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Human Impact and Rates of Shore Retreat Along the Black Sea Coast

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ABSTRACT

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The coast of the Black Sea is 4431 km in length, 47% of which is actively eroding. Much of the coast consists of cliffs, divided into three types: rockfall, landslide, denudation. Cliff erosion rates, for these types are: 0.3-0.5 m/yr to 4-5 m/yr; 0.1-0.3 to 2-3 m/yr; and 0.01 to 0.2 m/yr, respectively. Beach sediment available is: 5-7 m^3/m/yr in the Odessa region; 5-6 m^3/m/yr in the Western Crimea; and 3-6 m^3/m/yr on the Rumanian and Bulgarian coasts. Human impact has greatly accelerated erosion rates at many coastal sites; and there has been a policy change, from engineered structures to artificial nourishment, in dealing with this problem.

ADDITIONAL INDEX WORDS: *Beach erosion, Bulgaria, cliff retreat, erosion rates, Rumania, shore drift, Soviet Union, Turkey.*

INTRODUCTION

Field investigations and map analysis have provided considerable knowledge of erosional and prograded sectors of the Black Sea coast (SHUISKY, 1986a). Extensive accumulated data indicate that of the 4,431 km length of the Black Sea coast (Figure 1), 2,112 km (47%) consist of eroding cliffs. These cliffs may be divided into three types: rockfall (48%), landslide (41%), and denudation (11%) (SHUISKY, 1985; SHUISKY and SCHWARTZ, 1980a, 1980b; SHUISKY and SIMEONOVA, 1976).

Rockfall cliffs develop according to the classical scheme described by JOHNSON (1919) and ZENKOVICH (1946). At first the foot of the cliff is eroded, forming a niche or notch, which causes the collapse of the upper part of the cliff. The fallen blocks of rocks are disintegrated and reworked by wave action, and the resulting fragments are either distributed along the shore or transported offshore into deeper water. The foot of the cliff is then exposed to wave action again and the whole cycle is repeated anew. Such cliffs are usually 25-30 m high; as for instance, in Karkinitsky, Kalamitsky, and Feodosijsky bays, or in the vicinity of capes Tuzla (Rumania) and Shabla (Bulgaria).

Rockfall cliffs develop mostly in strata of unconsolidated sedimentary rocks (clay, loess, loam, sand, non-resistant limestone, marl, etc.). Rockfalls are frequent in such homogenous lithologies with similar physical and mechanical properties, and they result in comparatively steady annual rates of cliff retreat and sediment production.

As the resistance of the rock type increases, wave-erosion rates slow down and cliff height increases, up to 70-80 m and even 120 m, for example, on the Tarkhankut peninsula, and between Gelenjik and Tuapse, in the vicinity of capes Kalikra in Bulgaria, and Curu and Server on the Frakian coast in Turkey. Rock fragments at the foot of such cliffs are reworked for a longer span of time, and cliff resistance to wave erosion is, accordingly, prolonged.

Landslide cliffs are, generally, over 20-25 m high. They are made up of alternating layers of rocks of various kinds: clay, limestone, marl, shale, sandstone, and conglomerate. Accordingly, permeable and impermeable horizons alternate in cross-section. Wave erosion at the cliff foot makes the slope steeper and less stable, resulting in landslides involving huge co-

