Geogr. Fis. Dinam. Quat.
22 (1999), 99-104, 4 figg

GALINA V. VYKHOVANETS (*)

AEOLIAN PROCESSES AND FORMS DEVELOPMENT ON COASTS OF UKRAINE

ABSTRACT: VYKHOVANETS G.V., *Aeolian processes and forms development on coasts of Ukraine.* (IT ISSN 0391-9838, 1999).

The length of the Black and Azov Seas within Ukraine are 2835 km, from the Danube delta in the West to the Kryvaya spit in the East. Aeolian processes and relief forms are spread on sandy spits, barriers, terraces. They occupy almost 703 km of Ukrainian shore length, or 43.2% in total. Acute sediment deficit and prevailing of seaward winds by energy determine the small size of aeolian forms, their spreading as separate hearths and discontinuous ridges. As spits and barriers are very narrow (up to 100-250 m), aeolian forms being very low (usually 1-2 m, maximum not over 5 m high). During gales, 1-2 times a year waves overflow the spit or barrier on their dorsal side. Such phenomenon determines very close interaction of all elements on accumulative form surface, in contrast to these coasts where dunes are high and of great width. Besides the total sediment deficit, direction of prevailing winds and accumulative forms sizes, aeolian processes are influenced by composition and humidity of sediments, thickness of dry sand layer, density and height of vegetation, the distance of wind momentum over sandy surface, duration and reoccurence of wind action. Sediment supply in the coastal zone very often does not influence the size of coastal dunes: retreating shores can have in themselves bigger shore dunes than accumulative ones.

KEY WORDS: Aelian processes, Sedimentary balance, Black and Azov coastal zone, Ukraine.

RIASSUNTO: VYKHOVANETS G.V., *Sviluppo di processi e forme eoliche sulle coste dell'Ucraina.* (IT ISSN 0391-9838, 1999).

La lunghezza dei mari Nero e d'Azov all'interno dell'Ucraina è di 2835 km, andando dal delta del Danubio ad ovest sino al lido di Kryvaya ad est. I processi eolici e le forme del rilievo sono diffuse sui lidi sabbiosi, sulle barre e sui terrazzi. Queste occupano almeno 703 km della lunghezza della spiaggia ucraina, corrispondente al 43,2% del totale. Lo spiccato deficit dei sedimenti e la prevalenza dei venti diretti verso il mare determina, secondo l'energia, le piccole dimensioni delle forme eoliche, la loro diffusione come nicchie distinte e increspature discontinue. Quando i cordoni litoranei e le barre sono molto stretti (fino a 100-250 m), le forme eoliche sono molto basse (in genere 1-2 m, al massimo non al di sopra dei 5 m di altezza). Nel corso di tempeste,1-2 volte all'anno, le onde superano la parte sommitale del lido o della barriera. Questo fenomeno determina interazioni molto strette di tutti gli elementi sulla superficie della forma di accumulo. Effetti contrari a questi si hanno in aree costiere dove le dune sono alte e di grande larghezza. I processi eolici oltre che dal deficit totale dei sedimenti, dalla direzione dei venti prevalenti e dalle dimensioni delle forme di accumulo sono influenzati dalla composizione e umidità dei sedimenti, dallo spessore dello strato di sabbia asciutta, dalla densità e altezza della vegetazione, dalla distanza del momento del vento al di sopra della superficie sabbiosa, dalla durata e dalla ricorrenza dell'azione del vento. L'apporto di sedimento nelle zone costiere spesso non influenza le dimensioni delle dune: spiagge in erosione possono presentare dune di dimensioni più grandi rispetto a quelle in fase di accumulo.

TERMINI CHIAVE: Processi eolici, Bilancio del sedimento, Aree costiere del Mar Nero e del Mar d'Azov, Ucraina.

