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MORPHOLOGICAL AND DIACHRONIC STUDY OF THE LAGOON OF SIDI MOUSSA, MOROCCO

ABSTRACT

For 40 years the shift of the economic activities of Morocco from the interior to the coastline has been going on at a quickening pace. In view of this growing and continued pressure, the Moroccan coastline represents a fragile and unstable physical space, which enjoys neither protection nor development. The need therefore is growing, first to ensure the maintenance and the stabilisation of the coastline, and, secondly, to study and be prepared for phenomena that risk harming its role and/or its development.

Sidi Moussa lagoon (on the Moroccan Atlantic Coast) is part of an inter-dunal fissure of the oceanic territory protected by a baymouth bar of consolidated dunes made of bio-calcarenite from the plio-quaternary age. The lagoon lies on an area of 4.2 sq km. It is located in a region placed at the semi-arid tier. The lagoon is one of the Moroccan sites classified as humid zones of national importance for the conservation of birds within the framework of the Ramsar Convention on Wetlands. The lagoon of Sidi Moussa is known for its importance in terms of the safeguarding of rare birds.

With the goal of understanding the mechanisms of the morphogenesis and of analysing the morpho-dynamic variations of the split and the sandpit of the Sidi Moussa lagoon, an alimetric analysis of the beach profiles is suggested, and the evolution of the sandpit and the split of the lagoon between 1949 and 1997 was re-formed by using multi-date aerial photos (1949, 1984, 1987 and 1997). The findings of the evolution study of the split and the sandpit show that the evolution is quite slow. It is not clear whether this evolution could have a tendency towards a more or less large silting up and a development of the split, which could trigger the partial closure of the lagoon and hence the reduction of the lagoon-ocean exchanges.

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Above, The lagoon of Sidi Moussa is an important part of the barrier islands along Morocco's Atlantic Coast, and a site for the safeguarding of bird life as designated by the Ramsar Convention on Wetlands.

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INTRODUCTION

The lagoon of Sidi Moussa is situated on the Moroccan Atlantic Coast. It pertains to Morocco's coastline meseta and is one of the Moroccan sites classified as a humid zone of national importance for the safeguarding of birds as designated by the framework of the Ramsar Convention on Wetlands. This lagoon is known for its importance in the safeguarding of rare birds. Although the level of scientific knowledge of the other lagoons in Morocco has already been elaborated, the lagoon of Sidi Moussa – apart from the sedimentological study led by Maanan (2003) and the studies on the phytoplanktonic populations or the contamination of sediments (Sarf and Labraimi, 1997; Bennouna, 1999; Kaimoussi, 2002) – remains a site about which little information is available.

The sandy floors of the littoral and coastal regions often present morphological structures more or less on periodic evolution (barrier beaches, tidal pools, beds, dunes, ridges). These morphological changes are the outcome of external forces (seasons, tides, storms and such). Within natural contexts, stability is never reached. Because of hydrodynamic processes and the strong mobility of sand grains, a lagoon always shows morphological variations (Carter, 1988).

In this study, the effect of the swell and the current on the evolution of the sandpit and on the split, which constitutes the major tidal inlet of the lagoon of Sidi Moussa, are examined in order to have a global vision of the operating and the evolution of these systems.

It is very important that the lagoon of Sidi Moussa keeps a fixed geometry for several reasons. Firstly, if the lagoon remains stable, the quality of the waters and the ecological richness that depend on this system, especially rare birds, could survive. Furthermore, the lagoon plays a key role in the system of barrier islands. The delta of the ebb is a real reservoir of sand that could be used in coastal development operations. Its volume could attain that of barrier islands (FitzGerald and Hayes, 1980; Hayes, 1980). Finally, the maintenance of channel fairways is necessary for artisanal fishing activities, especially the socio-economic development of the inhabitants of the region.

Figure 1. Geographical localisation of the lagoon of Sidi Moussa.

SITE OF THE STUDY

The lagoon of Sidi Moussa (Figure 1) belongs to the great structural unit called Meseta Marocaine occidentale. It lies on an area of 4.2 sq km, and is separated from the oceanic territory by a chain of consolidated dunes. At the side of the mainland, the lagoon is dominated by plio-quaternary formation of calcarenites. The ridges and the inter-dunial depressions of the hinterland are in general directed towards the NE-SW. The setup of these old dune ridges was encouraged by NE trade winds that were stronger than today's on the Moroccan coasts (Weistrock, 1982).