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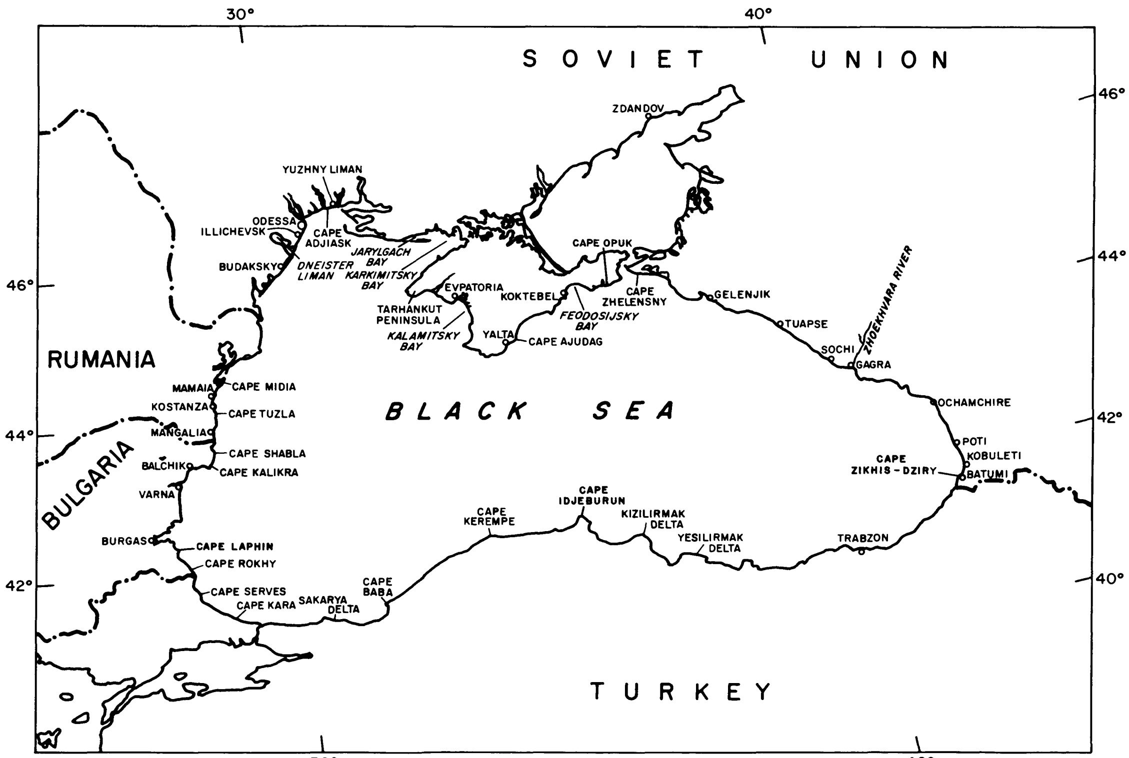

Figure 1. Black Sea location map.

hesive blocks of rock. These masses range up to 2,500-3,000 m^3/m, depending on cliff height, depth of the slide, and amount of shore retreat during the slide.

The time span needed for reworking this material by waves and the renewed erosion of slope steepness to the critical value depend on the strength and mass of the sliding block. No retreat occurs during this time, until, at last, a slide occurs and the shore retreats again. Landslide cycles of this type on the Black Sea coast vary from 2-4 to 60-70 years. The cycles are longer where the rocks are more resistant and wave action is weaker.

Denudation cliffs develop in conditions of highly resistant extrusive igneous and/or sedimentary rocks, where there is a shallow nearshore slope and little wave action. Physiochemical and biologic weathering and discharge of groundwater cause very slow shore retreat. Such cliffs are often considered stable, undergoing practically no retreat at all. Examples may be found on rocky shores near capes Ajudag and Opuk (Crimea), Cape Rolsky and Laphin harbor (Bulgaria), and Gelenjik harbor (Caucasus).

Abrasion rates of the different types of cliffs vary widely (SHUISKY, 1981). Generally, the highest rates are observed on the rockfall sectors, while the lowest are found on the denudation shores. Long-term comparisons of topographic maps and aerial photographs have been made for the Black Sea shores of the Soviet Union, Rumania, and Bulgaria (SHUISKY, 1981, 1986a). From these it appears that the usual erosion rates vary from 0.3-0.5 m/yr to 4-5 m/yr at rockfall cliffs, from 0.1-0.3 m/yr to 2-3 m/yr at landslide cliffs, and from 0.01 to 0.2 m/yr at denudation cliffs.

All three types demonstrate the obvious regularity that: the more resistant the rocks, the lower is the erosion rate. Rock strength is indicated primarily in one-axis compression strength (R comp, kg/cm^2), permeability, and solubility. These parameters have been used in the classification of rocks by resistance to erosion (SHUISKY and SIMEONOVA, 1976).