INTRODUCTION

Ukrainian territory is washed by the nontidal the Black and Azov Seas along 2835 km. Among them 1628 km are of the Black Sea shoreline, the remaining 1207 km being of the Azov Sea coastal line. Aeolian forms are spread on sandy shores 703 km long. Sandy forms of coastal relief are represented by barriers, spits, terraces. In contrast to the majority of such forms on the other seas shores, they are developing in conditions of the general sediment deficit in the coastal zone and prevailing of seaward winds. This general natural background essentially influences aeolian forms and processes on the Black and Azov Seas shores. Principal features of coastal dunes development under the influence size and landscape structure of barriers, spits and terraces surface, beach width, distance of wind momentum over the beach surface, nature of dry sand layer on the beach, sediment composition and humidity, saturation of alongshore drift flow within the frames of various lithodynamical cells are considered further.

COASTAL ACCUMULATIVE FORMS MORPHOLOGY

Main amount of stationary long-term investigation of aeolian forms was carried out on the Nothern Black Sea coast, where the majority of sandy accumulative forms are

(*) *Physical Geography Department, State Mechnikov's University, Odessa, 270026, Ukraine.*

located. That is why the data of this very region will be mainly used, it being the most studied one. Here works were carried out on eight main stationary sites (fig. 1). Absence of tidal flats on the Sea and opposite sides of accumulative forms is an important peculiarity as the Black and Azov Seas are non-tidal.

Barriers and spits of limans (up to 70%) are most frequent among sandy coastal forms. From the seaside they are subjected to the influence mainly of sea waves, wave currents and accompanuing short level fluctuations. As the result, strong deformations of beach relief develop. Dorsal side of barriers and spits faces shallow limans, lagoons or bays («limanic zone»), where deformation swing is minimal under the influence of corresponding hydrological factors. Central part of noted accumulative forms which is subjected to the strongest influence of wind action, temperature and humidity of the atmosphere with wide spreading of aeolian processes and forms is situated between them. Accordingly, three main landscape «zones»: sea (marine) aeolian and limanic are clearly seen along the long axis (fig. 2).

Beach is the main form of the marine (sea) zone. Its width can reach 60-80 m, but in the average it equals 25-30 m, the height being 0.8-2.5 m (in the average 1.0-1.2 m). Cross-sectional profile form most often is convexo-concave and concave.

In aeolian zone hummocky relief of low dunes (usually 1-2 m), which are caracterized by spreading in the form of hearths and fragmented ridge. In contrast to the sea beach, aeolian zone is covered with vegetation with 10-50% density on various sections. Aeolian zone width constitutes from 10 to 90 m, maximum over 200 m. Most often from 10 to 50 m^3/m of sand, maximum 120 m^3/m, which constitutes 10-40% of the amount in the above water part of narrow accumulative forms are concentrated in aeolian forms (Vykhovanets, 1993; 1995).

The limanic zone adjoins dorsal shoreline of barriers and spits in the strip of their contact with the liman, lagoon or bay waters (fig. 2). Its height over the average sea level does not exceed 0.1-0.4 m. It is the widest one among all landscape zones: from 30 to 200 m, and only in exceptional cases up to 3500 m (Khadjibey and Tiligul barriers, for instance). The front part of the zone facing the liman, lagoon or bay is occupied by windy flats. It is moistened, swamped, often salted, densely covered with galophite grass vegetation (up to 90-100%). Weak action of hydrological factors of the liman or bay accounts for the lower activity of the relief elements. But from the seaside stormy waves invade the limanic zone by overflowing the longitudinal crest of the spit or barrier, therefore marine sediments are brought here. As the result the limanic shoreline most often is accumulating. Against the background of the sea shoreline retreat, the accretion of the limanic one leads to the total displacement of the whole accumulative form landward(Vykhovanets, 1993; 1995).

