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ANTHROPOGENIC AND ENVIRONMENTAL IMPLICATIONS OF DELTAIC RIVERS: A CASE STUDY OF RIVER BASINS IN CAMEROON

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ABSTRACT *The paper examines the anthropic and environmental implication of deltaic rivers and disagrees with scholars who have tended to attribute delta formation to shoreline progradation. The paper argues that scholars have left the natural continuity between delta, flood plain and alluvial plain only loosely defined. Using measurements of suspended load as indicators of denudation in drainage basin the paper concludes that deltas are a manifestation of intense degradational processes within drainage basins. Accelerated erosion is fundamental to the initiation of deltaic processes. Finally, it concludes that with better land use management practices in drainage basins, deltas will be slow to form.*

INTRODUCTION

Cameroon is drained from the Adamawa Plateau and from the Nyong – Sanaga divide along four main drainage basins: Atlantic, Congo, Niger and Chad basins. The river channels, which drain these basins, provide important pathways for the transportation of the weathered mantle in the form of solid transport load. The ultimate end of these land-eroded materials is the sea where they are deposited. It follows therefore that the river mouth where the speed of the arriving sediments become drastically reduced is a critical point between the land/sea interface. Alluvial plains and deltas are common landforms. This paper seeks to examine the patterns, causes and environmental aspects of deltaic features along the Atlantic coast of Cameroon (Figure 1).

OVERVIEW OF DELTAIC PROCESSES

The term delta was first used by the Greek Historian, Herodotus, more than 2500 years ago to describe the land created by the deposits of the River Nile at its mouth, which resembled the Greek letter △ (Delta). Subsequent studies define deltas as the sub-aerial and submerged contiguous sediment mass deposited in a body of water mainly by fluvial action. Most authors have tended to over emphasize that Delta formation originated from a prograda of the shoreline loosing sight of the fact that deltas are the manifestation of intense erosion inland. Their ultimate development is favoured by the absence of strong currents at the river mouth. Strong currents will disperse or redistribute the sediments brought in and so slow down the speed of development. The Douala Basin along the coast of Cameroon presents several deltaic banks at the mouth of the River Mungo, Wouri, Sanaga and Dibamba (Figure 1). The discharge of water from these basins is about 65 milliard M^3/year (Morin,1982). The zone contains extensive mudflats and marshes. This is due to the absence of strong waves and the long distance that waves must travel across the shallow seas before they reach the river mouths. Their energy is lost before they reach the mudflats and marshes. One must also remember that at the slack of the tide at high water there is a short period when there is little movement. This is ideal for silt deposition on marshy beaches and mudflats.

The generation of sediments is therefore crucial to delta formation.

GENERATION OF SUSPENDED LOAD IN RIVERS

Fragmented investigation have been undertaken to establish the suspended load of rivers in Cameroon. Olivry (1978) has tried to summarize these studies. The suspended load consists of fine materials carried in suspension by the river itself. The amount of the suspended load depends partly on the quantity of materials available to the river and partly on the total volume of water involved. The suspended load is a weight measure obtained either by evaporation or filtration of a known volume of water sample from a river and weighing the residue. It indicates the amount of weathered rock exported from a river basin by fluvial action. The Sanaga River has a basin surface area of 77.000km^2 upstream from Nachtigal. The soils are ferrallitic and have developed on metamorphic rock. Floristic composition is 70% savannah and 30% forests. Riparian forest galleries characterize the Savannahs. The average annual rainfall of 1.580mm in the basin, which produces an average discharge of 153 litres/second/km^2. This is a runoff coefficient of 30.5%. The low stage discharge is about 183m^3/s while at flood stage the discharge is 36.000m^3/s. Enormous erosion occurs in the basin. At the beginning of the rainy season (March to July) the increased volume of discharge is accompanied by increased turbidity, 10gm/m^3 to 100gm/m^3, with increased discharge from 200m^3/s to 1500m^3/s. The first rains occur after the dry season when the basin slopes have been deforested for cultivation using slash-and-burn farming practices and the savannahs have been burnt to stimulate a flush of vegetation for natural pastures. At the onset of the rains the soils are greatly pulverized by farmers as the basin becomes bare of vegetation in most areas. The first rains therefore cause severe erosion. From July to August, discharge increases rapidly while the discharge of suspended sediments load falls to about 40gm/m^3 as the vegetation becomes more established (Figure 2). By the end of the rainy season, turbidity falls markedly. Erosion becomes limited only to stream banks and beds. At Nachtigal, the suspended load is about 28 tons/km^2/year. This is an approximate load of 58gm/m^3 or an approximate 2,150,000 tons/year in the entire Sanaga basin (Figure 2).

The River Mbam is a tributary of the River Sanaga. Upstream from Goura the drainage basin has a surface area of 12,300km^2. The Geology is Precambrian metamorphic rocks. However, 12% of the basin area is composed of basalts and trachytes. The vegetation is mainly savannah with riparian forest galleries. The relief is steep and there is intense demographic pressure on land. Cultivation associated with bush burning is intense and overgrazing is common in the basin. The river discharges an average water volume of 17 litres/second/km^2 for an average annual rainfall of 1.780mm. The runoff coefficient is 32%. Low stage and flood stage discharges are 80.4m^3/s and 2.540m^3/s respectively. Turbidity increases rapidly at the beginning of the rainy season to a maximum (300 to 420gm/m^3) in July and August. In the heart of the wet season daily concentrations vary between 150 and 250gm/m^3. These concentrations remain close to 100gm/m^3 up to November.

