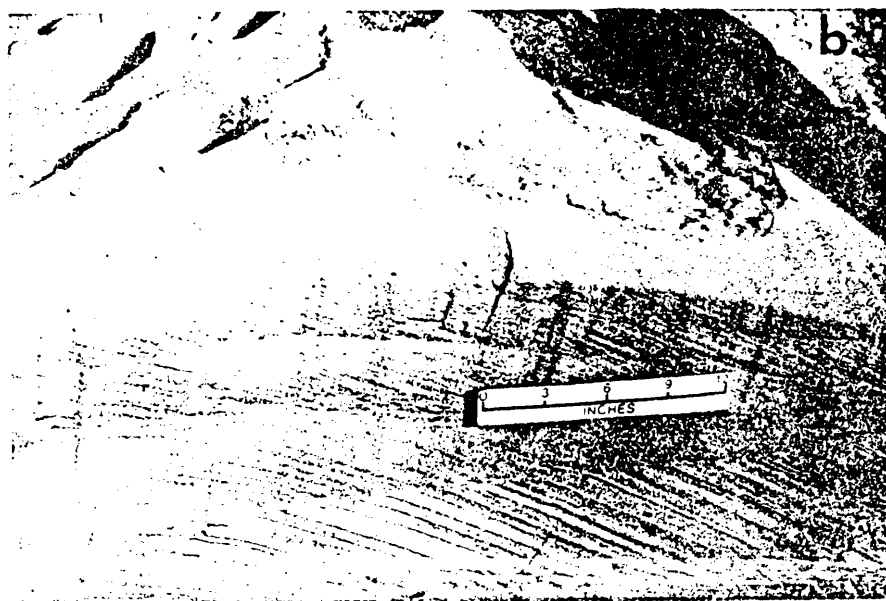
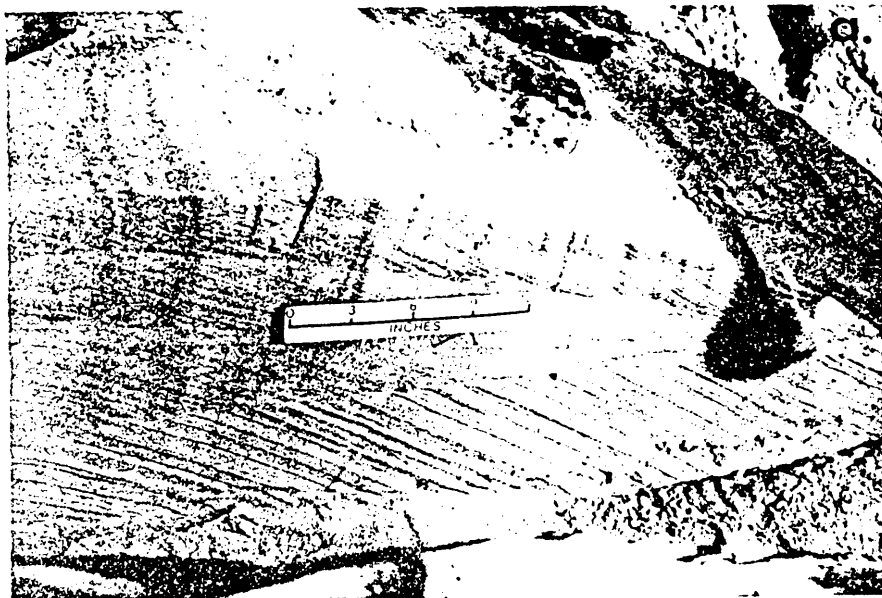


Figure 12a, b.--Wedge-planar cross-strata (a, b). Bank exposing section of sand-wave deposits near Puerto Páez on Rio Orinoco.

