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MORPHOLOGY AND CURRENT DYNAMICS OF THE COAST OF TOGO

Morphologie et dynamique actuelle de la côte du Togo

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RESUME

Le littoral togolais, long de 50 km et de topographie absolument plane, est constitué de deux générations de cordons séparés du bassin côtier tertiaire par un système continu de lagunes.

La côte est soumise depuis ces deux dernières décades à une violente érosion à la suite de la construction du port en eau profonde de Lomé, réalisée sans prise en compte de son impact éventuel sur l'environnement. La jetée, longue de 1200 m, bloque la dérive littorale d'W (1,2 à 1,5 Mm^3 an^{-1}) et a provoqué une accumulation de sable sur la face W de 10 km environ et une érosion de la côte vers l'est sur quelque 45 km. La vitesse moyenne du recul de la plage se situe entre 5 et 10 m an^{-1} La mer a donc dévasté plusieurs centaines d'hectares de plantation de cocotiers, interrompu en plusieurs endroits la route côtière nationale qui a dû être reconstruite plus loin à l'intérieur des terres et menacé certaines infrastructures économiques et sociales telles que les usines de phosphate et la ville d'Aného.

La gravité des dégâts a rapidement engendré des études géomorphologiques, des recherches de laboratoire (modélisation) et l'entreprise de travaux importants sur le terrain tels que la protection de la côte par des constructions en 1987-1988, de brise-lames et d'épis dont les effets s'étendent sur 15 km de côte. Un suivi sédimentologique régulier effectué par le projet "Erosion Côtière" de l'Université du Bénin (Togo), a permis d'une part la comparaison entre les prévisions du modèle et l'érosion effective et d'autre part de mesurer la vitesse de recul dans le secteur de côte non protégé.

ABSTRACT

The Togolese coast, 50 km long, and absolutely flat is made of two generations of beach ridges, separated from the sedimentary coastal basin, of the Tertiary age, by a continuous system of lagoons.

For the last two decades, it has been submitted to violent erosion subsequent to the construction of the deep water port of Lome. This construction was executed without any consideration of the potential environmental impact. The jetty of the port, 1200 m

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long, blocking the W-E offshore drift (1.2 to 1.5 million m^3 $year^{-1}$), has caused an accumulation of sand on the west side over approximately 10 km and is causing the gradual erosion along 45 km of the coast towards the east; the average speed of the retreat is between 5 and 10 m $year^{-1}$. Thus, the sea has devastated several hundred hectares of coconut fields, cut in several places the international coastal road, which has been reconstructed further inland, and threatened infrastructures: such as the phosphate factory and the town of Aneho.

The importance of the damages let quickly to the development of geomorphological studies, laboratory researches (i.e.modelisation) and significant fields works involving 15 km of coastline protected by breakwaters and groynes. Regular monitoring of the sedimentological evolution carried out by the "Erosion Côtière" project of the University of Benin (Togo) allowed, on the one hand the comparison between the model's forecasts and the effective evolution, and on other hand, the measurement of the speed of retreat along unprotected segment of coast.

Togo, situated in West Africa between Ghana to the west and Benin to the east, presents a maritime atlantic façade of 50 km in the gulf of Benin, the offshore zone of which is made of beach-ridges of different ages. The construction of the deep water port has brought about morphodynamic modifications recorded along the shore. It halts a powerful offshore drift with a littoral drift capacity among the largest in the world. (1.2 and 1.5 Mm^3 $year^{-1}$). To the west of the jetty lies a sector of coast in progradation. The eastern part is characterised by a loss which produces a rapid retreat of the coastline. Occasional retreat reached 40 m $year^{-1}$. This morphosedimentary desequilibrium has led to destruction of the coastal road, of villages and of hectares of coconut fields.

A battery of 16 groynes of variable length and a breakwater protect a total of 15 km of coast at Kpeme and Aneho (Fig.1). The morphosedimentary reactions around the protection zone have been monitored regularly since 1988, which allows a comparison of the evolution in a natural environment with the forecasts of the model.

GEOMORPHOLOGY OF A LOW SANDY COAST

The coast of Togo is situated in the center of a geosystem of beach-ridges in the gulf of Benin, which stretches from the sedimentary source of the Volta delta to the western front of the Niger delta in Nigeria. It stretches between 1°15 and 1°45 longitude east, from the Benin to the Ghana border. This coastal margin, which is quite narrow and 2 km wide on the east side of Lome and of about 500 m wide at Aneho, includes the lagoons, the wetlands and the sand barriers of the Holocene age. These zones lie parallel to the shore. They are dominated in the north by the meridional end of the Continental Terminal Formation which constitues a plateau with an altitude gradually increasing towards the north (BLIVI, 1985).