The Mungo and the Wouri River basins have had little hydrological studies. These rivers originate from the West Cameroon Highlands, and their basins are intensively cultivated. Slash-and-burn shifting cultivation has degraded the forests in these basins.

MORPHOGENESIS AND ANTHROPOGENESIS

Deltaic development is primarily due to land degradation and hence environment deterioration (Ojany, 1986). It is this accelerated erosion that promote a high discharge of sediments into the oceans and [illegible] water today. This also indicates diminution of water availability as increased surface runoff and decrease infiltration, which is a necessary condition for groundwater recharge. The history of the Nile waters attests to this, as does the literature on deltas, which in all cases records accelerated morphological changes especially since the Holocene times. It is possible to conclude too that these increased sediment yields are mainly due to increase anthropogenic activities on land, especially cultivation. Land use in deltaic river basins of Cameroon lucidly supports the above conclusions. A land use history is necessary to clarify this assertion. In the forested southern portion of the Sanaga Basin and the Dibamba Basin, the upper part of the thick silt or silty-loam layer often contains charcoal, charred palm nuts, potsherds and ceramics. The oldest age for the charcoal indicating the human interference with the forest dates back to 2900-3000 years BC (Kadomura, 1984). This is probably contemporaneous with the beginning of "Bantu migration" into the forest areas from the supposed homeland in the Cameroon-Nigeria border. Similar dates are also reported by de Maret (1982) for the forest area around Yaounde. In the West Cameroon Highlands, Tumara (1986) suggests that important degradation of forest vegetation began about 2000 years B.C. In the Yaounde-Ebolowa area or south Cameroon plateau a notable retreat of closed forest in this part of the Sanaga Basin began at 350-300 years B.C as a result of massive and successive migrations of agrarian populations into the semi- deciduous forests (Haruki, 1984). Slash –and -burn agriculture has been the main cause. The degradation of the forests toward the present day conditions has been accelerating since the early 20th century following the expansion of roads into forests, logging and commercial tree crop plantations. Kadomura (1986) has established that the anthropogenic transformation of the forest by farming practices and livestock raising intensified since 300 to 350 years B.C. The beginning of the prevalent use of iron implements in these river basins dates back 1000 years B.C. Vegetation destruction accompanied by soil degradation and sediment transport certainly are major contributing factors to the building of deltaic banks at the mouths of these river basins (See Table 1).

Table 1: Characteristics of Erosion in the Mbam Basin.

YEAR	1970	1971	1972	1973	Average
Total transport of sediments (millions of tons).	3.408	2.792	2.513	2.492	2.801
Discharge volume (m^3/s)	682	562	524	528	574
Average concentration of sediments (9/m^3)	158	158	152	150	154.5
Degradation rate (tons/km^2/year)	81	66	59	59	66
Equivalent depth of soil eroded (10^{-2}mm)	6.2	5.1	4.5	4.5	5.1

Source: Olivry (1978).

Paleocene and Middle Eocene deposits of soft sandstone, sand, clay and ferniginous crusts make up the inland margin of the estuarine – deltaic coast. Mio – Pliocene sands and clay deposits form the younger part of the plain from where the deltaic banks project into the sea. This area is characterized by the absence of any marked relief and a gentle seaward slope of 0.5 to 1.0%.

Sandstone and clay sediments in the Douala basin (deltaic-estuarine zone) date to the Paleocene when the area was occupied by a shallow sea, which facilitated the build up of deltaic banks. Nougier (1980) has established that subsequent marine regression occurred during the upper Eocene-Oligocene. A later marine transgression during the Miocene affected the Tiko-Missellele-Bonaberi plain during the Plio-Quaternary. The low-lying regions at the Wouri-Mungo consequently assumed a low and ragged coastline characterized by mangrove swamps and creeks (Morin, 1980). In summary, deltaic banks are characterized by Fluvio-Marine Quaternary alluviums and superficial deposits. The deposition of such sediments formed muddy banks. Red mangrove trees (Rhizophora racemosa) trees, which possess special silt roots and breathing roots, were perhaps the first plants to colonize these banks. The constant accumulation of mud and sediments continue to raise the banks. The red mangrove community eventually gives way to white mangrove trees (Avicennia germinans), which prefer higher and drier ground. New mud banks are continuously being formed further out into the shallow sea, so that the old banks are gradually converted into firm ground in inland areas. These areas were eventually raised well above high tide level and a more normal soil developed. The white mangrove was then slowly replaced by a large number of different trees, shrubs, herbs, ferns and climbers.