Rain showers in the lagoon are low and the rate of evaporation is high. It is classified as a semi-arid zone. This climate is characteristic of the Mediterranean area. The provisions in fresh water in the lagoon are the manifestation of the resurgences of the plio-quaternary nappe of the continental front of the Sidi Moussa lagoon. The tide in the lagoon is semidiurnal with a tidal range of 2 to 4 metres, and the state of the tide changes following its evolution in time (Chaibi, 2003). At the level of tidal inlets, the speed of the current is always higher than that of the ebb during shorter periods, which creates an important internal tide delta shown by the sandpit. The external tide delta is almost non-existent. The intensities documented at the level of tidal inlets are 86 cm/s (Hilmi *et al.*, 2002).

Moderate winds from W, N, and NE are predominant all along the coastline. But strong winds (11 to 16 m/s) always blow from the W and SW. The W and NW swells are almost permanent. Amplitudes range between 0.5 to 7 metres (swells reaching 9 metres can occasionally be registered). Periods vary between 8 to 18 seconds, with the strongest amplitudes linked to periods ranging between 10 to 16 seconds (in Maanan, 2003). SW agitation is associated with local winds and occurs only in the winter. The number of days of the SW swell was estimated at 21 per annum, with amplitudes from 1 to 3 metres and a period of 7 seconds.

Constantijn Dolmans, Secretary General of IADC (left) presented the IADC Best Paper Award to Khalid El Khalidi (second from right). Standing with (left to right) Mohamed Bachiri, Chairman of the African Section of CEDA, Ms Asmaa Mhamdi Alaoui recipient of an award from the Association of Sand Producers (ASP, Morocco), and CEDA President Rewert Wurpts (far right). Khalid El Khalidi is working on his PhD in Environment, Development and Integration Management of Coastline Spaces ST/18/05, School of Science El Jadida, Morocco. His subject of research is hydro-sedimentary dynamics, recent evolutions, risks and consequences of the planning of the south coastline of El Jadida (from Jorf Lasfer to Oualidia), Morocco (*photo courtesy of Tony Slinn*).

The sedimentary circulation along the coastline of Sidi Moussa lagoon can be of different types: general currents linked to mass circulations of oceanic waters (in Attilah, 1993); currents triggered by the swell; and currents created by the wind, especially during storms.

The present form of Sidi Moussa lagoon was imposed by the morphology of the inter-dunial depression. It is limited by the Ouljien cliff, covered by a soltanian rock avalanche and, to the West, by a post-Ouljien dune ridge. This translates into an extended form that is part of a straight strip that runs parallel with the coast at an average length and width of 5.5 km and 0.5 km, respectively.
The total area of the lagoon is evaluated at 4.2 sq km.

Four morphological units could be distinguished in the lagoon: two tidal inlets; the channels and the inter-tidal zone; and the salt-marshes and the baymouth bar, which is a sandbar that can completely close access to a bay, thus sealing it off from the main body of water. The lagoon of Sidi Moussa is marked by the existence of relatively different coastlines on each side. The NE coast is rocky, while the SW coast is a slender spit.

MATERIALS AND METHODS

Diachronic Study

The historical evolution of the baymouth bar and of the sandpit that exists inside the lagoon of Sidi Moussa is determined based on two types of documents: the topographic map and aerial photos. The aerial photos are compared and analysed in such a way that allows for obtaining evolution maps of the coastline. The morphological evolution of the lagoon of Sidi Moussa between 1949 and 1997 was re-formed by using aerial photos dating from 1949, 1984, 1987 and 1997.

Each of the two types of documents (topographic map and aerial photos) is a source of intrinsic error (Dolan *et al.*, 1980; Niang-Diop, 1995). In order to solve these problems, at the first stage the topographic map of Sidi Moussa region (1/25000) has been geo-referenced.
To do so, cartographic data that are based on this map have been used. As to the projection, the Lambert Maroc Nord projection was chosen. Subsequently, the aerial photos have been geometrically corrected; the procedure consists of localising on the image to be rectified the position of a noticeable pixel and assigning to it two data (latitude and longitude) taken from the reference document (the geo-referenced topographic map).