THE EXTERNAL BEACH-RIDGE

It consists of a series of accumulation alignments parallel to the coast in abevelled configuration, in an easterly direction. The width varies from west to east : 2 km near Lome, 1.5 km at Gbodjome, 0.6 to 0.8 km between Agbodrafo and Aneho. The morphology is characterised by a succession of joining spits, more or less narrow, straight, and curving. Its topographical surface presents a better preserved undulation in the undeveloped areas. The heights are between 4 and 5 m from Lome to Baguida, and slopes down to the lagoon which circumscribes it to the North. On the east side, it is connected with the yellow sand barrier. Between Gbodjome and Gumukope, there is a narrow swampy depression. With an abrupt profile, it dominates the marshy plain located between Gumukope and Aneho. The lagoon flowing in the Mono at Agbanakin separates it from the "earth barrier" relief. On the sea front, in the eroded sector, the beach is characterised by a micro-cliff of steep slope, between 1 and 2 m high. In the bottom of the beach appear areas of beach-rock playing an important role in the coastal evolution.

Concerning the granulometry, the barrier is made of medium to coarse sand. Analysis of sediments taken from the surface and at 1 to 2 m depth revealed 98 to 100 % of the sand. The medians vary between 0.315 and 0.600 mm; a clear classification and homometry are possible because of the uniform hydrodynamic conditions of the deposit.

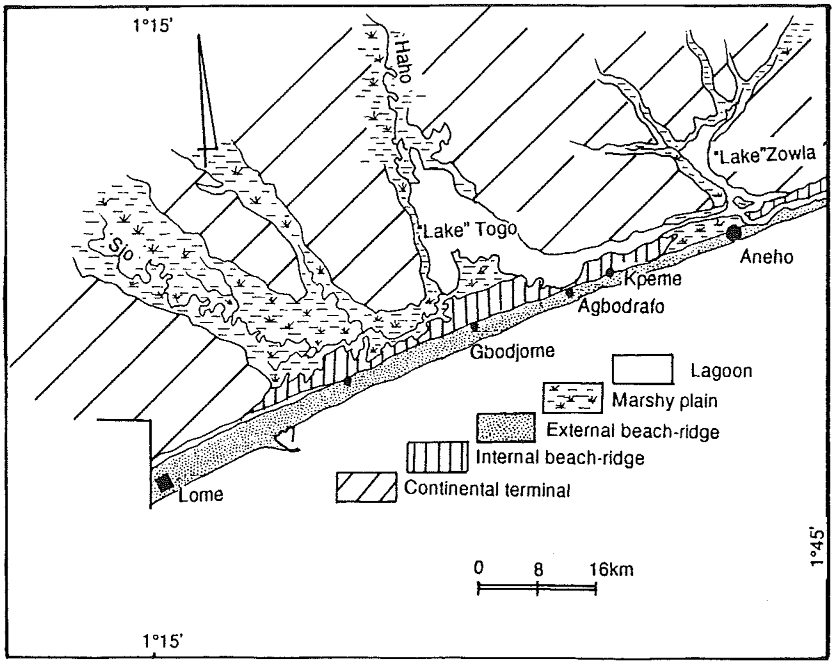

Fig. 1 - Coastal geomorphology of Togo

THE INTERNAL BEACH-RIDGE

It constitutes a 30 km barrier from Kelegougan to Gumukope, regularising a coast of "rias" or old openings of the Sio and Haho rivers since the transgression of the Nouakchottian. It isolates the flood-plains and the lagoons, slopes down to the east, at an altitude of 6 - 7 m. In large bands, the total width varies between 2 km in the Gbodjome segment and 1 km at Adakpame. It is relatively well preserved except in the sections where it is subject to sand exploitations. Its internal border creates successive openings, eroded by the defluviations of the Sio which isolate elongated islands, oval-shaped in the middle of the marsh. From Baguida to Devego, circular, elongated depressions, flooded in rainy season, take place between the barriers. The internal beach-ridge approaches Aneho as an island. On east of Agbodrafo, it is narrow, to 150 m wide between the Togo lagoon and the external beach-ridge. It finishes with an elbow shape on the north side of Gumukope, dominating a marsh 3 km wide and 10 km long with an abundant vegetation of *Typha australis.*

The pits make it possible to observe the homogeneity of the sediments over a depth of several meters. From the sedimentological point of view, the formation is essentially sand. The granulometrical analysis of two samples, taken from two different depths 40 and 60 cm give a proportion of clay of 9 and 12% respectively. Statistical analysis reveals a predominance of fine to medium sand which averages between 0.250 and 0.500 mm.