Rhizophora racemosa is associated with the rare occurrence of trees such as Nypa fructitans and Guibortia demensei, and ferns such as Acrostichum aureum. Thorn bushes include Drepanocarpus species and Pandanus parvicentralis nains while secondary formation include Hibiscus tiliceus. Guibortia demensei, Drepanocarpus lunatus, Pandanus candelabrum and Phoenix reclinata. Zones liable to daily inundation are colonized by Nypa fructicans. Raised banks of meanders (Figure 3) are colonized by Hibiscus tiliceus, Acrotichum aureum and Drepanocarpus lunatus among others.

Transition zones between continental formations and swamps are colonized by Avicennia nitida. Out of the inter-tidal zone the rarely flooded clay soils are colonized by a low strata forest (4-8m) of Carapa procera, Raphia nitida, cynometra mannli, Dalbergia spp and Drepanocarpus lunatus. Loamy sands and sandy loams in the Peaty areas have a stratified vegetation of Rhizophora harisonii, Pandanus candelabrum, Conocarpus erectus and a herbaceous undergrowth. Creek banks are dominated by Rhizophora harisonii, which seems to show tolerance to saline soils. Fresh water reaches of creeks are dominated by Phoenix reclinata and Rhaphia palma pinus (Morin and Kuete. 1989; Keute, 1998).

INTERACTION OF ANTHROPIC AND HYDRO-GEOMORPHIC PROCESSESS

Figure 4 presents the thalweg profiles of the River Sanaga and its tributaries. These take their rise from the Adamawa Plateaux and the Western Highlands. In general the profiles are concave and steep. The upper courses are broken by steep escarpments with slopes above 25% such as on the tide, Mungo and Nkam. The middle courses are equally steep (3.8% to 5.15% slopes). These slopes soon flatten out rapidly as the rivers approach the South Cameroon Plateaux and the coastal plain. Typically the profiles present a succession of plateaux sections and abrupt drops of calm reaches and rapids.

The fluvial regimes (Figure 4) conform to the seasonal variation in rainfall. Peak flows coincide with the peak of the wet season and the low stage to the heart of the dry season. The Wouri River has a peak discharge of 1.425m^3/s and a low stage of 49m^3/s. The average discharge is about 311m^3/s. Deforestation of this drainage basin and intensive cultivation combine with a discharge per unit surface area of 173 litres/second/km^2 and the steep gradients of the upper slopes to cause intense erosion and transportation of the soil. River Mungo has a flood peak of $636m^3/s$ and a discharge of $164m^3/s$ at low stage. The basin has intensive land use systems that have degraded both the soil and the original forest cover. Flood discharge per basin surface area is 2,631 litres/s/km^2. River Sanaga on the other hand has an average degradation of 28tons/km^2/year. Upper segments of the tributary basins suffer from intense grazing by cattle, bush burning and cultivation. The forested middle and lower portions are being degraded by deforestation, logging and slash, – and –burn shifting cultivation.

ANALYSIS OF THALWEG PROFILES

The thalweg (= valley way) of a river is the curve of the river course from source to mouth. It is a profile along the winding line of the valley floor. Figure 4 shows the form of the curve of the river which reveals that:-

The concave graded curve of the tributaries and the main rivers, in this case steepness of the curves, taken in conjunction with the volume, may betray early or late maturing.

Convexities in the Sanaga thalweg at Betare Oya and between Kikot and Nachtigale, may be due to arrested grading by resistant rocks.

Convexities in the Mungo thalweg may be due to rejuvenation; the curves in this case above and below the knick point are graded. This may be true for the Sanaga tributary upstream of Mbakao.

Prematurely flat reaches or sudden changes from steep to flat slopes downstream in the Sanaga thalweg are due to upstream encroachment of alluviation. This is because the cross section of valley floors is flat (alluvial) below and steep-sided and narrower above the breaks.

It is necessary to emphasize that map studies of this type are only preliminary steps in morphological analysis and that the reality of knick points must be checked in the field by careful survey before they are accepted and before they are called in evidence for any interpretation of geomorphological history.

It is important to examine the significance of thalweg profiles of the rivers on sediments transport and erosion potential. The attainment of maturity is reached earlier in the large rivers than in small and in main streams than in tributaries. On the other hand very small streams and headwater streams (figure 4), never having reached a condition of grade, usually contain irregularities of little significance. It has been a fallacy that the speed of flow of the main stream must be less than that of its mountain tributaries. These are often steeper, run over a more irregular bed and consequently have a much greater element of turbulent flow. This is frequently apparent to the eye, but turbulence must not be mistaken for mean velocity. The eddies and splashing of a mountain stream give an appearance of rapid flow, and it is true that individual whirls in the water may indeed be very fast and can cause enormous bank and bed erosion, that is, detachment of rock and soil particles. The point being underlined here is that eddies do not contribute to the mean velocity of flow and therefore to the competence of the stream to transport eroded material. Competence depends on the volume of water and velocity of flow. This is because water motion in turbulent flow is circular, although there is a component on one side of the circle flowing fast downstream. The component on the other side is flowing equally fastback upstream.