By their physical and chemical properties, according to this classification, the least stable rocks are consolidated sedimentary rocks composed of clay, carbonate and sand, of diluvium, alluvial, eolian, marine and deltaic origin. Rock resistance to erosion is decreased primarily by the influence of water, which leads to expansion, softening and dissolution, and, therefore, much faster weathering. Such rocks, under dry conditions, can provide durable preservation of cliffs, but when wet always have a negative impact on the stability of shores. Consolidated sedimentary rocks are widely represented on the shores of the Burgas, Odessa, Karkimitsky, and Kalamitsky bays, between capes Shabla and Midia, and near capes Zhelensny Rog, Zikhis-Dzirg, and Idjeburun. In general, about 1,100 km out of the whole length of the cliffs along the Black Sea coast are covered by unstable and fast-retreating slopes (SHUISKY, 1986a).

A most important cause of the modern retreat of active cliffs in this region is the sediment deficit in the shore zone. It is the reason for the small size of the beaches, 60-65% of the beaches being 10-20 m wide, with 10-30 m^3/m of sediment. Such beaches can not provide reliable protection of the shore from erosion. At least 130-150 m^3/m of sediment, with a width of 30-40 m and height of 1.8-2.2 m, are required for some degree of stability (SHUISKY and SCHWARTZ, 1980a, 1980b).

Retreat rates on the Soviet Black Sea shores have been measured at many different sites for 10 to 40 years (SHUISKY, 1981, 1986a). Each site was selected so as to represent the characteristics of a wider region. Experience has shown that the optimal length of a monitoring site varies from 0.2 to 1.1 km. Accuracy of the surveys is within ± 5 cm horizontally and ± 1 cm vertically (SHUISKY, 1981).

Another method employed in this study, mostly for the Rumanian and Bulgarian shores, was comparison of maps spanning a period of 120 to 150 years. The accuracy of this method, depending on map scales, is within ± 1.0-2.5 m (SHUISKY, 1985).

HUMAN IMPACT

Similar to other coastal sectors (BIRD, 1985; PASKOFF, 1981; SHEPARD and WANLESS, 1971; SHUISKY, 1982; WONG, 1981), human impact on the coast is observed near construction of maritime settlements, coastal-protection installations, ports and navigable channels, excavation of beach and nearshore sediment, and beach renourishment projects. Since eroding shores retreat under natural conditions at certain rates, if the rates at a particular site slow down or even approach zero, due to human intrusion, the impact is positive (beneficial); and if the rate of shore retreat increases after human intrusion, the impact is negative.

Research on the Black Sea coast shows that a positive impact is achieved through such coastal-protection measures as beach nourishment. The expediency of spending money on protecting settlements, industrial and transport facilities, or other valuable land is essentially determined by the relative costs of the protecting measures and the object under protection (MELESHKIN and STEPANOV, 1982). However, shore protection cost is usually ignored when the sites in question are cultural or historic memorials.

On the Black Sea shores traditional defensive structures, built of concrete and stone, are being implemented less and less frequently to protect actively eroding cliff sectors (ZENKOVICH and SCHWARTZ, 1987). Such protective structures are utilized mainly now in regions of extensive landslides, or when necessary in combination with embankments and replenished beaches. Examples are to be found at eroding sites within the cities of Odessa (Figure 2), Yalta, Tuapse, and Sochi (Figure 3).

Non-protected, replenished beaches are now being implemented more widely. They now extend for 2 km in Odessa, for 0.2 km in Koktebel harbor, and for 0.8 km in Gelenjik harbor. All in all, they now cover more than 40 km of the Black Sea coast, while the length of replenished beaches combined with protective structures exceeds 200 km (ZENKOVICH and SCHWARTZ, 1987).

Traditional shore protection structures are being improved, while others that have not proved reliable are being dismantled and removed. As the result of a new policy change,

Figure 2. Coastal protection structures at Odessa (Photo: M.L. Schwartz).

these are replaced by nourished beaches, either protected or non-protected. A frequently implemented artificial method is the building of embankments of heterogenous sediment. These are built to be eroded by waves, which separate the beach-forming fractions while reworking the material. In this manner beaches are nourished. A prime example (Figures 1 and 4) is near the entrance to Port Yuzhny (BERTMAN and SHUISKY, 1983). The same method has been utilized near the ports of Illichevsk, Evpatoria, and Zhdanov, and it has been particularly popular on the Soviet Caucasian coast near the towns of Gagra, Ochamchire, Poti, Kobuleti, and Batumi (ZENKOVICH and SCHWARTZ, 1987). The total area of nourished beaches has grown by 30 hectares over the last five years, preventing shore retreat along 25 km of coast. Nevertheless, old installations of concrete structures still serve as reliable shore protection near Cape Adjiask and near the cities of Mangalia, Odessa, Yalta, and Tuapse.