THE LAGOON SYSTEM

The lagoon system is separated from the sea by beach-ridges. It features a large lagoon of 46 km², named "lake" Togo, a 15 km lagoon channel in Togoville and Aneho, and the small Zowla lagoon. They occupy the depressions between the plateau. "Lake" Togo is fed by the Sio and Haho rivers. The lagoon branches supply water to Aneho lagoon through which the system is almost permanently linked to the sea. Wherever the estuary is closed at Aneho, the water flows into the Mono river at Agbanakin. The lagoon system is under a sub-equatorial climate, thus benefitting from two rainy seasons. In the dry season, the lagoons are dominated by low wet zones, consisting of white sand and hydrodynamic earth (Fig. 1). In Lome, the lagoon system is made of three "lakes" artificially developed in 1972. It is a prolongation of the Ghabian lagoons.The Lome lagoon system is fed by used water and runoff and then discharged to the sea by two channels.

The margino-littoral formations of Togo were established after the transgression of the Nouakchottian. The internal beach-ridge is formed from the sand coming from the shoreface and the continental sediments loads carried by a very active littoral drift. The sand brought by the Volta river formed the beach-ridge of red sand. This morphosedimentary evolution during the Holocene period characterises the entire coastal relief of the gulf of Benin. All the barriers have the same arrangement and geometry. Stratigraphical and geomorphological data and their processes revealed a correlation between the variations of the sea-level and the formation of sedimentary units (TASTET, 1981; LANG & PARADIS, 1984; AMIEUX *et al.*, 1989). Due to the construction of Lome harbour, the present coastal topography and morphodynamics is changing.

CURRENT EVOLUTION

A disruption in the physical equilibrium of the low sandy coast results from the construction of the deep water port without any consideration for environmental impacts. The coast dynamic is marked by the considerable loss of sedimentary volume, causing spectacular retreats of the coastline, on an average of 5 to 10 m year^{-1}; they reach 40 m year^{-1} elsewhere on the coast.

NATURAL CONTEXT OF EVOLUTION

The hydrological and climatic regime

The Togo coastline is dominated by a warm, wet, sub-equatorial climatic zone with two rainy seasons and two dry seasons. The rainfall regime contrasts sharply with seasonal variability and inter-annual irregularity. The average annual temperatures vary between 25 and 26°. The main climatic abnormality of the gulf of Benin coastline results in a pluviometric decrease of 1500 mm to 800 mm from east to west. On the Togolese coast, the average rainfall is 800 mm year^{-1}.

The whole area is influenced by latitudinal deplacements of the NE-SW convergence point of the NE and SW wind currents. The drift of these currents depends on the continental and oceanic pressure centres: the Saint Helena and Sahara anticyclones. From the anticyclone blow constant SSW and NE winds predominating during the "Harmattan". For the marine winds from the south ocean play an important role. They generate large swells, waves which create a W-E offshore drift along the coast, fundamental in coastal morphosedimentary processes.

The Volta river flows from the delta located on the west of the barriers and feed with sand the entire gulf of Benin geosystem. It drains a sandstone basin 400 000 km² with significant tributaries well structured over the whole basin. Its sediment loads amount 1095 m^3 s^{-1} in dry seasons; and 6 000 m^3 sec^{-1} in rainy seasons.

The Mono river flows along the oriental boundary of Togo. It is 450 km long and drains a 21 000 km² basin essentially made of crystalline rocks. It reaches the sea at Grand-Popo, located 20 km west of the Benin border. The solid load of the Volta river is about 1 Mm^3 year^{-1}; the Mono carries 100 000 m^3 year^{-1}. Since 1966, the Akossombo dam on the Volta river traps 99% of the sediments (CHENG, 1980), mainly sandy eroded from the basin, and representing 40 t km^{-2} year^{-1} (CEE, 1989). Such a sedimentary deficit has repercussions on the dynamics of the outflow zone.

Dynamic factors

Waves, swell and currents due to the waves are the hydrodynamic factors which directly intervene in the evolution of the beaches. The waves are 1.25 m high; with average period of 4 to 6 seconds (Fig.2).

The drift is formed by waves of moderate to high energy due to a shoreface which limits the dissipation of large swells. When these waves approach the coast, because of the depth reduction, they break on the shoreface. On the Togolese coast, like in the gulf of Benin, the breakings occur in periods of rough weather about 150 to 200 m

