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The influence of the trade winds on the coastal development of the Guianas at various scale levels: a synthesis

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Abstract

The coastal development of the Guianas is dominated by extensive, shoreface-attached and alongshore westward migrating mudbanks. The behaviour of these mudbanks is mainly determined by a combination of the large supply of Amazon-borne silt and clay and the trade wind generated wave action. In the front zone of the mudbanks, fluid mud is formed. As a result, the incoming waves are strongly attenuated and deposition is favoured. At their rear side, compacted clay deposits are eroded by waves. The mudbanks, migrating in this manner, are the driving mechanism in the development of the smallest coastal unit, which consists of a mudbank and the eastward adjacent interbank area.

Eisma et al. [Neth. J. Sea Res. 28 (1991) 181] has demonstrated that the frequency of the northeast trade wind, which blows towards the coast of the Guianas, in the windy season (January till April), shows a systematic change in time. For the period 1953–1986, there is evidence that the frequency of winds coming from directions between 50° and 80° (roughly east–northeast) increases. The same applies to the wind velocity from that direction. In the last 10 years a reversal of these trends appears to occur.

For a more or less east–west directed coastal section, e.g. the coastline of Suriname, a more easterly direction of the northeast trade wind results in an increased longshore wave energy flux in the coastal waters. This causes an increase in length of the mudbanks, at the detriment of the usually eroding interbank parts of the coast. This is evidenced by the large-scale coastal development during the related period, demonstrating an increasing length of the mudbanks and consequently an increasing net accretion. It is hypothesised that this development will reverse if the new trends in wind direction and velocity develop further.

At the geological scale, it is considered that a coincidence of a systematic increase of more northerly directed wind frequencies and a fall in sea level are responsible for the two erosive interruptions in the generally accreting coastal plain during the Young Holocene Period.

Keywords: coastal development; mudbanks; large-scale coastal behaviour; smallest coastal unit; trade wind

1. Introduction

The coast of the Guianas is part of the 1600 km long chenier coast between the embouchures of the Amazon River and the Orinoco River (Fig. 1). This coast is characterised by a wedge-shaped Holocene mud deposit, extending to the contour of 20 m depth. Beyond the minus 20 m contour line, the shelf bottom configuration and related sediments are to be considered a relic of the late Pleistocene and Holocene transgression.

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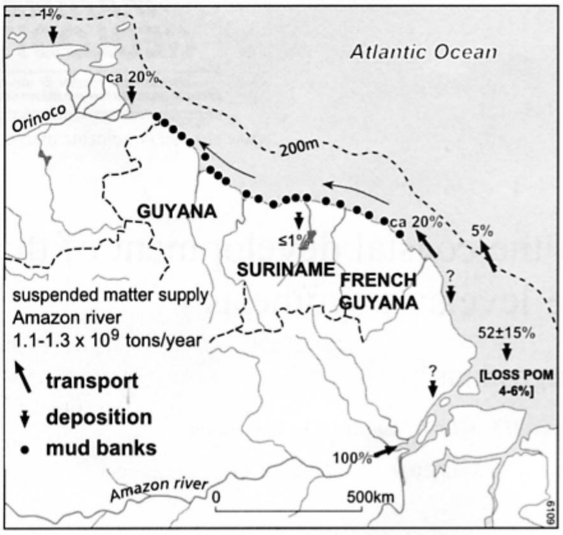

Fig. 1. Sketch map of the Amazon mud dispersal system. Percentages indicate the relative amounts of Amazon-borne mud, transported westward (long arrows) or deposited (short downward arrows) or, in the case of particulate organic matter (POM), mineralised in the different areas. Mudbanks along the coast are indicated by black dots (from Delf Hydraulics Laboratory, 1962). After Eisma et al. (1991).

On top of the mud wedge, extensive shoreface-attached mudbanks migrate steadily alongshore to the West. In Fig. 1 they are indicated as black dots. The muddy sediment originates from the Amazon River (Fig. 1). On a yearly basis this river discharges more than one billion tons of fine sediment into the Atlantic Ocean (Meade et al., 1985). About 20% of this mud supply is transported westward along the North coast of South America (Eisma et al., 1991), roughly 150 million tons in suspension and 100 million tons stored in the migrating mudbanks (Wells and Coleman, 1978). The mudbanks are separated by deeper interbank areas where cheniers develop, if sufficient sand and/or shells are available (Augustinus, 1978, 1980; Augustinus et al., 1989). At the terrestrial side of the coastal system, mangrove forests grade into brackish and freshwater swamps.