Thus, accumulative forms within the coastal zone of the Black and Azov Seas are characterized by small sizes. Their width in general constitutes from 80 to 250 m as usual, the height being up to 1.5-3.0 m (maximum 5.8 m). Between separate seats of aeolian forms there are lowerings, not higher than 1.2 m above zero water level, double-slope beach of the full profile is reflected on the cross profile. That is why during strong storms, when the sea waves height exceeds 3 m and the storm-surge elevates the sea-level on more than 1 m, the wave surf is able to cover up to 80% of the accumulative form area. Waves overflow to the

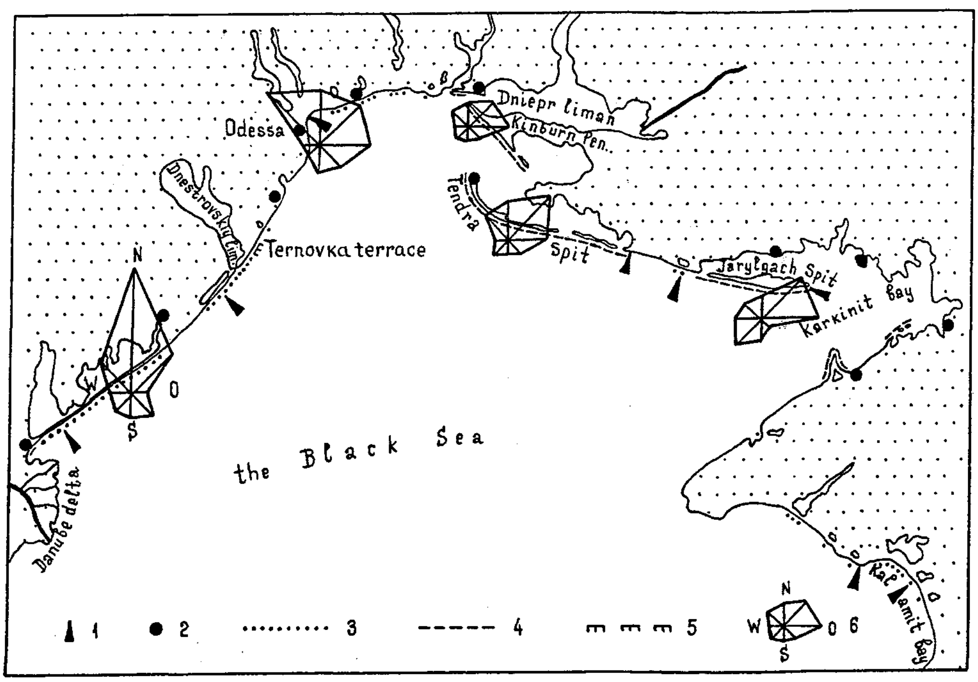

FIG. 1 - Diagram of the Northern Black Sea shores: 1) sites of long-term observation of aeolian processes; 2) points of long-term observation of wind regime; 3) barriers; 4) spits; 5) terraces; 6) wind roses based on the datum of long-term observation.