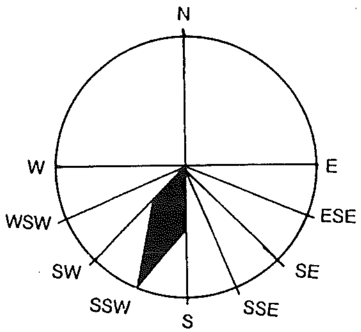

Fig. 3. - Waves direction

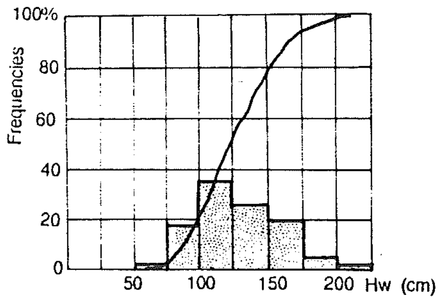

Fig. 2. - Waves height

from the shore at -3 to -5 depths. The exceptional swells reach 2 to 3 m in July and August. From October to June, it is around 0.4 to 0.5 m. The average period is about 11 - 12 seconds. The directions are constant by the S to SW sector (Fig. 3).The obliqueness of the swell at the coast varies from 4 to 9° with an average around 6 to 7°. This affects the height of the wave as it breaks. Orthogonal swell concentration zones have been identified. The tide occurs in a synchronised way over the whole coast of the golf of Benin; it is a half diurnal tide with two maximum and minimum heights each day. The average amplitude is about 1 m. The tidal range is weak, contrasting with the coasts of Gambia and Guinea where it reaches 3 to 5 m.

Two coastal currents can be distinguished: the one of Guinea, far from the shore, which goes from the W to the E with an average speed of 1 m s^{-1} (PITON, 1986) and the coastal current, the main hydrodynamic agent, which is responsible of the easterly transport of sediments. The offshore drift results from the angle created by the alignments of waves and coast, and the height at breaking-point. As a matter, of fact, the energy arriving all along the coast varies as a function of the angle of incidence, which results in the potential volume of sediment in transit. When the energy level is high, it favours displacement of sediment; erosion is mostly evidenced in locations where there is no sedimentary compensation.

The weak gradient of the dynamic parameters leads to accumulation of sediment. However, when they are moderated due to the absorption of the waves in the breaking zone, the offshore drift maintains the equilibrium of the beaches. On the Togolese coast, the sands are transported into the zone between +0.8 m and -0.5 m and on the marine beach between 2 and -11 m the lowest limits of the swell (L.C.H.F., 1985). The movement is carried out in a channel about 200 to 300 m long and in a W- E direction. The movement capacity was evaluated, through studies, to an average of 800 000 to 1 Mm^3 $year^{-1}$ (NEDECO, 1975; LACKNER & PARTNERS, 1983). The sediments are made of medium to coarse sand with an average diameter of 0.4 to 1 mm. On the sub-marine beach, they are finer, 0.08 to 0.125 mm. This equilibrium has resulted in rapid morphosedimentary changes.

The gulf of Benin coast is subject to highly marked beach erosion. This is due to developments of the Akossombo dam and the ports of Lome and Cotonou. Before these disturbances of the morphodynamic equilibrium, the progradation of the beach-ridges from the recent Holocene to the beginning of the present time, took place in positive conditions evidenced by an often constant and regular feeding of sediments to the littoral drift. Fluctuations of the coastline are marked by weak retreat and insignificant forward movement around a median line.The outlets of the coastal lagoons have quasi-natural evolution and had shown a dynamic equilibrium which was later disturbed by the ports.

Developments

The demands for electrical power, domestic water supply and irrigation water had forced the construction of dams and ports, which has had a serious impact on the coastal environment.

The construction of Akossombo dam on the Volta river in Ghana in the Akwapim chain, 113 m high, 640 m long, using 8 millions m^3 of rock, creates an 8 700 km^2 artificial lake, the largest in Africa with a 165 billion m^3 of water. The wall has an altitude of 88 m; the water level varies between 76 and 84 m. and regulated by overflow through a spillway. The energy production capacity is 768 MW. A regular flowrate of 1090 m^3 s^{-1} from an average fall of 66 m, would supply a power of 617 MW (ENTZ, 1969). According to the size of the dam, il was supposed to solve the electric power problem of the subregion. However, fifteen years later, the blockage caused by alluvial deposits carried by the Volta river is felt at its mouth and on the oriental coast (ROSSI, 1989). The littoral spit is broken because of the under-feeding of the littoral drift. Beach erosion was quickly triggered with impressive retreat and resulting desolation. According to predictions, a new dam constructed on the Mono river, between Togo and Benin, and put into service in 1987, will have morphosedimentary repercussions on the Benin coast about thirty years later.

The port of Lome was built between 1964 and 1967 behind a jetty developed on the west side. Il is a deep water port on a coast where littoral transit is very important. The development consists mainly of a jetty to the west, the purpose of which is to protect boats in the harbour against swells and to prevent silting. A counter-jetty demarcates the harbour to the east. Between the two jetties, there are quays on landing stages, where water depths can reach 15 m. The main jetty acts as a dam, blocking all sands coming from the west. It has triggered the development of an artificial beach which is enlarging very rapidly. To the east of the port, the reaction is negative, since the beach feeds sand to the sea and subsequently cannot maintain its stability. In fact, the port of Lome is the main cause of coastal erosion in Togo.