The flow of the main river (figure 4) with smoother bed and banks is generally less turbulent. The apparent speed of flow seems less, but the mean velocity and discharge is relatively high. When the discharge of the tributaries exceeds that of the main river such as is the case of the Sanaga, the water first deepens and then floods. From the South Cameroon plateaux and the coastal plain these rivers develop a very high potential to transport eroded materials in suspension. The turbulence in the tributary rivers can be very important because the speed of moving water within an eddy or cascading over a rock can be sufficiently high to cause the entrainment of small particles. This is one of the factors which, after heavy rains, helps to account for the muddy appearance of the main rivers not sufficiently turbulent themselves for entrainment to take place. Surface wash and runoff process entrain and provide transport for fine particles into streams and rivers where they enter directly into suspension. Very important factors leading to entrainment under these conditions are land use practices causing bare soils and the "explosive" effect of the impact of raindrops on bare soil. There are also other ways in which fine particles can become part of the suspended load of a stream, for example, when a bank is undercut and portions of soil or sub soil fall into the water. It follows that whereas the erosion velocity may account for the entrainment of only part of the suspended load, deposition is wholly controlled by the fall velocity as the rivers enter the shallow waters of the shore. For the mathematically minded, Stoke's law expresses the settling velocity for small spherical grains (McCullagh, 1978):

$$V = \frac{2 \times g r^3 (d_1 - d_2)}{9 \quad U}$$

Where V = the settling velocity

g = the acceleration of gravity

r = the radius of the particle

d_1 = the density of the particle

d_2 = the density of the liquid

U = the viscosity of the fluid.

This formula should be used with caution because it holds only for small particles, which are roughly spherical in shape. This is the case of materials constituting estuarine deltaic banks. Calculations for large particles and those of irregular shapes become much more complex.

The amount of material transported by a river can be very great. The total depends upon the size of the drainage area, the annual discharge of the system, the geological characteristics and structure through which the rivers pass and the anthropogenic factors accelerating soil erosion in the drainage basin. The generation and transportation of suspended sediment load by fluvial process within a drainage basin and their subsequent deposition as deltaic banks at the mouth of a river is a good example of one of the ways in which the works of man may greatly affect physical processes.

DISCUSSIONS

From the above observations it is difficult to know where to include deltas. Many of them are coastal, though others are found in lakes and coastal lagoons. Conditions favouring deltaic accumulation are:

- A large load of river sediment;
- Usually a large river, otherwise the action of the sea might disperse the sediments;
- Reasonably shallow water offshore, though the necessity of this really depends on the amount of sediment available and the strength of the marine erosion;
- A coast on which the wave energy is low, though here again how low. Low will depend on other factors such as sediment supply and tidal range; and
- A small tidal range. However, deltas can be built in areas of larger tidal range provided that conditions 3 and 4 above are met.

Deltas are fundamentally features of river deposition, not marine deposition, though marine sediments may be incorporated in their fronts and intercalculated with the river deposits if phases of subsidence alternate with phases of delta building. They develop basically because the velocity of a river diminishes fairly rapidly at its mouth (Stoke's Law), a condition which must have been accentuated during post-glacial rise of sea level, whereby deposition starts, probably aided by flocculation of the finer particles. Where the effect of salt water is felt, progradation ensues, which further reduces the gradient and so increases deposition by a positive feedback process (Ojany, 1986). The deltas of Cameroon are virtually continuations