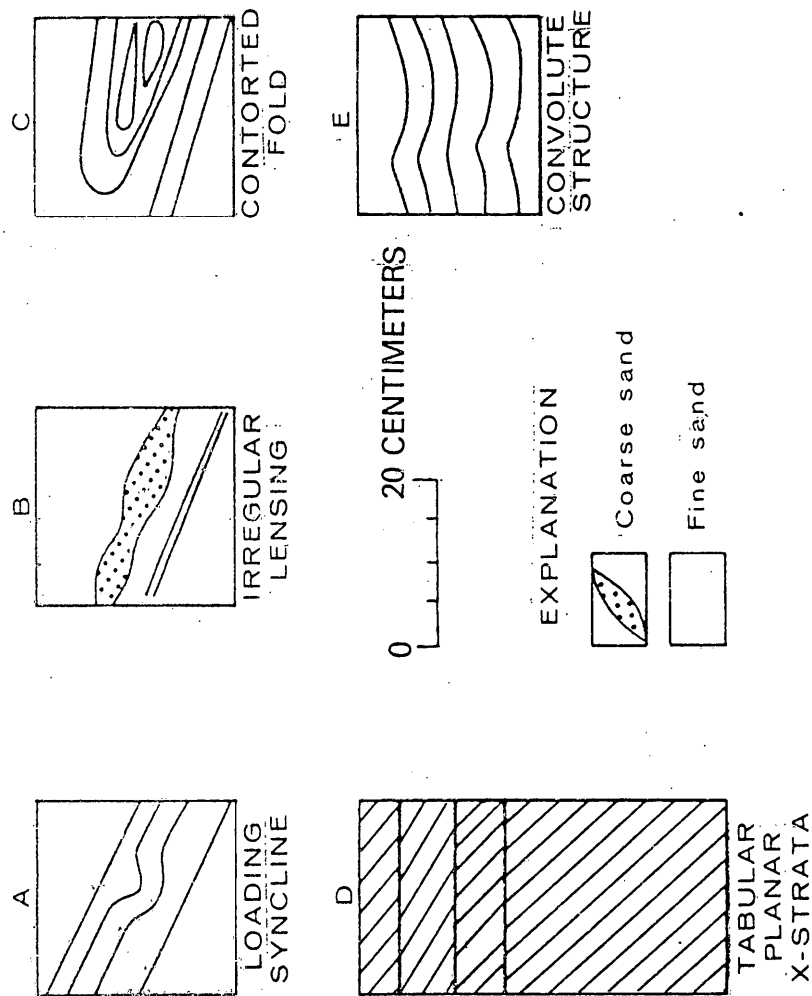


Figure 13a-e.--Minor sedimentary structures (a-e), exposed on face of bar in center of Rio Orinoco, 2 km downstream from Puerto Ayacucho.