The coastal dynamics

Monitoring the shore shows two states of coast: a state of erosion characterised by an abruptly sloping profile of the beach and a state of accumulation corresponding to the stopping point of the sand. These two forms of beach reveal distinct mechanisms.

a .-the mechanisms

1) the mechanism of accumulation

The volume of sand deposited by waves in the breaking zone, varies as function of the characteristics (height, angle, energy) of the incidental swell, and forms a bar below the low-tide mark. This bar increases in size to the benefit of successive deposits and gradually moves in order to emerge above the high-tide mark at the top of the beach. It takes the form of a beach-ridges relief and blends with the old beach. As the coalescent alignments emerge, forming the beach, the breaking zone is displaced and the progradation of the beach is evidenced. This process continues in one direction of the littoral drift, with the persistence of hydrological parameters and of the permanent and sufficient supply of sand materials (Fig.4).

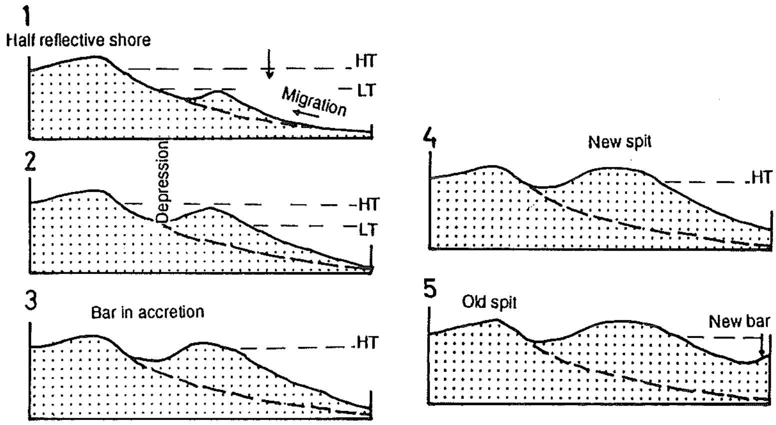

Fig. 4. - Diagrams of mechanisms and beach-ridges formation phases

This combination of hydrosedimentary processes and of formation of a beach-ridge has been monitored by observation and measurement of spatial and temporal variations of the beach. The available data revealed a transport capacity, of 1.2 to 1.5 Mm^3 $year^{-1}$ (SIREYJOL, 1977). Using the method of cubature, the volume of sand accumulated between the groynes has been estimated. The forms of accumulation on the Togolese coast are a forced type because they are the result of a blockage of littoral transit due to the jetty of the port, the groynes and the breakwaters.

2) the erosion mechanism

Since the conditions favouring the equilibrium of the beach are no longer present, especially the permanent transport of sand and consequently its deposit by the waves, the beach-ridge recedes. This phenomenon is furthered either by works which mobilise the sand, leaving the littoral drift under-saturated, or by the erosion sector corresponding to the starting zone of a part of the littoral drift. Under normal conditions, waves bring sand to the beach and take back some of it back as they return, which translates into a saturated drift. From the moment when waves break with a weak charge without being able to compensate the volume which is mobilised, the beach is in a state of sedimentary deficit; it recedes. In morphodynamic terms, the beach is entirely reflective which means that the profile of the beach is steepened by waves of sufficiently high energy (ANTHONY, 1990) from the granulometric point of view, the beach is made of coarse to medium sand. This fact characterises 40 km of the Togolese coast, topographically marked by an abrupt mini-cliff, of variable slope. It is in direct contact with the sea or separated from it by a narrow beach exposed at low tide. In contrast to an accumulating beach, the bar does not exist right along an eroding beach because of insufficient feeding of sand. In fact, waves form the beach during high tides by undermining the sand, by sliding of the sedimentary mass. We distinguish convex-concave and protruding profiles with a basal path.

The study of the evolution of the drift combines anterior measurements, carried out within the framework of the coastal erosion project, observations in situ, and the interpretations of aerial photographs.

b. - *the spatio-temporal modifications*

The Togolese coast as a whole constitutes a good example of beach evolution. The construction of the west jetty of the port of Lome in 1964, with a total length of 1200 m, plays a role both positive and negative at the same time in the coastal environment.