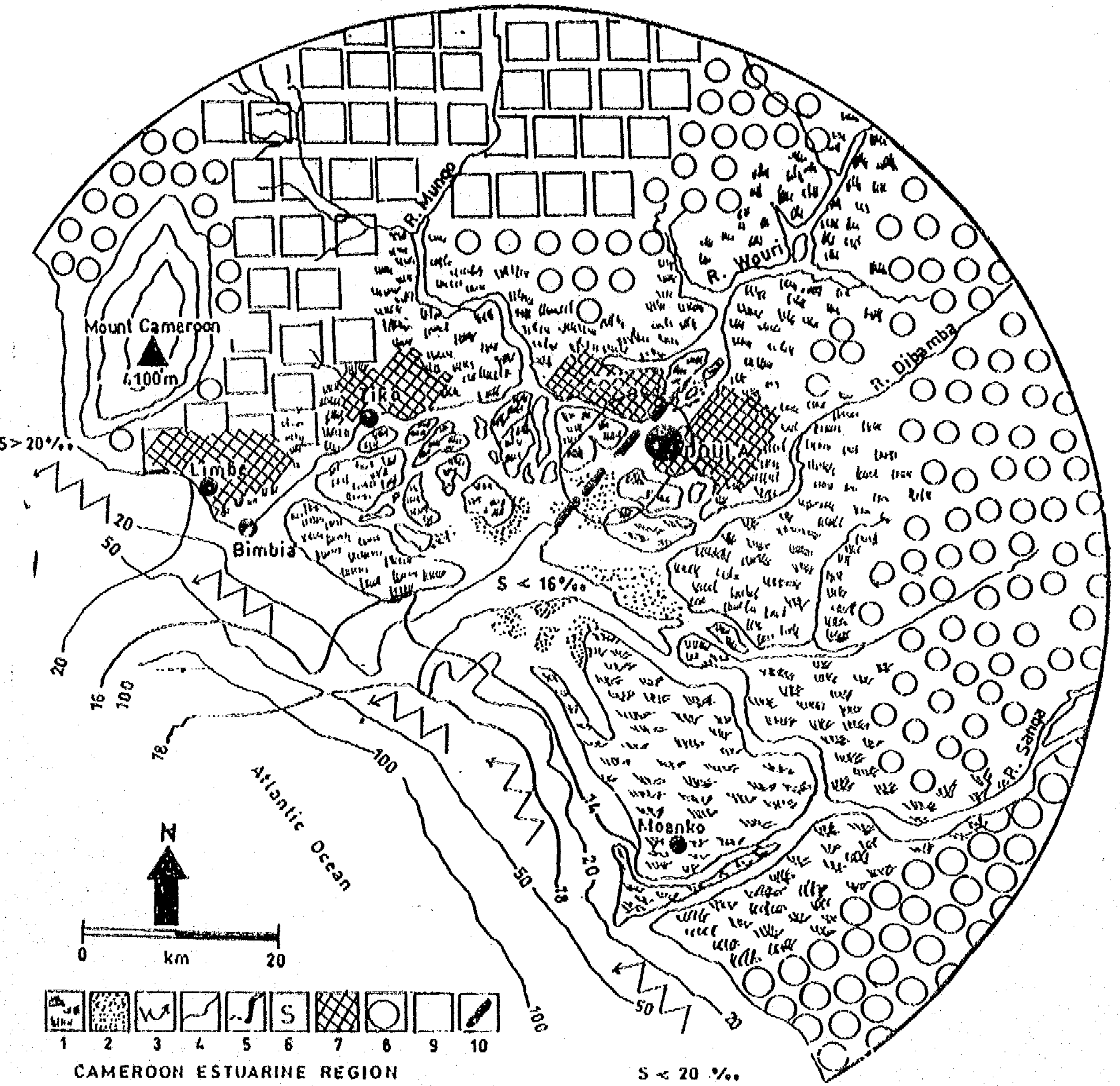
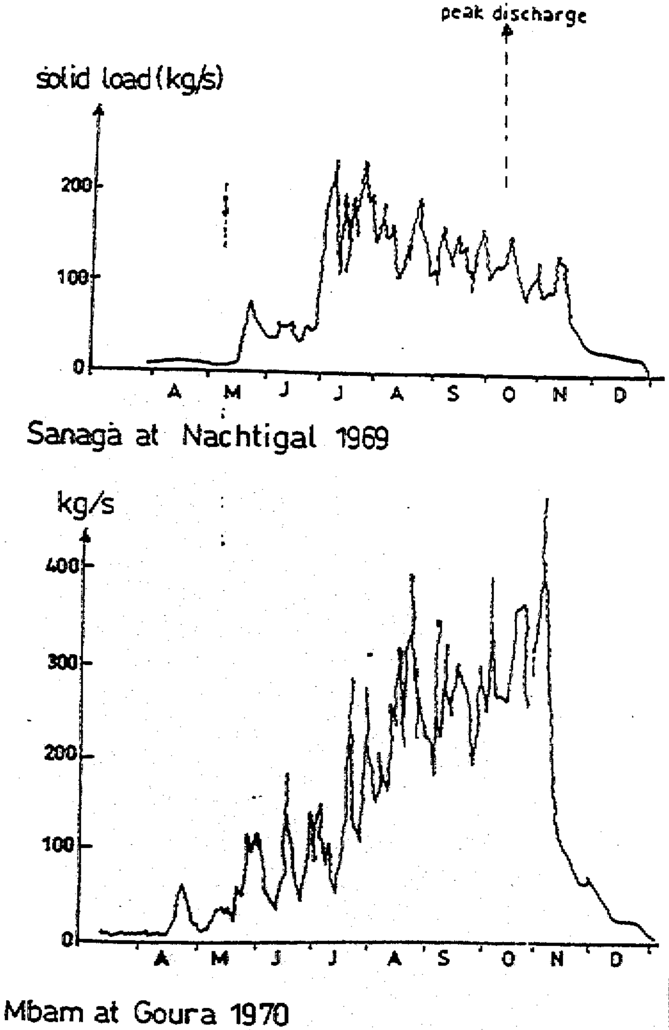


Fig.1: Anthropic stress on the mangrove ecosystem: 1. mangrove swamps, 2. sandbanks, 3. longshore drift, 4. isobath (m), 5. isohaline (‰), 6. salinity, 7. urban sprawl, 8. slash and burn cultivation, 9. agro-industrial-plantations, 10. on-going dredging and land reclamation