Fig. 13

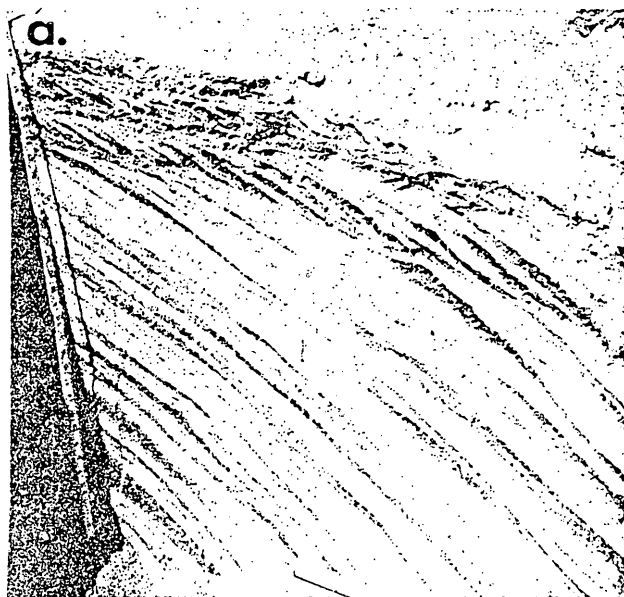
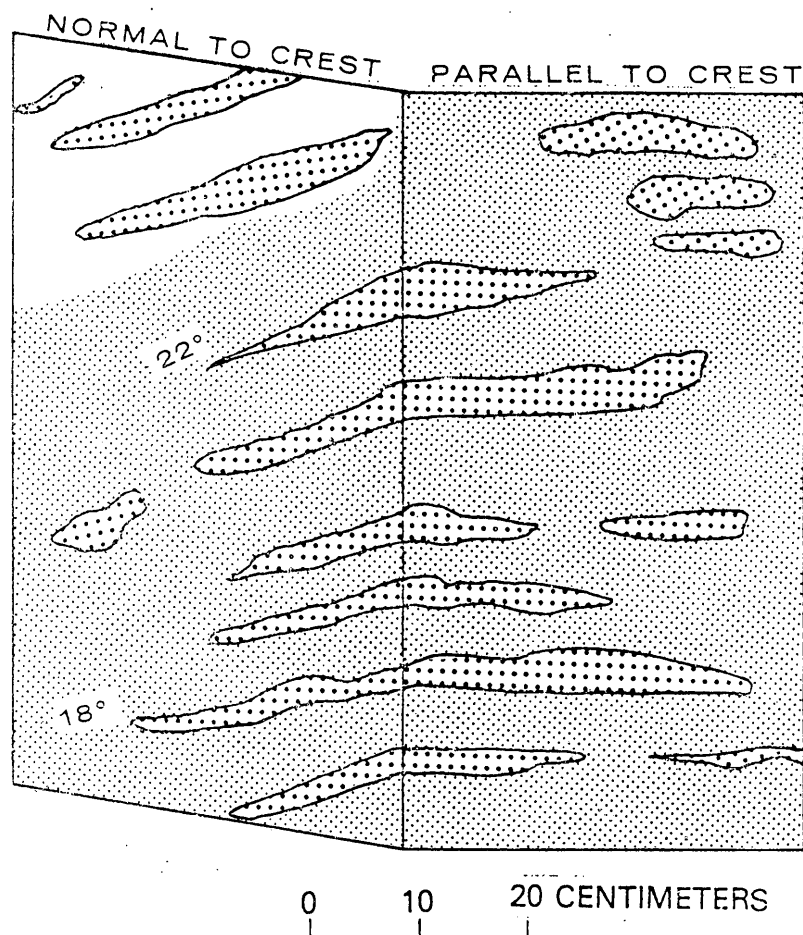


Figure 14a, b.--Lenticular laminae and lenses or flow toes (a) of coarse sand (dark) in foresets of sand-wave deposits, including folds and low-angle faults (b). Rio Orinoco, 2 km downstream from Puerto Ayacucho, center bar.

CEIBA ISLAND, STATION 401



EXPLANATION

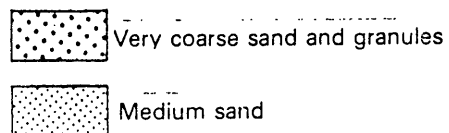


Figure 15.--Alternating coarse- and fine-grained sand laminae and lenses in sand-wave deposits, Rio Orinoco at Isla Ceiba (station 401, km 1269).



Figure 16.--Sand-flow toes at base of foresets, sand-wave deposits.
Right bank of Rio Orinoco, 2 km downstream from Puerto
Ayacucho. Photo by Lois Hernández.

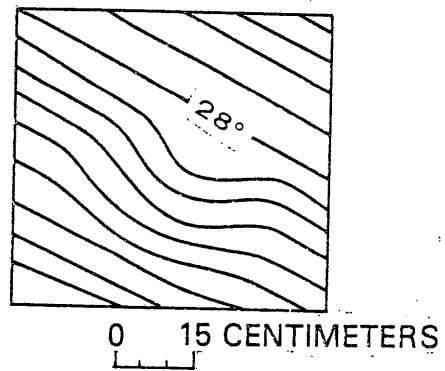


Figure 17. Penecontemporaneous sag or fold, probably caused by loading during deposition. Right bank of Rio Orinoco near Curiquima.