At the second stage, the aerial photos that had been corrected and geo-referenced are taken back to be digitised. Evolution maps of the baymouth bar and the sandpit of the lagoon are thus realised.

Contour Survey-based Study

Contour surveys allow for achieving emerged beach profiles and thus to produce a cartography of their morphology. When comparing the surveys, the morphological variations were visualised.

Contour surveys with the help of a level are classically used in coastline geomorphology in order to measure the altimetrical evolution of beaches. In general, the morphological follow-up is reduced to the achievement of transversal profiles in the beach. Contour surveys are, therefore, carried out following the perpendicular radials alongside the coast down to the shallow water.

The follow-up of the topographic evolution of Sidi Moussan lagoon was carried out following five profiles in transverse place (Figure 2), and according to random point DTM taking into account the nickpoints.

These surveys were carried out at low tide during spring tides. The surveys were led during spring tides every other month for two years (between March 2001 and January 2002). The processing of raw data of the topographic surveys was done after the transfer of data to the computer in order to represent profiles, and therefore, analyse them to calculate the sediment surface displaced all along each profile (emaciation, growth).

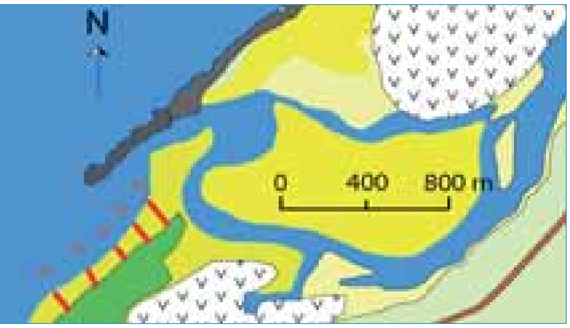

Figure 2. Localisation of the profiles.

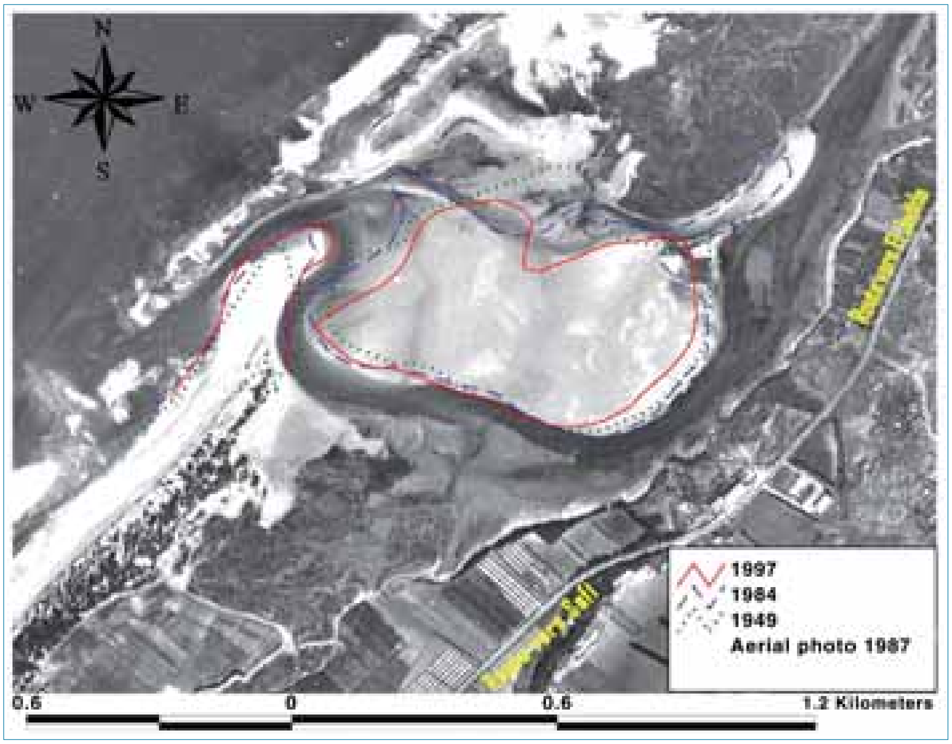

Figure 3. Chart of the evolution of the littoral arrow and the sand pit of the lagoon of Sidi Moussa between 1949 and 1997.