Generally, coastal development can be considered at different spatial and temporal scales. This has been exemplified for the coast of Suriname by Augustinus (1993). Three different scale levels are distinguished: a meso-scale, the lowest level at which a coast can be considered as a unit, a macro-scale and a mega-scale. Coastal behaviour at meso-scale comprises the actual development of coastal sections (km's to tens of kilometers) over a period of months to a few decades. At a macro-scale, coastal behaviour comprises the development of the entire Suriname coast on a time scale of decades to a few centuries. Meta-scale coastal behaviour comprises the (geological) evolution of the coastal plain on a temporal scale of centuries to millennia (Augustinus, 1993). The three scale levels are characterised by specific patterns of accretion and erosion. Using a systems approach, the coastal development at these three scale levels can be described. An important problem is, however, how the coastal development at a higher scale can be explained from the development at a lower scale. Therefore the driving forces of the respective scale-bound coastal system must be known. In this paper it is considered that the trade wind plays a key role at all three scale-levels and is the driving force at the macro-scale.

2. Methods

The coastal development study at various scale levels is based on extensive field observations and measurements in the past, complemented by the interpretation of aerial photographs (Augustinus, 1978, 1980, 1993; Augustinus et al., 1989).

To investigate the behaviour of the coastline in time and space the coast of Suriname has been divided into 339 sections, each with a width of 1 km. Net erosion/accumulation of the coast was measured by comparison of the various coastlines deduced from the available series of air photographs (1947/1948–1957–1966–1970 and 1981). The conversion of this linear displacement of the coast into tons per year has been achieved by multiplying the area of displacement in landward (−) or in seaward (+) direction for every km section, by the distance of displacement times the tangent of the nearshore slope (till the 3 m depth contour), and subsequently with the specific density of fresh clay (1850 kg of dry sediment per m^3 of bulk wet sediment). A generalised slope angle of 0.6° has been used. The length of the mudbanks is determined in alongshore direction in the upper intertidal part of the banks.

Wind data, collected at the coastal station Rochambeau/Kourou (French Guiana), has been analysed for the period 1953–1986 (Eisma et al., 1991). Data has been used which is measured at 12 o'clock at an altitude of 500 m, to avoid the effect of land/sea breeze as much as possible. Wind frequency and wind force have been determined for the windy season (January to April), because the physical coastal changes appear to be restricted to this period. The recently obtained wind data of 1991–2001 are treated in the same way.

2.1. The lowest scale level

At the lowest scale level, the behaviour of the Suriname coast is dominated by the mudbanks, which steadily migrate westward, due to deposition at the west side and erosion at the east side (Fig. 2). Suspended silt is transported by a westward coastal current with maximum velocities of 1 m s^{-1} at the surface and of 0.10–0.35 m sec^{-1} near the bottom. The bi-diurnal tide, average amplitude 1.8 m, approaches the coast more or less perpendicular. Tidal currents are only important in the mouths of rivers.

As a consequence of the high content of suspended particles in the coastal waters, regularly, fluid mud is formed and deposited at the western side of the mudbanks, especially in periods of strong trade winds when water turbulence is high. The waves are generated by the northeast trade wind. When they approach the shore over a mudbank, they are transformed into solitary waves. These push the fluid mud further shoreward (Wells and Coleman, 1981). In the mean time, they lose their energy due to the high internal friction the orbital movement experiences in the fluid mud. Therefore, deposition at the west flank of the mudbanks is further increased.

Going eastward across a mudbank, the originally fluid mud is compacting. At the intertidal part, mangroves start growing and subtract water from the sediment, thus intensifying the compaction process. At the east side of a bank, the muddy sediment has matured to young clay, which has lost its wave attenuating property. Therefore, the east side of a mudbank is subject to erosion. Due to sedimentation at the west side and erosion at the east side, the mudbanks migrate westward.