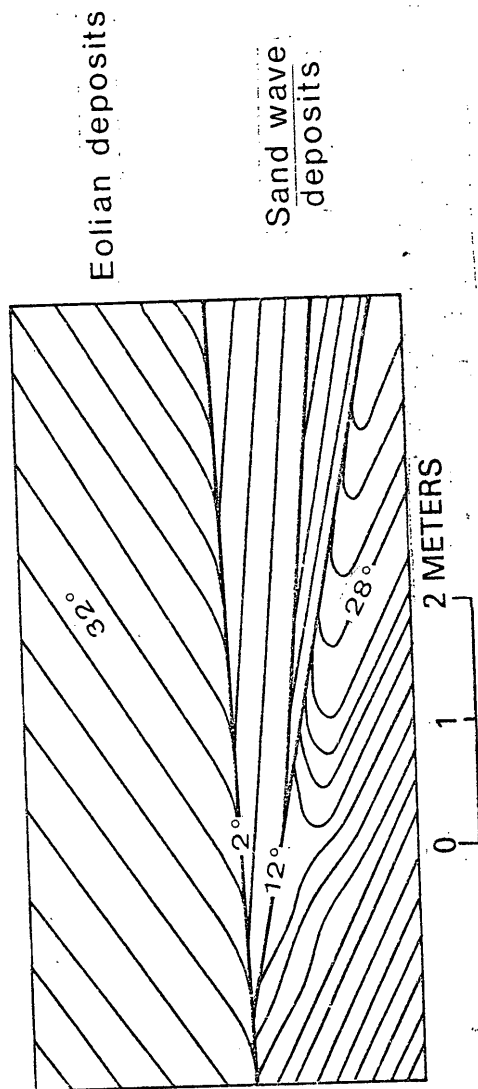


Figure 18.--Recumbent fold, probably result of drag by sand load during deposition of overlying foresets. Updip-dipping eolian foresets above sand-wave deposits dipping down river. Rio Cuchivero near mouth.

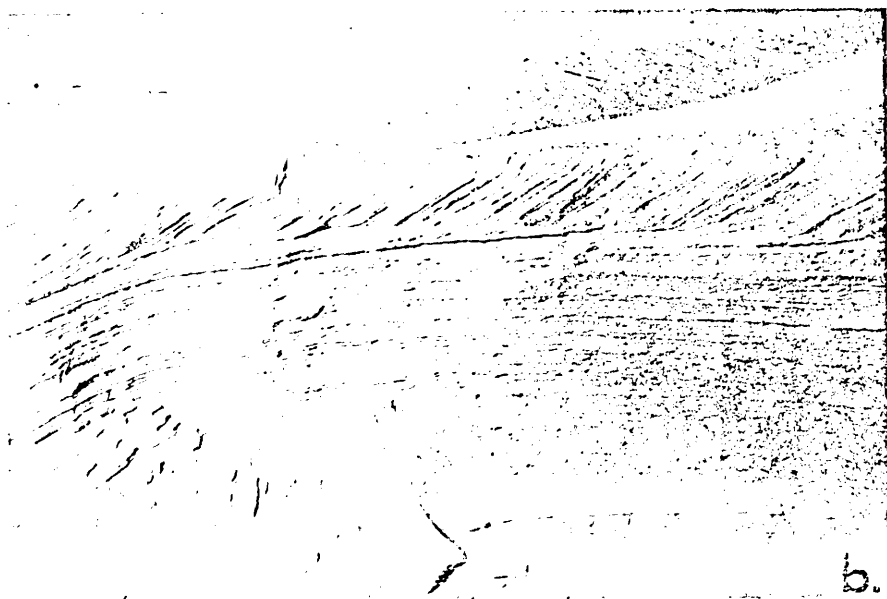


Figure 19a, b.--Climbing megaripple structure on large scale, face of sand bar on right bank of Rio Orinoco, upstream from Rio Cuchivero. Foreset dips are down river parallel to current movement. Thickness of set about 3 meters.