RESULTS AND DISCUSSIONS

Classification of the Lagoon

The classification of the lagoon was a subject of several studies (Bruun and Gerritsen 1960; Postma 1969; Galvin 1971; Oertel 1972; Hayes 1975; Jarret 1976; Nichols and Allen 1981; Hume and Herdendorf 1987; Steijn 1991, and many others). The findings of these studies, showing characteristics that are peculiar to each system, have allowed for the establishment of morphological and energetic classifications or classifications based on the operating mode of these systems. According to Maanan (2003), the lagoon is mesotidal according to the classification of Hayes (1975), neutral according to Postma (1969), completed by the estuarian type of Nichols and Allen (1981). Based on the morphological classification of Hume and Herdendorf (1987, modified), the Sidi Moussa lagoon is a "barrier enclosed lagoon" type 4 "single spit enclosed." And, according to the geometrical classification established by Galvin (1971), the lagoon of Sidi Moussa is an "overlapping offset".

The most recent classification of the descriptions according to the hydrodynamic parameters of Davis and Hayes (1984, modified) leads to the conclusion that the lagoon's type is strong mesotidal to macrotidal: moderate since the tidal range is situated between 2 and 4 metres.

Diachronic Study

In this section the results of the study of the evolution of the baymouth bar and the sandpit (delta of the ebb) of Sidi Moussa lagoon based on the aerial photos that cover the 1949-1997 period (Figure 3) are presented.

As far as the 35-year period from 1949 to 1984 is concerned, the observation was made that the baymouth bar moves northward, and that the morphology of the sandpit inside the lagoon is changed by migrating towards the NW, while conserving about the same morphology.

During the 5-year period from1984 to 1989, the baymouth bar changed its morphology especially towards the top where it was observed that it is rather inclined towards the NE. The sandpit continues to move westward while getting closer to the baymouth bar, and a diminution of the volume of sand in the northern coast can be seen.

In the 8 years from 1989 through 1997, the baymouth bar remained stable. On the other hand, the western part of the sandpit withdrew, and a change in the morphology of the northern coast was noticed.

Westward and north-westward swells, whose amplitude ranges between 0.5 and 7 metres (occasionally 9-metre swells were observed) with periods varying between 8 to 18 seconds, are almost permanent.

These data do not explain the migration of the baymouth northward; because these swells are due to bring about a coastline drift from the north to the south.
After the analysis of the results the conclusion can be drawn that the major agents that participate in the movement of the baymouth to the north-east are the following: tide currents, the currents that by-pass the rocky bar help sand particles move northward. To this is added the agitation towards the south-west which is associated with local winds even if they only blow in wintertime.

The baymouth bar did not remain stable as it appears in the comparison of aerial photos of the years 1989 and 1997, because the 1997 photos were taken after the storm that struck the region in December 1996. The evolution of the sandpit is primarily a result of the tide currents that are the major intra-lagoon currents, which could explain the movement of the sandpit westward. The sandpit could also be affected by the currents created by swells and seasonal storms, hence the appearance of the other channel of the northern side of the sandpit.