Between the mudbanks, the waves propagate towards the shoreline, until they break. Usually a chenier is formed. The sand is supplied by local rivers and/or is winnowed from the muddy, Amazon-borne sediments, which contain some 2% of sand. Shells are of local origin. Sand and shells are transported mainly by beachdrift and, with continuing erosion, by overwash processes to the landward side of the chenier. Cell circulation is rare in this environment and, if present, weakly developed.

Just beyond the outer tip of a mudbank, the westward transported chenier sediment is not replen-

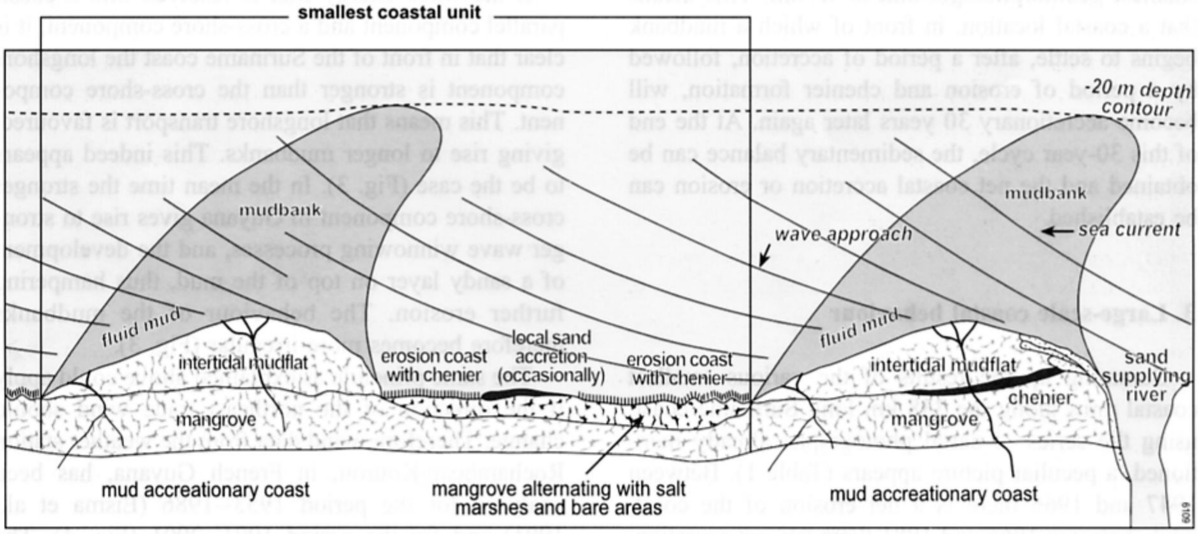

Fig. 2. Sketch map, not to scale, of the coastal system in Suriname. The smallest coastal unit, consisting of a mudbank and an eastward adjacent interbank area, is indicated. After Augustinus (2003).

ished. The supplement of coarse sediment is prevented because over the nose of a mudbank the waves are attenuated by fluid mud, thus inactivating the chenier behind the mudbank. Severe coastal erosion is the result. Further to the west, where the east side of the next mudbank is eroded, space is created for the westward extension of the chenier. The behaviour of the cheniers appears to be highly determined by the migrating mudbanks.

In summary, the Suriname coast can be considered as a coastal system characterised by a westward shifting alternation of accreting and eroding parts. The smallest coastal unit reflecting this principle consists of a coastal stretch characterised by a mudbank, with an erosive eastward part where a chenier develops (Fig. 2). The related behaviour of the coastline demonstrates seaward and landward shifting in the order of a few tens of meters per year, with local peaks of over 200 m in the seaward direction and over 100 m in the landward direction. The most important drivers of the migrating coastal system at this scale are the continuous silt transport and the wave action, which is determined by the northeast trade wind.

Using series of aerial photographs from different years, the average migration velocity of the mudbanks has been established. The mudbanks in Suriname appear to migrate with an average celerity of 1.5 km/year. The average alongshore dimension of the smallest geomorphologic unit is 45 km. This means that a coastal location, in front of which a mudbank begins to settle, after a period of accretion, followed by a period of erosion and chenier formation, will become accretionary 30 years later again. At the end of this 30-year cycle, the sedimentary balance can be obtained and the net coastal accretion or erosion can be established.