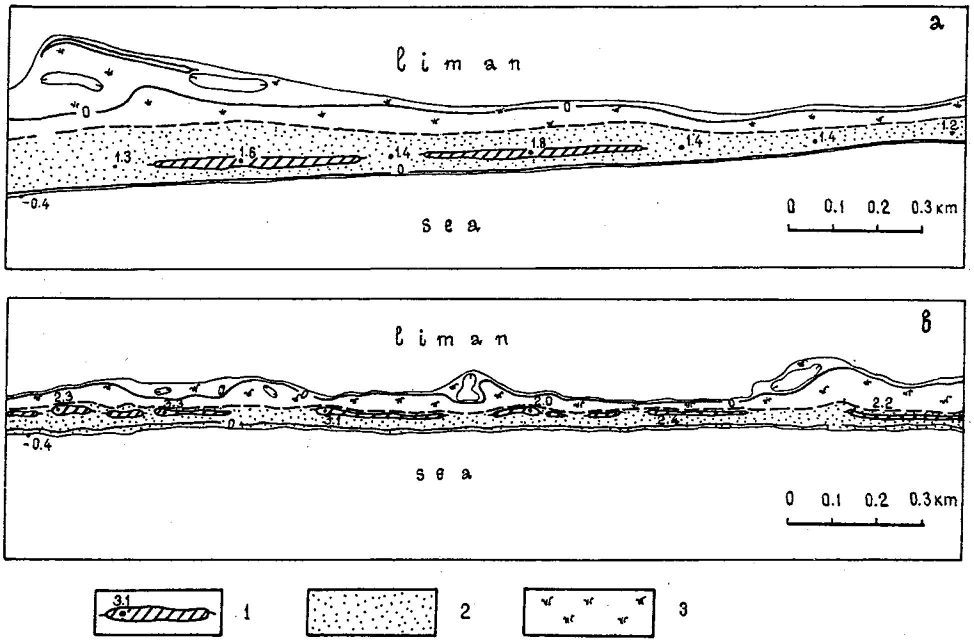

FIG. 2 - Typical composition of narrow barriers and spits on the examples of fragments on Tendra spit (a) and Budaki barrier (b), longitudinal landscape zones: 1) aeolian; 2) sea beach; 3) low swamped surface of limanic zone. Numbers show absolute bathimetric marks.

dorsal side of narrow spits or barriers, into limans, lagoons or bays.

In the connection, all three landscape zones (sea, aeolian, limanic) are under the impact of sea waves which accounts for the unity of their development and their close interaction. The bigger are the sea waves and the more often and longer they occur, the greater is the manifestation of wave factor influence on all landscape zones simultaneously. Such peculiarity is generally typical of low and narrow barriers or spits not only of the Black and Azov Seas coastal zone. It turns out to be possible, because of two main reasons: a) in general profound sediment deficit formed historically in the coastal zone, which led to the small size of sandy accumulative forms; b) prevailing direction of wind energy flow from the land seaward according to the character of the atmospheric circulation (fig. 1).

At the same time in the coastal zone of other seas the situation may be different. The coastal zone may be more saturated with sandy sediments and therefore the width and height of accumulative forms turns out to be greater. In addition the winds blowing from the sea landward prevail, and that is why the main part of sand constantly and abundantly nourishes the coastal dunes. As the result conditions for the development of wide (more than 500 m) and high (more than 5 m) belt of the coastal dunes, as for instance on the eastern and southern shores of the Baltic Sea, on the eastern shores of the Biscay bay, on the southern shores of Australia. Wave regime can be more severe than on the Black and Azov Seas, but stormy waves are not able to overcome high and wide dune ridge. That is why waves influence only the sea beach within the sea zone. Aeolian and limanic zones develop in general autonomously and without sea waves participation. The process of sediment exchange between barriers (or spits) zones takes place under the prevailing influence of aeolian factor and between all landscape zones.

The abovementioned sediment exchange is relatively intensive, but it is connecting all zones unmeasurably less actively that stormy waves within low and narrow barriers or spits on the Black and Azov Seas coasts. High general saturation of the coastal zone with sediments accounts for the supply of great amount of sand to the dunes, and this amount is constantly supplied by sea winds. But during decades and centuries coastal dunes have been displacing from the sea towards the liman, lagoon or bay, usually with the average rates of 5 to 20 m/year, as for instance on the barriers of lagoons Kurshiu Nerung, Leba, Bukovo, Jamno and other on the Baltic Sea coast. Thus «grey», «yellow» and «brown» dunes can be formed. At that autonomous formation of the marine, aeolian and limanic zones have taken place for many decades and centuries. Therefore the higher the coastal dunes on the spits and barriers, the more strongly pronounced are the features of the separate, relatively autonomous development of each of the three mentioned landscape elements on the above-water surface of sandy accumulative forms.