By-passing is not used on the coasts of the Black Sea due to the general deficit of beach-forming sediment, the amount supplied from all sources being about 7.1 m^3/m/yr, or 2.5 times less than the average for all of the world's shores (SHUISKY, 1981). Therefore, accumulated sediment lenses in front of piers, groins, and jetties are not large enough to provide sufficient material for viable downdrift beach protection. The required sediment is taken from sources on land.

Thus, nourished beaches are the only reliable approach to slowing down or stopping cliff retreat. Experience has shown that sandy beaches are mobile features (BRUUN and SCHWARTZ, 1985; SHUISKY and VYKHOVANETS, 1984), in contrast to rigid structures made of concrete, stone, or metal. It is the ability of beaches to change swiftly in response to new conditions that determines their stability and makes them a reliable protection for cliffs. Thus, they provide optimal dissipation of wave energy in the wave zone.

The beach-forming sediment deficit is caused by productivity of different sources of sedimentary material. The amount of sediment that is available to be deposited on Black Sea beaches varies in different coastal regions. For example, it is 5-7 m^3/m/yr on the northwestern coast, 5-6 m^3/m/yr in the Western Crimea, and 3-6 m^3/m/

Figure 3. Coastal protection structures at Sochi (Photo: M.L. Schwartz).

yr on the Rumanian and Bulgarian coasts. However, the minimum amount of beach-forming sediment (coarser than 0.1 mm), supplied by all sources, should be at least 30-50 m^3/m/yr in order to provide adequate protection of the shore against erosion (SHUISKY and VYKHOVANETS, 1983). In reality, the total amount of sedimentary material supplied to the sea is an order of magnitude smaller (SHUISKY, 1981). That is why densely populated coasts, where valuable property is located, require protection. All artificial removal of sediment from beaches and large accumulative forms is forbidden, even though this sediment is often the only available inexpensive source of sand and gravel for construction. In this connection it has been necessary to solve the task of selecting suitable sites where excavation of gravel and sand does not increase shore erosion (ideally, these are river flood-plains, inland glacial deposits, or raised former coastal deposits). Along the shore of the Black Sea the solution has been based on the proportion between the amount of such excavated sediment supplied to renourish the shore zone and the amount provided for construction.

Technological possibilities of industrial excavation of sediment at sea have also been studied. The shallower the depth of excavation, the more economical is the cost of excavation. Therefore, it is necessary to determine the limiting depth of the nearshore bottom within which the subaqueous profile undergoes the most noticeable changes and the bulk of the sediment is moved. These limiting depths have been found to be different in regions with different types of wave environment and nearshore bottom slope, and they vary from 5-6 to 12-13 m. The coastal sectors recommended for industrial excavation are in submerged relict

Figure 4. Cliff retreat downdrift, southwest, of the Port Yuzhny jetties and channel (Photo: Y.D. Shuisky).

coastal forms, located beyond the limiting depth of noticeable changes in the subaqueous nearshore bottom profile.

The deficiency of sediment in the shore zone along the Black Sea coast has been favorable for the operation of some ports and navigable channels. At the existing rates of cliff erosion and with the cliffs being largely composed of clay, the bulk of the eroded material (up to 85-90%) is removed in suspension to the open sea, with shore-drift involving only a minor part of it. Therefore, shore-drift volumes are rather small, usually within 3-7 m^3/m/yr. This means that ports and channels are filled with sediment much less frequently than on the shores of the Baltic and North seas (SHUISKY, 1986a).

On the other hand, where cliffs with a high rate of retreat are located near and updrift of port installations, the problem of sediment infilling and shoaling does occur. A great deal of funding has gone into protecting the ports at Illichevsk, Yuzhni, Evpatoria, Poti, Kostanza, and Mangalia.