1) the beach of Lome, its phases of evolution

The accumulation of sand stretches for about 6 km to the west of the jetty. It is formed by a succession of spits and depressions, of decreasing width towards the west: 900 m immediately around the jetty, 200 to 300 m between the PK 7 and the PK 4[1] . The progress of the beach has been rapid. As the construction progressed towards the sea, the sedimentation followed. It reached the "elbow" of the jetty, which allows the circulation of sand right along the final section of the installation. In this way, in the course of around three decades the whole sedimentary volume (1.2 Mm^3 $year^{-1}$) has been deposited on the western façade of the port, enlarging and stabilizing the shore of the town of Lome.

Before the construction of the port, the coastline was situated between 60 and 100 m from the coastal road, according to aerial photographs of 1949 (West Africa series). The coast was stable, in fact, slight variations of the coastline around an average line, marked by insignificant retreats and advances were observed. Between 1964 and 1965, the accumulation brought the shore 150 m forward. The width progressively diminishes towards the west, down to 100 m opposite the centre of the port, then meets the original coastline at Ablogame beach, situated 40 m from the coastal road. Aerial coverage of 1966-1967 shows a progression of the silting-up. Between 1970 and 1972, the coastline advanced by 25 m, to locate at 500 m from the road. In 1978, the shore is at 700 m ; near the Ghana border, the coastline has not progressed. In 1990, the shore reached 950 m from the original coast; a progression of 100 m in relation to 1986. The overflow of the lagoon is closed by a deposit of approximately 100 m; which makes difficult the flow of water into the sea (Fig. 5).

[1] P.K. kilometric point from the border Togo-Ghana

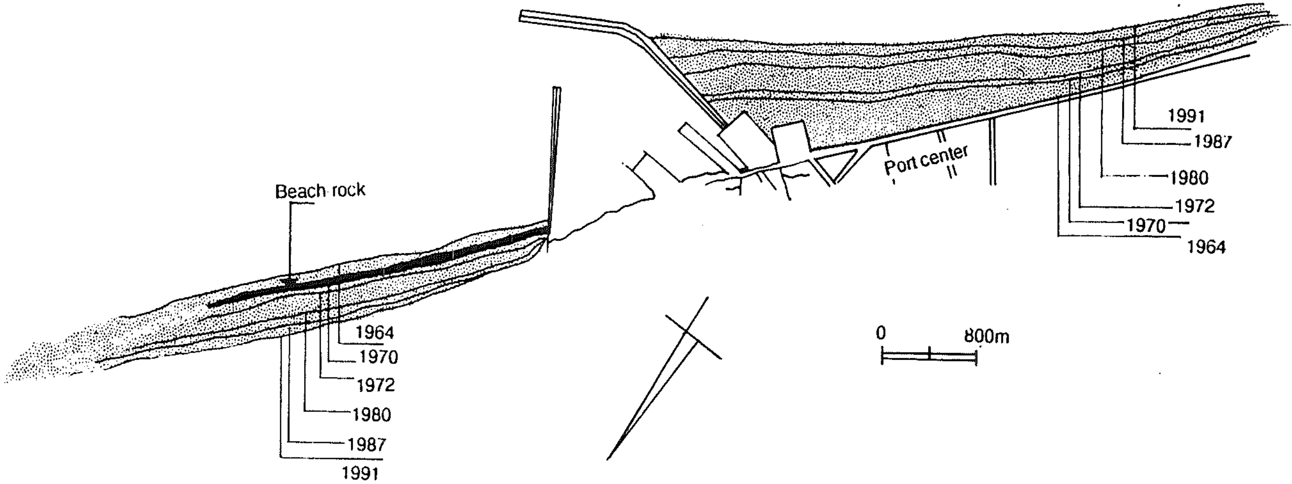

Fig. 5. - Evolution of the shoreline around the port of Lome

2) erosion of the shore to the east of the port; the role of beach-rock

The westward stopping of the sand generated an eastward rapid and spectacular erosion of the beaches 40 km from the jetty during the last three decades (Fig. 6).

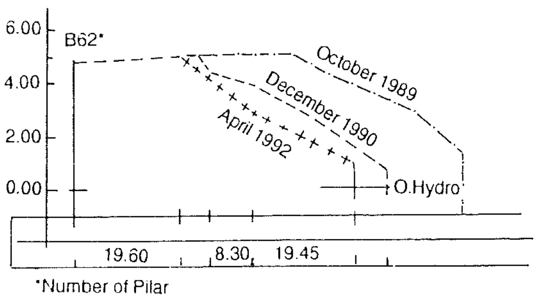

Fig. 6. - Retreating of the shore at Aneho

On the 1965 aerial photographs, we can see the SW swell refracts around the end of the jetty, generating frontal waves which violently attacked the coast. The coastline had retreated about 60 m, the original coast road over a distance of about 900 m. The lengthening of the jetty of some 700 m, according to the aerial photographs of 1966-1967, has only increased the effects of the frontal waves over 1500 m to the east, accentuating the beach erosion over some 40 m. This causes erosion of the road opposite to the current site of the Robinson hotel at PK 11.