The correlation between the size of the coastal aeolian forms and wave regime of the sea determines the principal differences of the development of coastal accumulative forms on which high (more than 5 m) and low (less than 5 m) dunes, wide (more than 120 m) and narrow (less than 120 m) belt of dune crests and separate forms are situated. At that it is necessary to take into account the whole complex of reasons determining the existance of all their combinations, beginning with the narrow belt of low and to wide belt of high dune forms.

BEACH IMPACT TO THE AEOLIAN FORMS DEVELOPMENT

The impact of the beach to the development of coastal aeolian forms is determined by its being the source of sand in all cases (Pye, 1983; Goldsmith, 1989; Vykhovanets, 1995; Zenkovich, 1967). No matter which side relative to the direction of the long axis of the barrier or spit the wind blows from aeolian forms are always nourished by the beach sand. The sand comes to the dune belt directly from the beach when the belt is narrow and dunes are very low (for instance, on the Black and Azov Seas shores). If the dunes are high and aeolian belt is wide, the beach sand firstly comes through the «gate» (break) in the ridge of foredunes and then is distributed by winds of various directions within the aeolian zone (for instance, on barriers of the Southern Baltic Sea and Eastern North Sea coasts). Such phenomenon is observed on Australian coast as well (Short, 1988). Thus, the degree of saturation of the coastal zone with sediments and differences in the morphology of barriers and spits determine different ways of the supply of the beach sand to the aeolian zone. The greater the general saturation with sediments, the wider the beaches and the greater the amount of sediments coming to the aeolian zone.

In conditions of the Nothern Azov Sea coast accumulative forms are nourished mainly by biogenic sediments. On beaches, spits and terraces there are in the average 50-60% of mollusc vesicles as, for instance, on Biryuchiy Ostrov, Obitochnaya, Berdyanskaya spits, Arabatskaya Strelka bar. During stormy winds action of the speed exceeding 15 m/sec all sand (usually up to 10% of the above water volume of the beaches) is taken off the surface. Wind-steady surface under whose impact the wind movement of sand stops is created. That is why conditions for aeolian forms feeding are extremely unfavourable. In addition prevailing of seaward winds blowing from the land determines blowing off the sand into the sea, and not to the aeolian zone. That is why within the Azov Sea coast aeolian forms exist in embrio, their size and area of spreading being essentially less than of those observed on sandy the Black Sea shores even.

Wind-steady beach surface is also formed on low barriers and spits of the Black Sea. Such shelly surface is especially prominently on the barriers of Donuzlav and Solenoye limans, on Bakal spit. But the dry sand layer is the principal factor of wind-steady surface formation. Even in summer during long dry and sunny weather the thickness of this layer is 3-16 cm (fig. 3). Farther from the shoreline, as the thickness of the beach grows and the water-bearing horizon lowers, the thickness of the dry sand layer increases up to 20-25 cm. During strong and long wind action (speed more than 10 m/sec) during the first 1-5 hours all dry layer is blown off and the damp surface of the sand (up to 50%) does not allow the following feeding of aeolian forms as on the shores of other seas (Pye, 1983; Short, 1988).

At last the beach width is the great importance as it determines the distance of wind momentum over the sandy surface. The investigations of Japanese geographers with K.Horikawa at the head (1991) showed that wind-sandy flow reaches saturation at the distance not less than 10 m depending on the sand coarseness. Therefore, feeding of aeolian forms from the beach (Horikawa & *alii*, 1991) is effective in cases when the whole complexity of factors determines the dry sand layer width not less than 10 m. It is worth remarking that the development of embrional aeolian forms in the dorsal side of the Black and Azov Seas beaches occurs when the beach width is 30-40 m.