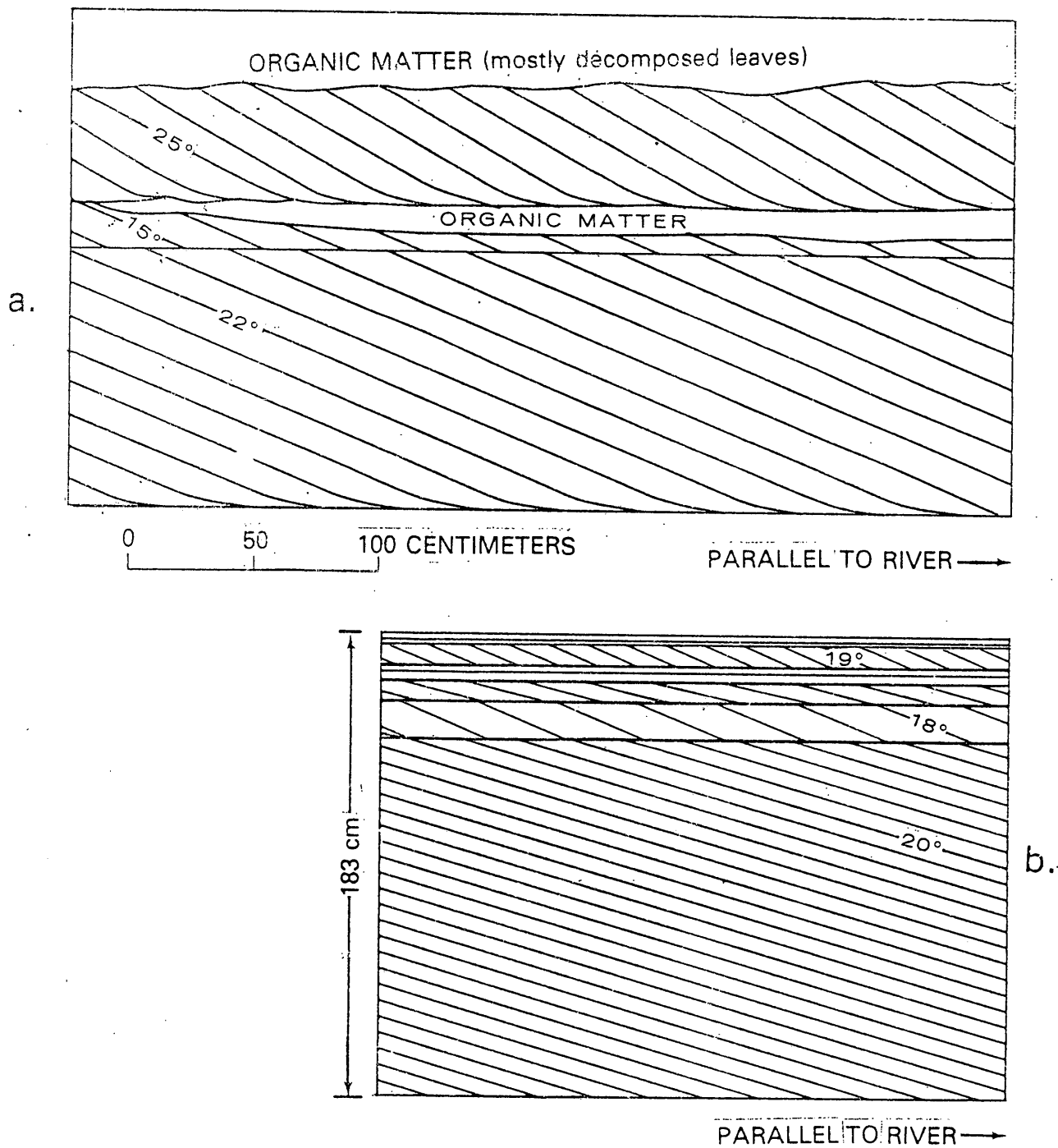
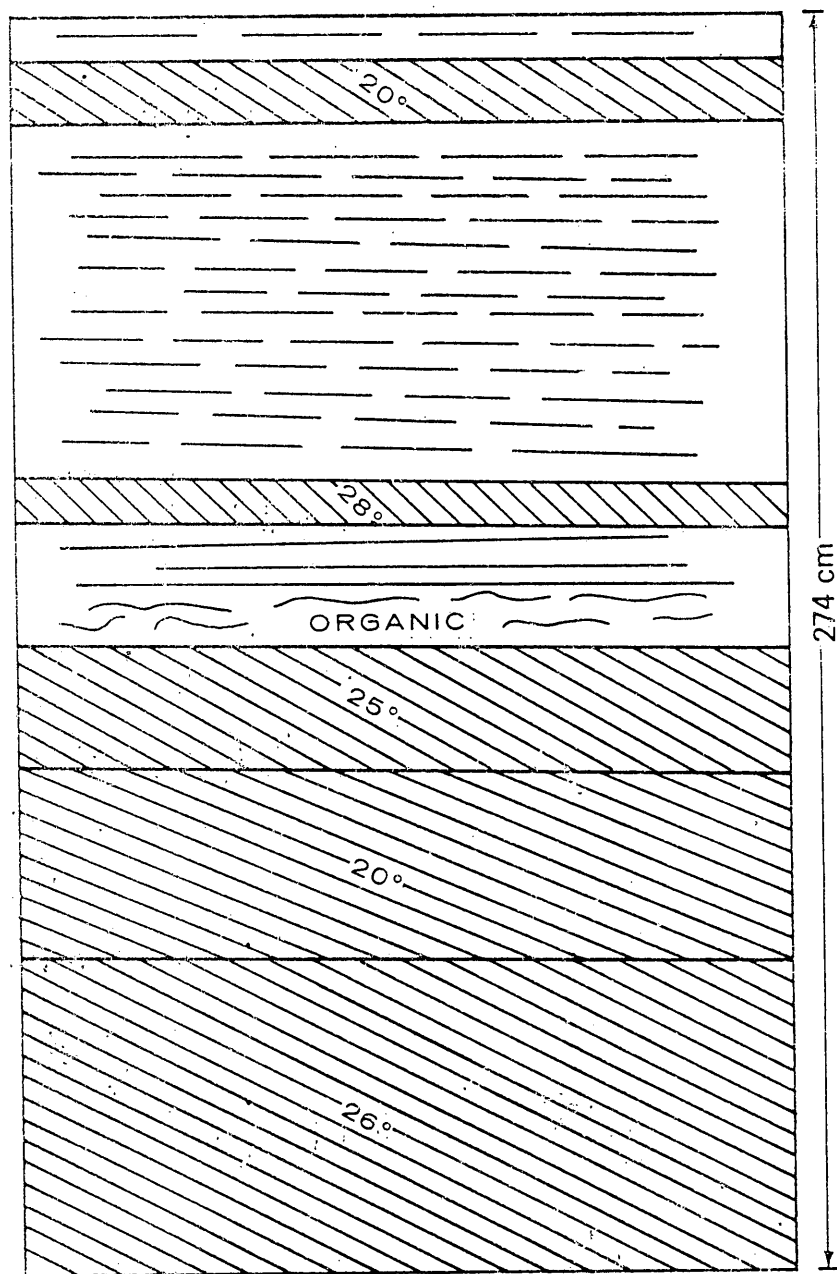


Figure 20a, b.--Flat beds and lenses of carbonaceous matter among tabular-planar sets of sand. Rio Parguaza near mouth, left bank.

Fig. 20a



EXPLANATION

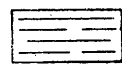
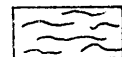
-  Fine sand forsets
-  Fine sand structureless
-  Organic debris and twigs

Figure 21.--Organic matter (leaves and twigs) among tabular-planar sets of cross-stratified sand-wave deposits. Mouth of Rio Meta on left bank of Rio Orinoco at Puerto Páez.

Fig. 21



Figure 22.--Eolian dune on surface of sand-wave deposits. Rio Orinoco at Punta Brava, 11 km above Rio Cuchivero.