Until 1972, the average annual retreat between PK 11 and PK 18 was 150 m. Erosion has thus uncovered the beach-rock; its gradual emergence will play an important role in the beaches evolution. Erosion has made progress towards the east where it has reached a rate of 5 to 6 m year^{-1} between the PK16 and the PK18. Until 1980, between the PK11 and the PK16, the retreat is between 2 and 3 m year^{-1}, leaving the beach-rock exposed. Before 1987, the coast retreated to Aneho, on the border between Togo and Benin. With the emergence of beach-rock over the whole coast, the rate of erosion has diminished to 1 to 2 m year^{-1} along the first 10 kilometres.

Beach-rock plays an important role in the coastal dynamic since it is found at an altitude sufficiently higher than the average sea-level. It dissipates a large part of the energy waves. At a height of + 1 m, the beach-rock blocks the sedimentary movement between the shore and sub-marine beach. Until 1980, the depth of the beach-rock (between +2 and +0,5 m) allowed it to dissipate the energy of the waves at breaking point, to slow down the rate of retreat and to stabilise progressively the coast at to 30 to 60 m on about 8 km from the head of the counter-jetty. Therefore, over about 10 km to the east side of the port, the rate of retreat has reduced enormously, 0.5 to 1 m year^{-1}, in contrast with 10 to 15 m year^{-1} ever more in the years when the beach-rock had just been exposed (ROSSI, 1988; BLIVI, 1989). The retreats observed in recent years result from the fact that the swells pass across the depressions due to occasional sinking of the flag stones where the level is low. The energy of the waves is dissiped just a little and the coast is submitted to their attack. In the other sectors, it appears but is of little height and does not allow the dissipation effect; sedimentary movements occur within the profile.

Because of the consequences generated by the phenomenon, such as the destruction of the coastal road and villages; the threat to the phosphate factory and the town of Aneho, studies have led to a development scheme to protect the coast.

THE COASTAL ENVIRONMENT

The degradation of the coastal area lead to the setting-up of a scientific team that in 1987 proposed a stabilisation plan for the important socio-economic sites.

PROTECTIVE MEASURES

In 1985, following violent erosion in the phosphate embarkment wharf sector at Kpeme, a beach-level installation was constructed to stabilise it. Two years after, a protection scheme for 15 km of coast, including in the Kpeme-Gumukope sector a battery of 7 groynes and at Aneho one breakwater and five groynes, was established. The lengths of the installations vary between 60 and 100 m at Kpeme; 45 and 75 m at Aneho (Fig. 7).

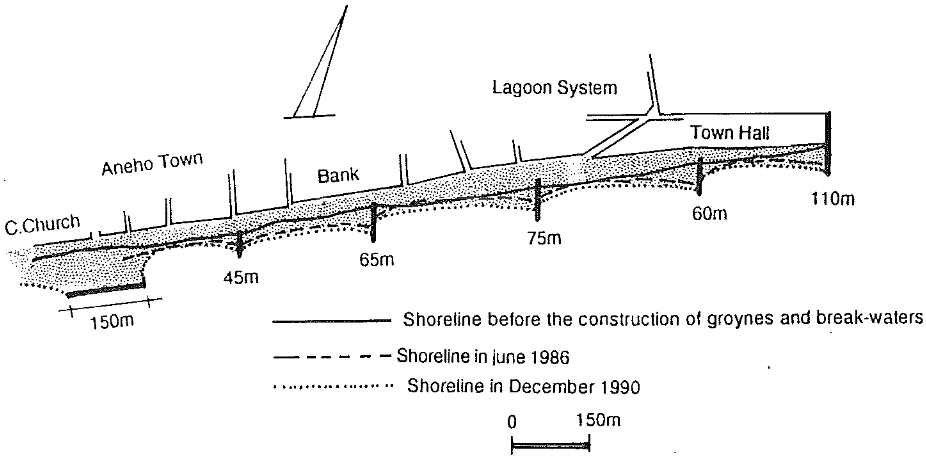

Fig. 7. - Scheme of protection of the coast at Aneho

The spacing is also different; it is wider between the groynes at Kpeme and narrower, on average 100 m, between the ones at Aneho. The groynes, constructions perpendicular to the coastline and the breakwaters parallel to the shore are constructed with gneiss stones and have a well-defined structure. After four years, these installations have been consolidated, and are now very effective in the stabilisation of the coastline between Aneho and Kpeme.