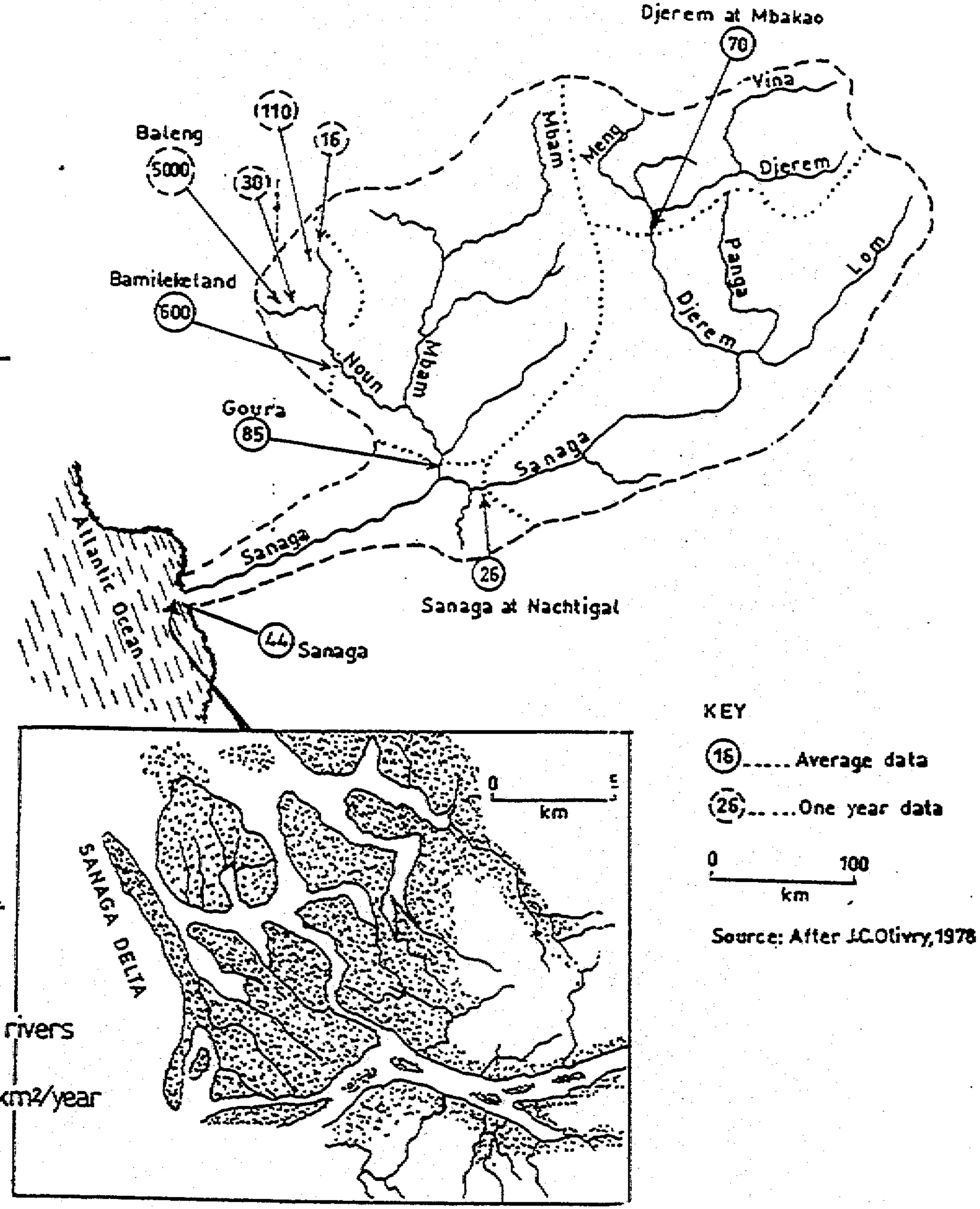


Fig.2a: Daily solid load of the Mbam and Sanaga rivers

Fig.2b: Estimated suspended