At that the action of stormy winds blowing from the sea side is accompanied by wave and wind level short-term rise. Depending on the relief and inclination of the nearshore bottom, the shoreline contours, velocity, duration and direction of wind it can be essential and reach 1.5-2.0 m over the zero-water level. The average height of sandy beaches equals 1.38 m, the inclination being 0.040. It is natural that the storm-surge leads to partial or full flooding of the beach surface (fig. 3). For instance, if the set up val-

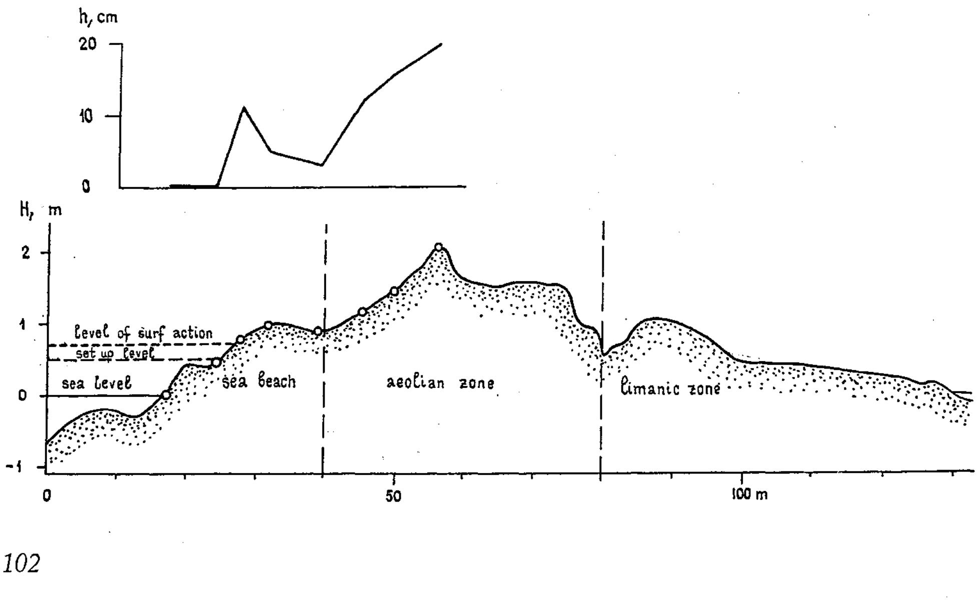

FIG. 3 - Typical crossing profile of low and narrow barrier, and diagram of distribution of the dry sand layer on the sea beach. Reduction of the beach width during stormy set up is represented.

ue is 0.5 m, the beach width reduces in the average by 30-40%, in some cases up to 60% depending on specific beach parameters. Accordingly, the distance of wind-flow momentum over the sandy surface decreases. In addition, during the storm the air is saturated with dusts of water, aerated sea water particles, which moistens the sand. That is why in overwhelming majority of cases not fully saturated wind-sandy flow is formed during gales. As the result considerably less amount of sediments than might be in the ideal conditions come to the aeolian and limanic zones.

But when the winds flow from the land seaward water is driven away and the beach width increases. Accordingly the distance of wind flow momentum over the sandy beach grows, lowering the underground water level and the increase of the dry sand layer (up to 5-20%) occur. It makes aeolian evacuation into the sea more intensive and therefore is an important unfavourable factor for the formation of coastal aeolian forms.

DEPENDENCE OF DUNES SIZE ON THE SEDIMENT SUPPLY

In professional literature one can often come across the conclusion that the coastal dunes sizes is the larger, the greater is the supply of sediments in the coastal zone (Zenkovich, 1967; Short, 1988; Goldsmith, 1980). This conclusion was checked by corresponding investigation in conditions of the Black and Azov Seas shores development. These conditions, as it has been shown, are specific and determine small height and width of sandy accumulative forms. We studied separate alongshore lithodynamical cells with relatively homogeneous conditions in each and compared sectors with saturated (great sediment supply) and non-saturated (a little sediment supply) alongshore drift flow in every of cells.