3. Large-scale coastal behaviour

Summing up the results of the various smallest coastal units along the 338 km long Suriname coast, using the series of aerial photographs already mentioned, a peculiar picture appears (Table 1). Between 1947 and 1966 there is a net erosion of the coast, while between 1966 and 1981 there is a net accretion.

Table 1
Total net amounts of mud eroded (−) or deposited (+) along the coast of Suriname in million tons per year

	Net amount of sediment × 10^6 tons/year
1947–1957	−0.82
1957–1966	−1.00
1966–1970	+2.18
1970–1981	+7.61

Obviously there is a steering factor, which influences the behaviour of the smallest coastal units in such a way that, at a higher scale level, a new characteristic trend in net coastal erosion and accretion develops, with seaward and landward displacements of the coastline of over 10 m. This steering factor appears to be caused by a systematic change in the frequency and velocity of the northeastern trade wind.

The relation between the direction of wave approach, kept constant at 45°, and the shoreline of Suriname (~ 90°) and Guyana (~ 120°), has been brought out by the behaviour of the respective mudbanks. In Guyana they are shorter than in Suriname and their behaviour is more erratic (Augustinus, 1986). Both appear to be caused by the difference in angle between the coastline and the direction of wave propagation, which is determined by the trade winds. There are no significant differences in external hydrodynamic conditions, which could be used for an explanation.

If the wave energy flux is resolved into a coast-parallel component and a cross-shore component, it is clear that in front of the Suriname coast the longshore component is stronger than the cross-shore component. This means that longshore transport is favoured, giving rise to longer mudbanks. This indeed appears to be the case (Fig. 3). In the mean time the stronger cross-shore component in Guyana gives rise to stronger wave winnowing processes, and the development of a sandy layer on top of the mud, thus hampering further erosion. The behaviour of the mudbanks therefore becomes more irregular (Fig. 3).

The same principle as explained above could apply if the direction of the northeast trade wind should change. Therefore, wind data from the weather station Rochambeau/Kourou, in French Guyana, has been analysed for the period 1953–1986 (Eisma et al., 1991) and for the period 1991–2001 (Fig. 4). The data from 1953 to 1956 are incomplete and have been omitted. The data from 1987 to 1990 are not available.

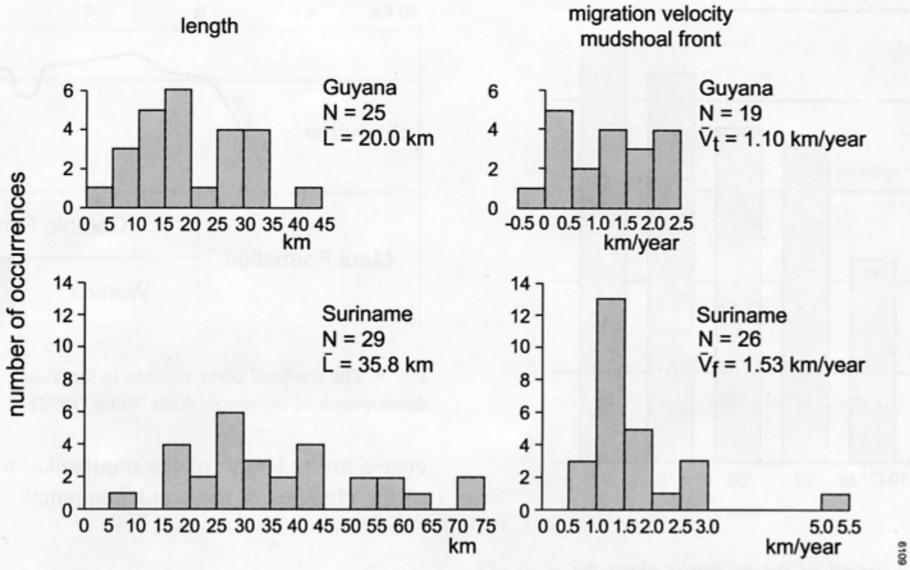

Fig. 3. A comparison of the length of the (intertidal part of) mudbanks in Suriname and Guyana, as well as their migration velocity. After Augustinus (1986).