sediment/load tons/km²/year in Sanaga Basin

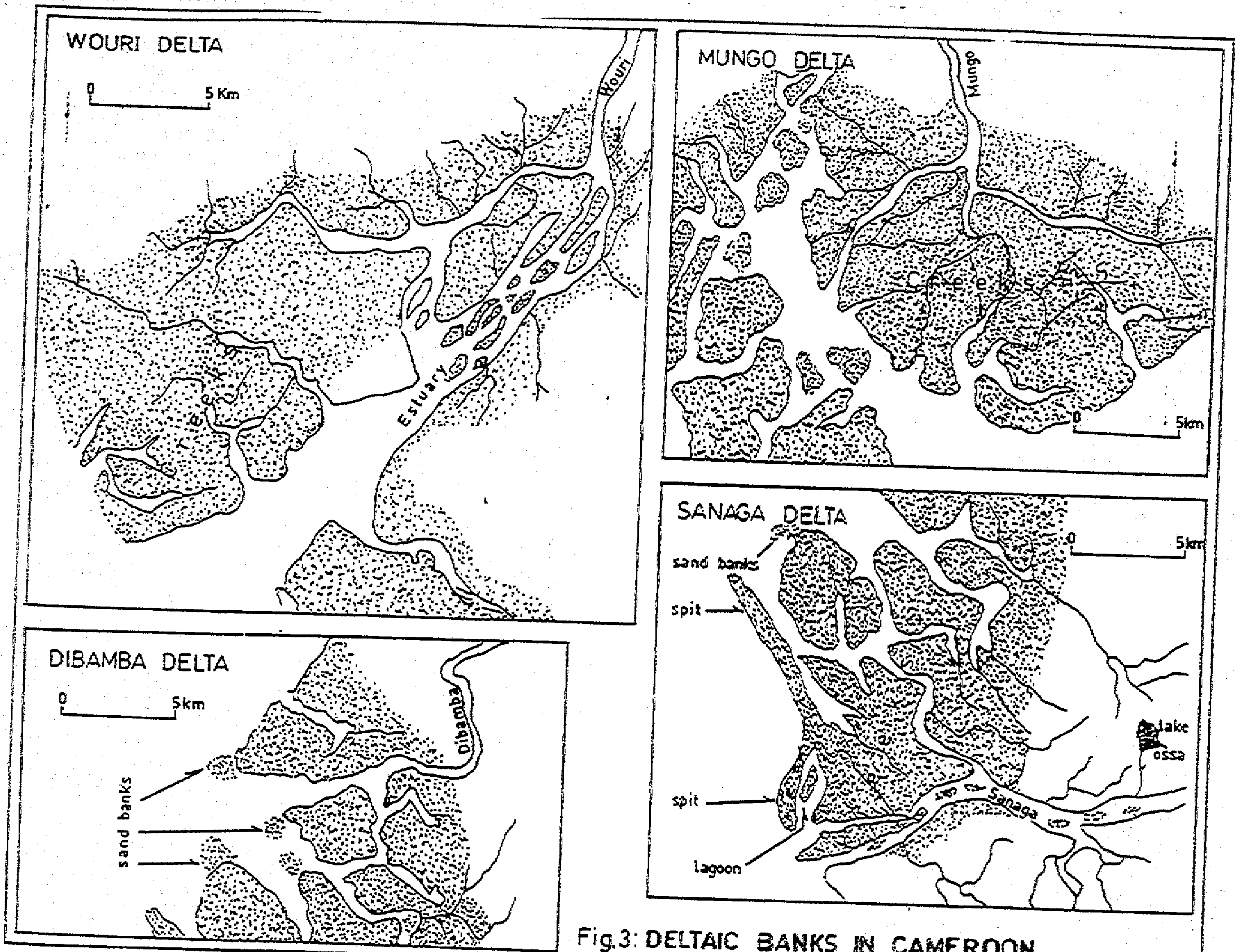
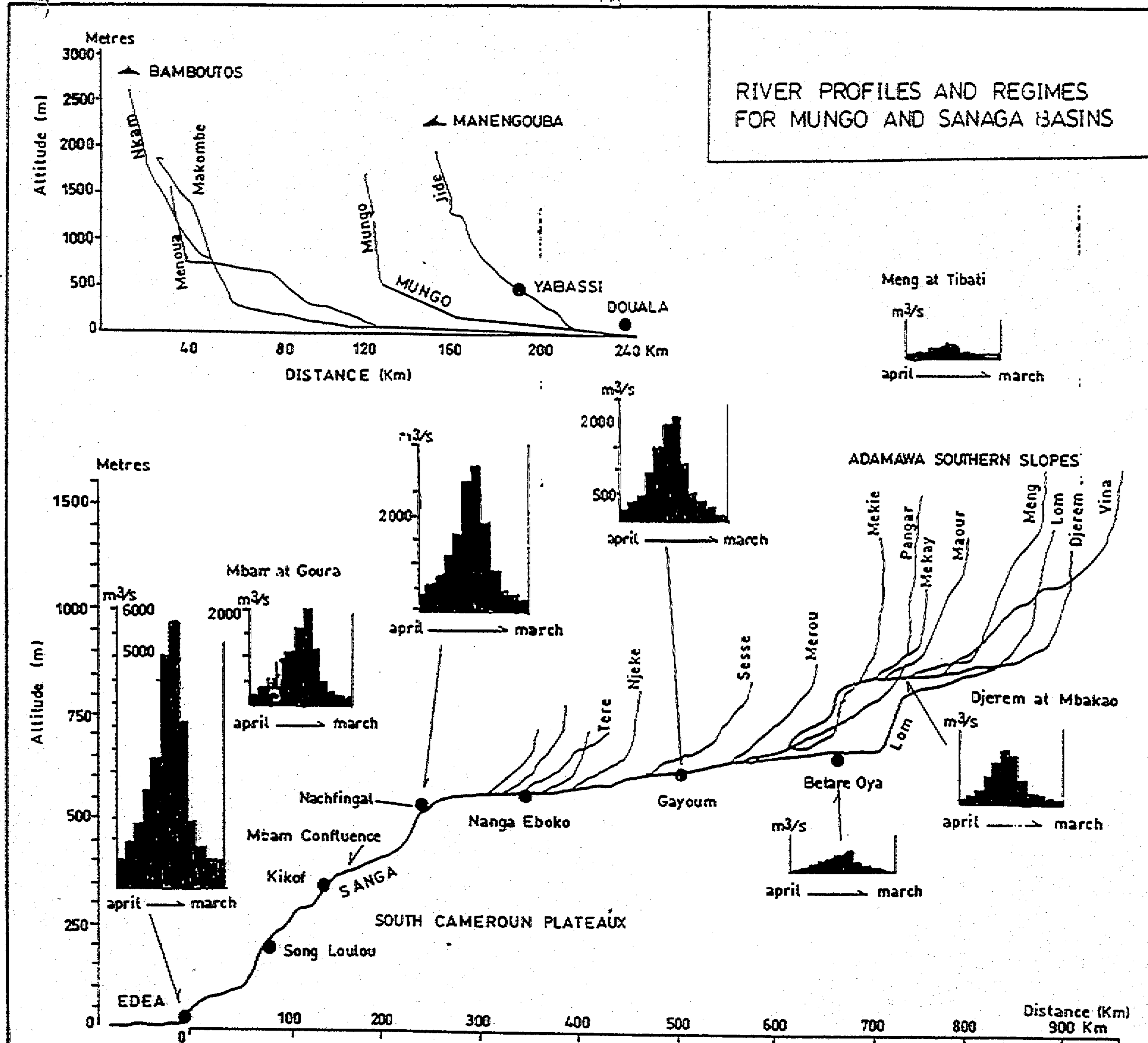