Long-term instrumental observations were carried out within several cells. In particular, conditions and processes of the development in North-Western lithodynamical cell between Odessa and the Danube delta were studied rather fully (fig. 1). Intensive sediments accretion have taken place in Jebriyan bay and the Ternovka terrace during last decades (fig. 4). In the late 30's on Ternovka terrace there was a beach, not more than 15 m wide along base of active clayey cliff (Zenkovich, 1967). By the beginning of the 70's the beach width reached 30-35 m, and it started to turn into a terrace. It was formed 10 years later and in 1981 its width was 48-53 m. The rested dune up to 1.5 m high was formed in its dorsal side. Up to 60 m^3/m of sand were accreted in its abovewater part. During all following years steady growth of the shoreline and the accumulative forms height were observed.

During 1981-1995 the shoreline prograted 55-66 m into the sea, i.e. the average rate was 4.2 m/year. The height grew 1.5 times and amount of sediments in the abovewater part of the terrace –3.8 times (fig. 4). The shoreline was on the place where in 1981 the depth was 2 m. Such phenomena made one aspect corresponding increase of linear and volumetric dimensions of coastal dunes.

However the expectations were not justified, dune crest were only 1.3-2.4 m higher than the beach surface. Such height also occurs on these sectors of the studied lithodynamical cell where the coastal zone is subjected to the acute sediment deficit, and the shoreline is retreating with the average rates from 1.3 to 3.1 m/year, as for instance, on the barriers of Budaki and Burnas limans, Ustrichnaya lagoon, in site of the Eastern frontal side of Jebriyan spit.

The northern shallow shore of Jebriyan bay (submarine slope inclination is 0.004) is also characterized by intensive sediment accretion (Vykhovanets, 1993). Here 120-150 10^3 m^3/year of sediments are accreted along shoreline of 9 km long. As the result the coastline grows with average rate up to 6 m/year during the period from 1863 to 1995. However, aeolian forms height is 1.0-2.0 m as on the majority of barriers and spits on the Black Sea coast.

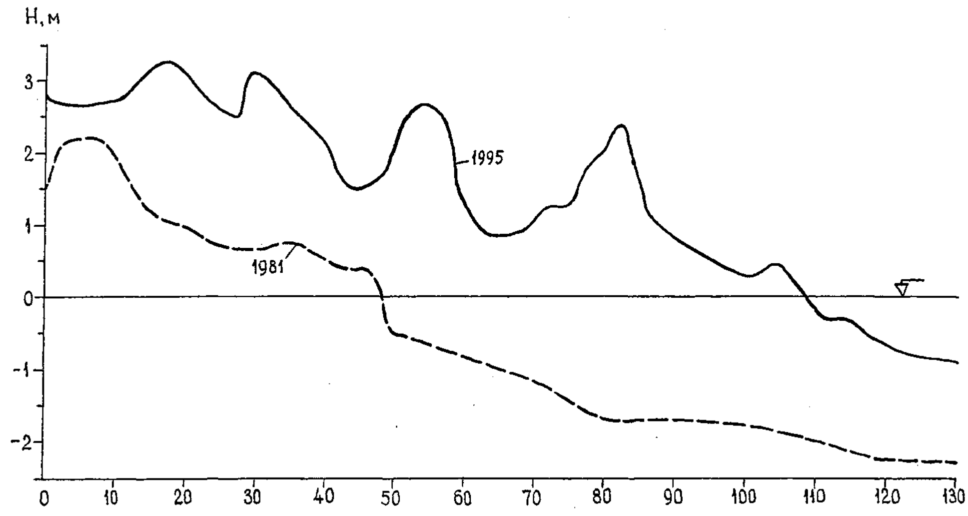

FIG. 4 - Curves of cross-sectional profile across Ternovka terrace according to the data of surveys in 1981 and 1995.

The distal side of Tendra spit with the very steep nearshore bottom (0.07) in the period from 1827 to 1993 grow with the average rate 4.5 m/year up to depth of 14 m, influenced by the sand accretion of approximately 360,000 m^3/year along 6 km of the shore length. Nevertheless coastal aeolian forms are embrional, and their height being not more than 0.5 m. The higher forms occur father, in the direction of Belye Kuchugury peninsula. At the same time dune ridges up to 1.5-2.0 m higher than the beach surface are observed on the sectors where the shoreline of Tendra spit is retreating with the average rate 1-3 m/year.