The results demonstrate that the frequency of winds from the direction 50° to 80° (roughly east–northeast), in the windiest months of the year, from 1957 to 1986, shows a clear increase in time (Fig. 4). The frequency of winds from directions between 30° and 50° is more irregular.

The more east–northeast directed trade winds will generate waves that approach the coast of Suriname under a more acute angle than in the past. In terms of longshore and cross-shore resolved components of the wave energy flux, this means an enhancement of the longshore component at the expense of the cross-shore component. Over the same period the wind velocity has increased, as shown here for the sector 50–80° (Fig. 5). Applied to the smallest coastal unit, this results in a decrease of erosion at the east side of a mudbank and in the interbank area. In the mean time, the formation of fluid mud will increase, due to the higher turbulence, as will the longshore transport of

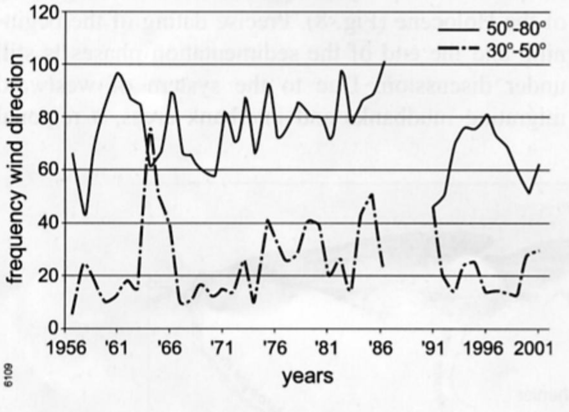

Fig. 4. Frequencies of the trade wind, measured at an altitude of 500 m at Rochambeau/Kourou (French Guiana) during January–April 1957–1986 and 1991–2001, coming from directions between 30° and 50° (roughly northeast) and between 50° and 80° (roughly east–northeast).

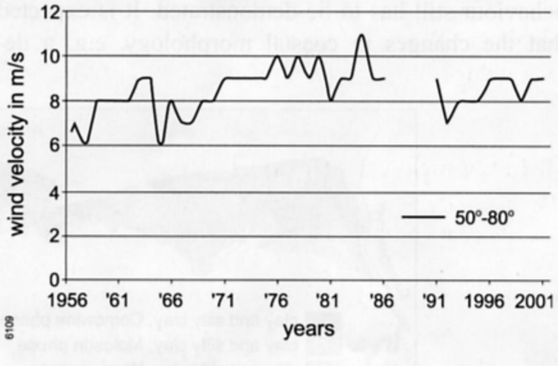

Fig. 5. Mean wind velocities calculated on the basis of daily measurements at an altitude of 500 m at the Rochambeau/Kourou weather station (French Guiana) for winds coming from directions between 50° and 80° (roughly east–northeast).

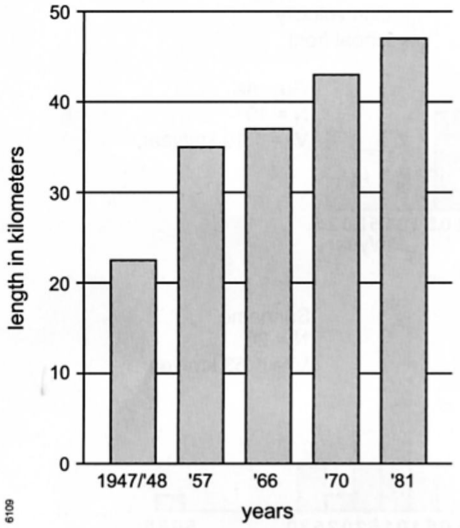

Fig. 6. Increase in length of the mudbanks along the coast of Suriname between 1947 and 1981.

fluid mud. As a result, the average length of the mudbanks will increase and this appears to be the case indeed (Fig. 6). The point of reversal from net erosion to net accretion is supposed to lie somewhere in the mid sixties (Table 1).