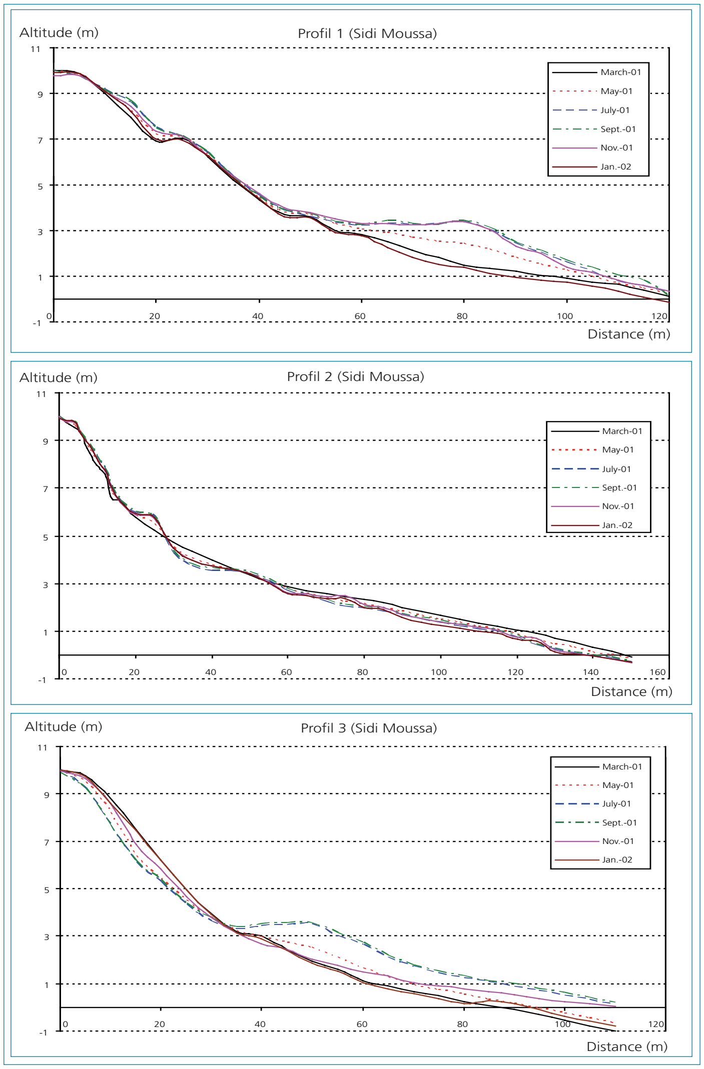

Figure 4A. Morphological evolution of profiles 1, 2 and 3 between March 2001 and January 2002.

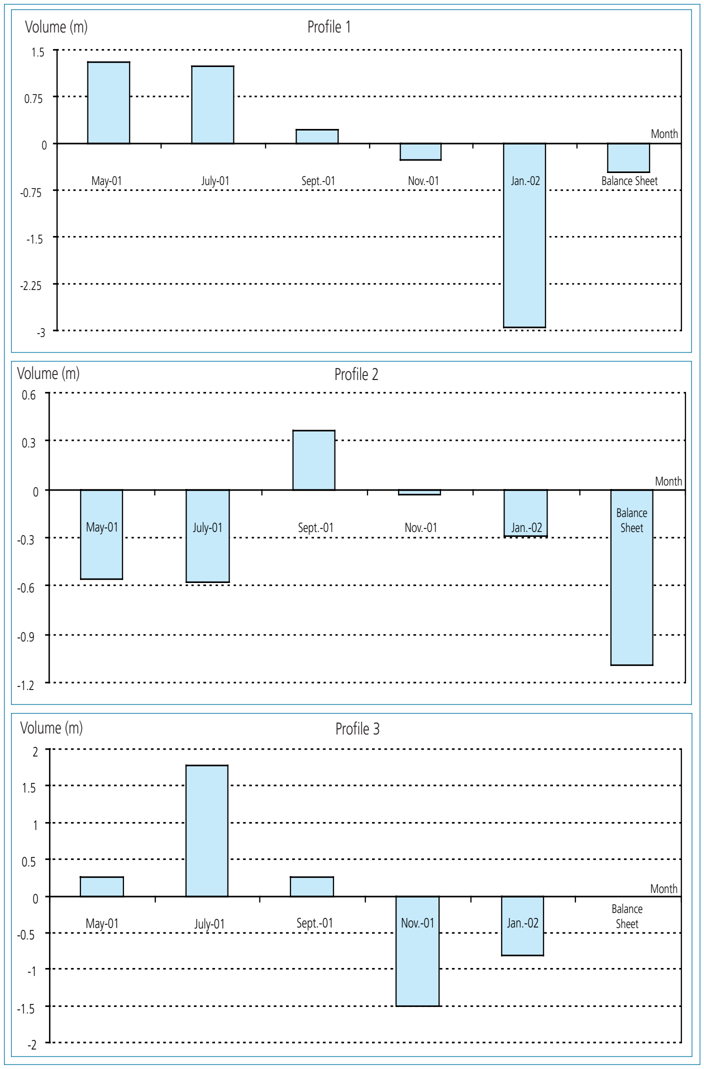

Figure 5A. Variation of volumes of profile 1, 2 and 3 between March 2001 and January 2002 and the assessment of each profile.

Carruesco (1989) and Zourarah (2002) have pointed out the presence of some cyclicity of 15 to 20 years in the evolution of the ebb delta at the Oualidia lagoon.