Examples can be continued, but those already given allow to conclude that not always increase of saturation of the alongshore drift flow leads to the exact corresponding growth of coastal dunes dimensions. Therefore, the conclusions of mentioned (Zenkovich, 1967; Short, 1988; Goldsmith, 1980) and not mentioned here authors cannot be considered universal. Process of aeolian forms development is more complex. The analysis showed that in conditions of prevailing wind direction from the land to the sea, essential influence of molluscs valves and then dry sand layer on the beach, limitation of the distance of wind flow momentum over the beach during storms, specific landscape structure essential decrease of aeolian sand movement intensity takes place. And this in its turn reduces coastal dunes feeding with sediment even there where the coastal zone is saturated with sediments.

CONCLUSION

Sandy shores of the Black and Azov Seas were studied in order to determine the peculiarities of the aeolian processes development. On these shores narrow (80-250 m) and low (1.5-3.0 m) spits, barriers and terraces prevail. Aeolian forms are also small here: up to 1.0-3.5 m (usually lower than 1.5 m) high. All this explained by prevailing of winds blowing in the directions from the land to the sea, and historically formed general deficit of sediments in the coastal zone.

Three main landscape elements («zones»): sea beach, the belt of aeolian forms, and limanic low swamped terrace are located. They interact closely and with higher intensity by means of stormy waves influence and storm-surge of the level rise on sandy shores. However, the higher the dunes on spits and barriers, the more prominent are the features of independent relatively autonomous development of each of three landscape zones and the importance of wave and set up is preserved only for the sea beach.

Wave energy flow is always an activest factor trying to more maximum amount of drifts for the development of aeolian processes. All other factors try to put out this energy or limit the area of wind action. Among such passive factors there are: disruptedness of the relief, composition and humidity of the sediments, wave surf and storm-surges, vegetation, etc.

Not always the increase of sediments supply on the way of alongshore drift flow within different lithodynamical cells lead to the corresponding increase of coastal dune sizes in natural conditions of the Black and Azov Seas coastal zone. On the sectors of saturation of the alongshore drifting and shoreline growth, the dunes may be of small size or be absent at all, and vice versa. The shown main features of sandy dunes development on Ukrainian shores are of great practical importance.

REFERENCES

GOLDSMITH V. (1989) - *Coastal dunes.* In: Davis R.A. (ed.), *Coastal Sedimentary Environments.* 2nd Ed. Springer Verlag, New York, 171-236.

HORIKAWA K., HOTTA S., KUBOTA S. & KATORI S. (1991) - *Field measurements of brown sand transport rate by tranch trap.* In: *Study of wind-blown sand on beaches, Japan.* Saitama Univ. Press, Tokyo, 213-232.

PYE K. (1983) - *Coastal dunes.* Progr. Phys. Geogr., 7, 531-557.

SHORT A.D. (1988) - *Wave, beach, foredune, and mobile dunes interaction in Southern Australia.* Journ. Coastal Res. Special Issue, 3, 5-10.

VYKHOVANETS G.V. (1993) - *Sandy accumulative forms within the Black Sea coastal zone.* In: Kos'yan R.D. & Magoon O.T. (eds.), *Coastlines of the Black Sea.* Am. Soc. Civil Eng., New York, 452-466.

VYKHOVANETS G.V. (1995) - *Impact of the vegetation on aeolian processes within coastal forms of the Black Sea.* In: Healy M.G. & Doody J.P., (eds.), *Directions in European Coastal Management.* Samara Publ., Cardigan, 325-334.

ZENKOVICH V.P. (1967) - *Processes of Coastal Development.* Oliver & Boyd, Edinbourgh, 738 pp.