In the 1990s, a decrease in the frequency of the east–northeast direction of the trade wind can be observed. The coastal behaviour will adapt to this new energy distribution. It will result in a decrease of the longshore component and thus shorter mudbanks. In the mean time, the cross-shore component will grow in importance, furthering processes of winnowing and coastal erosion. This part of the coastal behaviour still has to be demonstrated. It is expected that the changes in coastal morphology, e.g. a decrease in the length of the mudbanks, will lag behind of the changes in the wind frequency.

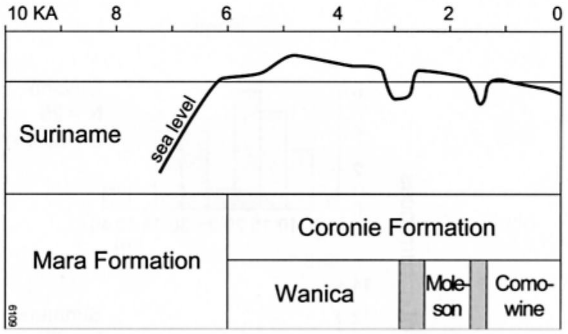

Fig. 8. The sea-level curve relating to the Young Holocene coastal development of Suriname. After Wong (1992).

4. Geological development

Taking the geological development of the whole 1600 km long coastal zone between the Amazon and the Orinoco Rivers into account, than a net accretion over the past 6000 years is evident. In Suriname, three sedimentation phases of theYoung Holocene Coronie Formation (< 6000 years BP) are distinguished (Fig. 7). The relating sands and clays were deposited during a period of more or less constant sea level (Fig. 8). The Coronie Formation is preceded by the clayey deposits of the Mara Formation, which settled during the period of rapidly rising sea level at the beginning of the Holocene (Fig. 8). Precise dating of the beginning and the end of the sedimentation phases is still under discussion. Due to the system of westward migrating mudbanks and interbank areas, a regional

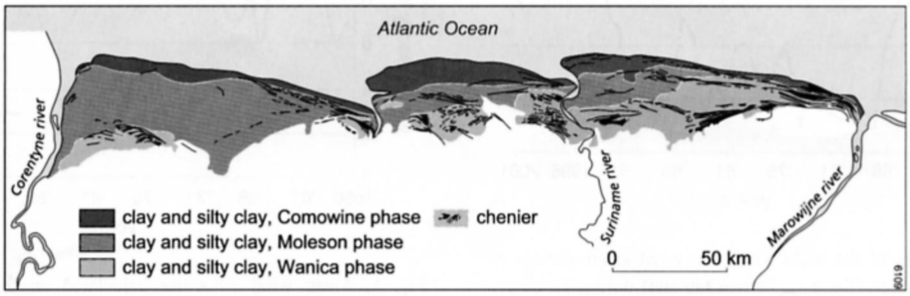

Fig. 7. Sketch map of the outcrops of the three sedimentation phases of the Young Holocene Coronie Formation (< 6000 years BP) as well as the main cheniers and chenier bundles. After Augustinus (2003).

trend in age can be noticed, e.g. for the end of the Moleson phase (Versteeg, 1979, 1980; Augustinus et al., 1989).

Along the Corentyne River, the Young Holocene coastal accretion is roughly 40 km (Fig. 7). This corresponds to an average accretion of 6–7 m/year. However, the accretion appears to be interrupted twice by an interval of erosion or non-deposition (a.o. Brinkman and Pons, 1968; Wong, 1992), recognisable by extensive chenier bundles (Fig. 7).

Both relatively short periods appear to coincide with a slight drop in sea level (Fig. 8). As such, the formation of chenier bundles during lowering sea level does not seem very logic. However, if the slight drop in sea level should take place in a period with more northern trade-wind frequencies, furthering erosion and chenier formation, the development appears plausible.

5. Conclusions

In conclusion, three different scale-levels in coastal development can be distinguished in Suriname. At all three levels the trade winds are playing an important role. Especially, the apparent oscillation of the north-east trade-wind system between north–northeast and east appears to have a great influence on the large-scale coastal behaviour in Suriname. Further analysis, however, is needed in order to be able to draw more detailed conclusions.

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