Contour Survey-based Study

The results shown (Figures 4A, 4B, 5A and 5B) are the outcome of several bi-monthly altimetrical campaigns. The chosen profiles are listed in Figure 3. In the study zone, the topography is quite varied. For each profile, the move was successfully made from the dune to the beach and to the foreshore. Profile 1 in Figures 4A and 5A shows that the evolution is situated chiefly at mid-foreshore. It is there that changes could occur up to 3 metres. During the period March through July, a considerable accumulation at the dune as well as at the foreshore was noted. This accumulation can be estimated at about 1.25 m. The period July through November seems calm. But starting November up to January, large erosion especially in the foreshore can be seen. The annual sheet of this profile is more or less stable.

As to profile 2 in Figures 4A and 5A, they show that during the period March through July, the losses affect the foreshore, but gains profit the dune. During this period, erosion is estimated at -0.6m. As to the period of July through January, not much change is noted; the profile seems stable. The balance sheet of this profile shows that it undergoes a 1-m erosion.

The analysis of profile 3 in Figures 4A and 5A shows that during the March to July period, the accumulation is situated at the foreshore, but large losses are pointed out at the dune. The sheet of these months shows a gain estimated at 1.7 m. As to the period of July to September, it appears rather calm. During two months from November to January, the sheet shows a loss estimated at -1.4 m. The annual balance sheet of this profile shows it is stable.

Profile 4 shown in Figures 4B and 5B shows that the most significant losses occur between March and July. They can reach 0.8 m at the foreshore, and they mainly touch the beach and foreshore. The sheet corresponding to this period could reach 1.7 m. The period running between July and September is

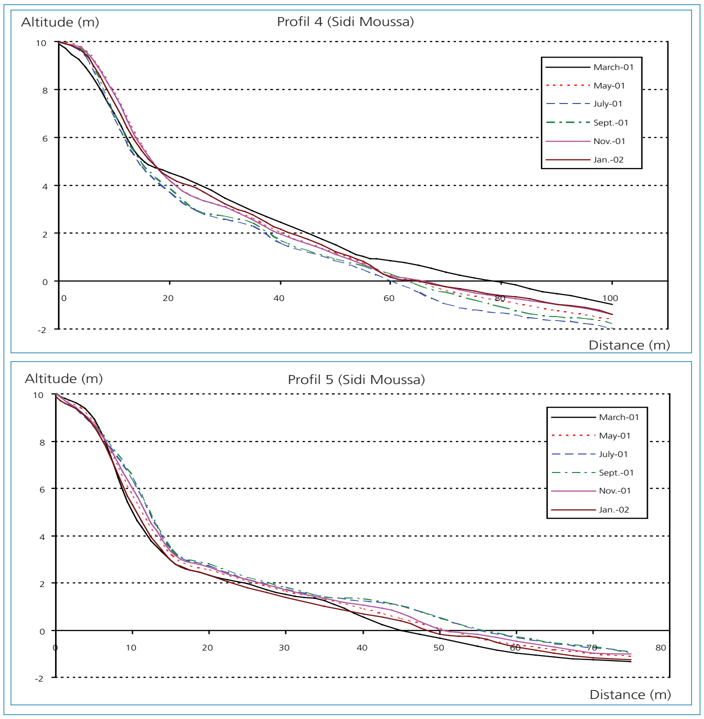

Figure 4B. Morphological evolution of profiles 4 and 5 between March 2001 and January 2002.