IMPACTS OF THE INSTALLATIONS AND FUTURE EVOLUTION

The construction of the installations insures the safeguard of the coastline in the protected sectors; the refilling of the portions of coast between the structures, has evolved rapidly and restored the coastline to the end of the groynes over about 40 to 60 m. The breakwaters constructed to 100 m from the coast have stopped sediments and generated an artificial beach 90 m wide to the east of the church of Saint Peter and Paul. Its effect is felt over 1 000 m on the west side with the gradual reduction of the width of accumulation. In the Kpeme sector, the installations stabilise the coastline and have helped the progression of the coast to the west side of the wharf for a few dozen metres.

The impact of the Aneho installations has led to erosion of the lagoon barrier. Normally at a height of + 3 m, this fragile structure was broken two weeks after the construction of the last groyne of the sector. This quasi-permanent installation has, during the year, led to profound modifications to the lagoon ecosystem. The marine waters, with high salinity now occupy the lagoon for a longer period. This ecological change has an impact on the economy and the life of the river population. Previously the developments brought natural openings of the barrier, when the water flowed in the rainy season, the lagoon was artificially opened for the duration of the descent of the continental waters into the sea. Generally, this situation lasts from August/September to November, then the opening is closed by the establishment of a new barrier which helps the weakening of the lagoon currents.

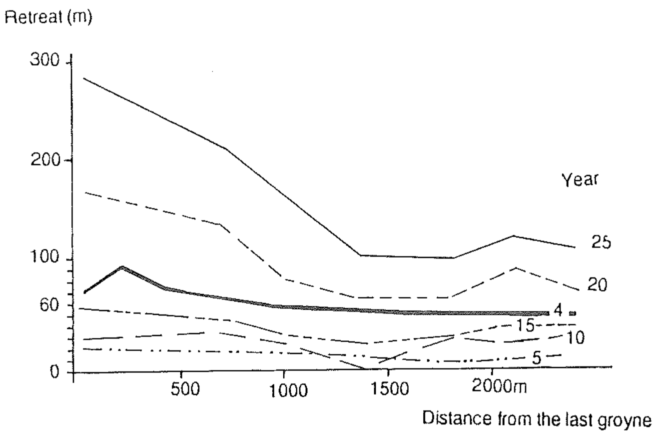

Fig. 8. - Evolution of the shoreline at the east side of the Aneho protected zone on model and on natural state

Regular monitoring of the morphosedimentary evolution of the whole coast and especially beyond the Aneho installations has allowed a comparison between the observed evolution in the natural environment and the results of the exploitation of physical models (SOGREAH, 1989). It has been deduced that the distortions are linked to overestimate of the sedimentary deficit and of the hydrological conditions which can be explained by earlier circumstances, up to date uncertain. The complexity of the phenomenon found along this coast make the interpretation and application of the model difficult. However, the results collected are valid as regards the general evolution of the coastline. For around l5 years, the protected sector will set no problems; only in the long term, because of the sedimentary deficit between the installations, the risk of undermining of sand is high on the east coast. In the medium and long terms the lagoon barrier will be completely open after some 15 years and the erosion in the estuary to the level of the continental road bridge will become evident. Viewed closely, the erosion eastwards from the Aneho installations is rapid, what would not be the case according to the model (Fig.8).

The complete emergence of the beach-rock would lead to a sedimentary deficit which would affect deposits in the protected sectors, in particular the one of Aneho and at the same time the whole east coast in the direction of the Benin border. The latest topographical findings of 1991 from the Benin University Coastal Erosion Project allowed an evaluation of the current easterly movement, and which will be of the order of 1 Mm^3 $year^{-1}$. Realistically this should be reduced in the coming years, with the blockage of sedimentary exchanges in the profile; it is thought, therefore, that in 25 years this volume would pass 0.7 Mm^3 and would cause a retreat of about 250 m in the lagoon overflow zone. The effect would be felt over about 15 km towards the east.

CONCLUSION

The managment of coastal environment problems is conceived within the framework of a coastal study programme devoted to non-living resources. The monotiring of the coastlines evolution, over the past 5 years allows the defining of the limits of retreaded coastlines and the suggestion of schemes complimentary to those already implemented. A fruitful attempt at hydrochemical works in the lagoon has given encouraging results. They will certainly continue in order to define the characteristis of the area at different times of the year, to establish an approach to the evaluation of living resources which are likely, to adapt to the new lagoon environment where the exchange of fresh and high-salinity waters for a large portion of the year will predominate. The stability of the shore could be re-established by feeding sand, by pumping from the accumulation zone or from the sea. This solution is not feasible for an underdeveloped country; it would be useful to closely study the complexity of the phenomena on physical model sand to propose cheaper solutions adapted to the retreat . In the light of all the results, morphological modifications will intervene in twenty years above all the perceptible decline of the coastal drift and the brutal erosion of Benin coast.

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