Fig.3: **DELTAIC BANKS IN CAMEROON**



RIVER PROFILES AND REGIMES FOR MUNGO AND SANAGA BASINS of the aggradation type of river floodplain due to the high weak destructive potential of sea waves.

The main fluvial factors involved in the formation of deltas are:

- Supply of a large sediment load and its particles size which is determined by a rivers regime and the source of the sediments within the river basin; and
- The potential of denudation agents within the drainage basin to provoke erosion and the competence of the rivers to transport the sediment load to the land/sea interfaces.
- In examining the above points, one environmental fact, which emerges, clearly is that accelerated erosion is an important factor in the promotion of deltaic bedding. The historical studies of the evolution of the River Mississippi Basin eloquently illustrate that a sudden reduction in the supply of sediment will alter the pattern of deltaic bedding shaping the delta (McCullagh, 1978; Oojary, 1986)

CONCLUSION

This paper has used evidence from the amount of sediment load emanating from river basins to establish the fact that delta development is primarily due to anthropogenic degradation of the land. Deltas are therefore indicative of environmental deterioration in the river basins concerned. Present day accelerated erosion in the Wouri basin is affecting Douala seaport, which is, located some 24km upstream from the sea on the left bank of the river. Dredging is constantly being carried out to a depth of nine meters in order to provide deep water for ships. Regular dredging attests to the intensity of anthropic degradation. This implies that with better land use management within the drainage basin, deltas should not be forming. For example, River Sanaga which in 1968 had a suspended sediment transport load of 2,330,000 tons and a dropping to 1,870,000 tons in 1969 following the construction of the Mbakao dam in one the major sub catchments (Morin, 1982).

REFERENCES

De Maret, J.(1982). New survey of archaeological research and dates for West Central Africa and North-Central Africa. Journ of Agri. Hist. Vol.23, p 1-15.

Haruki, M. (1984). Silviecological studies in the forest and savanna Zones of Cameroon. In Kadomura. (ed.), Natural and man-induced environmental changes in tropical Africa; case studies in Cameroon and Kenya. Hokkaido University, Sapporo. P. 75-91.

Kuete, M and Morin, S. (1989). Le Littoral Camerounaise: problémes morphologiques. Trav. de Lab. de Géographyisque Appliquee. Univ. Bordeaux III.

Kuete, M. (1982). Le milieu de l'ecosystéme mangrove: le cas de bouches du Cameroon. In J.A.S.S. Vol.1, No.1 Univ. of Buea.

Kadomura, H. (1984). Problems of past and recent environmental changes in the humid areas of Cameroon. In: (ed.) Natural and man-induced environmental changes in tropical Africa: case studies in Cameroon and Kenya. Hokkaido University, Sapporo. p. 7-20

McCullagh, P. (1978). Modern concepts in geomorphology. Science in Geography 6. Oxford Univ. Press, Oxford.

Morin, S. (1982). Notes d'hydrographie et hydrologie Camerounaises. Trav. et doc. Dept. de Géoge. Univ. de Yaounde.

Morin, S. (1980). Geology. In: Atlas of the United Republic of Cameroon. Editions J.A, Paris. p. 9-12.

Nougier, J. (1980). Geomorphology. In: Atlas of the United Republic of Cameroon. Editions J.A, Paris. p. 9-12.

Olivry, J.C. (1970). Transport solides en suspension au Cameroun. In: ONAREST Scientific papers. Vol. 1, No.1 p. 47-60.

Ojany, F. (1979). Tana River Delta and other Deltaic rivers in Kenya: A contribution in fluvial and environmental georomorphology and environmental changes in tropical Africa: Case studies in Cameroon and Kenya. Hokkaido University, Sapporo. p. 165-177.

Tamura, T. (1986). Regolith-stratigraphic study of late Quaternary environmental history in the West Cameroon Highlands and the Adamaoua Plateau. In:Kadomura, H. (ed.): Geomorphology and environmental changes in tropical Africa: Case studies in Cameroon and Kenya. Hokkaido University, Sapporo. p. 63-87.