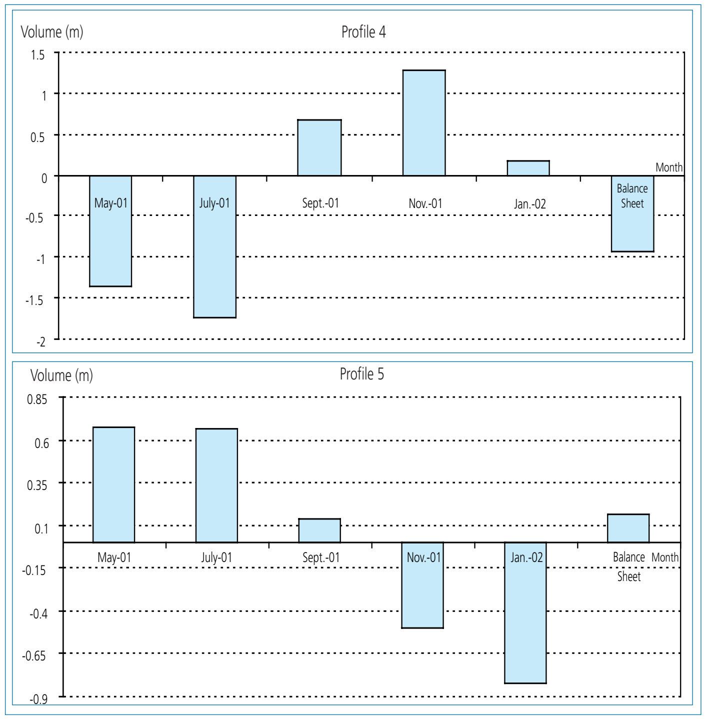

Figure 5B. Variation of volumes of profiles 4 and 5 between March 2001 and January 2002 and the assessment of each profile.

marked by accumulations at the level of the foreshore, but the September-January period shows accumulations could also touch the dune. The general balance sheet of this profile shows it is eroded at -1 m.

For profile 5 in Figures 4B and 5B sand accumulations are noticeable on both the dune and the foreshore, but they are more significant in the foreshore. This mainly happens between March and July. Gains are, thus, estimated at 0.7 m. Between July and September, the evolution of the profile is calm. From September to January, losses are noted that appear either on the dune or on the foreshore. The general sheet of this profile is positive; it is estimated at 0.15 m.

Based on the analysis of profiles, the conclusion was drawn that the evolution touches each profile from the top to the bottom, which explains the combined action of winds and swells on the profiles. Three main periods have been distinguished:

- March to July: a tendency towards growth for all profiles, except for profile 4;
- July to September: a generally calm period. The evolution of profiles is more or less stable;
- September to January: a period marked by a tendency towards emaciation, except for profile 4.

These results show that the direction and the power of swells undoubtedly govern the evolution of these profiles, because it can clearly be seen that during the season when the swells are aggressive, they cause the emaciation of profiles. On the other hand, the periods when swells are calm or when they run in a direction that allows the baymouth bar to be sheltered by the rocky bar situated before the tidal inlets of the lagoon on the north are characterised by the growth of the profiles. One could conclude, therefore, that the rocky bar contributes to damping and dissipating westward and north-westward swells that are almost permanent.

As to the case of profile 4, during site visits the existence of a rocky mass, which appears only during low water and spring tide periods, was observed. This explains the evolution of this profile contrary to the others. Profile 4 constitutes then a reservoir for the beach from each side. It is mobilised mainly thanks to the coastline drift.

CONCLUSIONS

The goal of this work was to understand the mechanisms of the morphogenesis and to analyse the morpho-dynamic variation of the baymouth bar and of the sandpit of the lagoon of Sidi Moussa. The lagoon of Sidi Moussa was categorised as a “barrier enclosed lagoon” type 4 “single spit enclosed,” “overlapping offset” of the type strong mesotidal to macrotidal. Breaking swells constitute the most important transport and erosion agent in coastline dynamics. The dominating swells are caused in 78% of the cases from NNW and NW directions, that is to say the opposite direction of the prevailing coastal winds: this co-existence of two sub-parallel but opposed dynamics is one of the possible explanations of the complexity of the observed sedimentary transports characterised by divergences and convergences all along the beach of Sidi Moussa. The evolution of the sandpit and the baymouth bar seems to be quite slow. However, it is certain that this evolution could move towards an increasingly significant silting up and further development of the baymouth bar, which could trigger a partial closure of the lagoon and thus reduce lagoon-ocean exchanges. Profiles show that the morphological variation happens during three seasons (March to July, July to September, and September to January). The influence of the rocky bar on the evolution of these profiles, as well as the rocky mass in the lower foreshore of profile 4, has been noted. In order to better understand and establish precise circulation and sedimentary balance sheets in this coastal zone, it is necessary to follow-up and multiply on-site measures (beach profiles, Aeolian traps and such). The evolution towards the lagoon landfill with tourist and industrial development requires more profound study and a regular follow-up of the sedimentological and geochemical conditions of the coastline environment in order to ensure efficient intervention, to develop applicable knowledge in the form of help tools for taking decisions that facilitate the permanence of the activities of the region (agriculture, oyster culture, tourism, fisheries, exploitation of salt and so on), and to understand the evolution of the tidal inlets of the lagoon and neighbouring beaches.

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