Cliffed shores downdrift of harbor entrances and navigable channels are also a problem. With a further decrease in the sediment budget (SHUISKY and SCHWARTZ, 1983) at these sites, the downdrift beaches are subject to further depletion and, in turn, expose the base of the cliffs to renewed erosion and an increase in the rate of retreat.

SITE EXAMPLES

The influence of shore installations on Black Sea coastal dynamics has been studied since the beginning of the present century. For instance, a jetty built in 1914 at the estuary inlet of the Zhoekhvara River in the Caucasus has caused shore retreat amounting to 2-3 m/yr in the five years following construction.

Figure 5. Embankment built in front of cliff site shown in Figure 4 (Photo: Y.D. Shuisky).

Interception of shore-drift sediment at port installations has caused downdrift shore retreat since 1937 of 2-4 m/yr near Sochi harbor, 1-2 m/yr near Illichevsk harbor, and 1-3 m/yr near Mangalia harbor. Each of these sites is located in close proximity to the port entrance on the downdrift side of the port installation which acts as a sediment trap, and each constitutes a fairly local phenomenon.

On a larger scale, human intrusion that causes shore-drift interference in the middle of a drift cell (i.e., in the transport zone between cell origin and terminus) changes the balance of coastal processes along a whole region. The impact of port installations on shore dynamics within lengthy drift cells has been studied since the early 1960's in the Western Crimea and since the late 1960's in Georgia (Caucasus). Even more detailed studies have been conducted over the last 20 years between the bay of Odessa and Cape Adjiask. This latter drift cell is about 50 km in length. Eighteen profile stations have been maintained along this sector, with changes recorded across the cliff, beach, wave cut-platform, and nearshore bottom down to a depth of 10 m. Sediment samples were taken across each profile station in the years 1963, 1966, 1974, 1975, 1984, and 1985.

The outer installations (two jetties bracketing a navigable channel) of Port Yuzhny were engineered in this drift cell during 1972-1974. In the ensuing years the regional cliff sectors that were protected remained stable, but those that were not protected began to undergo higher rates of retreat.

Prior to construction, natural erosion rates within this drift cell were 0.5-0.7 m/yr, and the beaches were from 8 to 30 m wide (averaging 21.3 m). The jetties and channel interrupted the net shore-drift, resulting in narrower beaches. The beaches were reduced to 4-21 m widths (average 10.3 m), contained an average of 11.2 m^3/m of sediment (about ½ the prior volume), and mean grain size of the sediment increased by a factor of 1.6 to 2.6. The amount of sediment accumulated in the 11 m-deep channel and on both sides of the jetties has been calculated to be 35-40% of the available supply from all the different available sources.

As the beaches became narrower, rates of cliff retreat began to increase. Between 1975 and 1985 the rates varied from 1.16 to 2.71 m/yr, for an average of 1.77 m/yr. Incidentally, erosion rates increase from each end of the drift cell towards the port and are higher on the southwest, downdrift side. The series of photographs, Figures 4, 5 and 6, illustrate this problem, and how it has been dealt with by building a sediment embankment on the southwest side of the port entrance in order to provide beach nourishment in the downdrift direction.

The wide occurrence of sandy barrier beaches (liman coasts) on the Black Sea shores is favorable for the development of recreational facilities. Because of the sediment deficiency, the bars and spits are low (2.5-3.0 m above mean sea level), narrow (250-300 m wide on the average), unstable, and sensitive to changes in sediment budget (SHUISKY and SCHWARTZ, 1983) and wave regime. Most of the barrier beaches are closely associated with nearby cliff sectors (Figure 7), the source of their sediment; and the barriers and cliffs usually retreat together at the same rate over long periods of time (SHUISKY and VYKHOVANETS, 1983; ZENKOVICH, 1962). The mean rate of barrier beach retreat is between 0.5 and 3.5 m/yr (Figure 8).

The barrier beaches are frequently topped with sand dunes, up to 1.5-2.5 m in height above the beach surface, which are an important feature in providing barrier stability (SHUISKY, 1986b). The amount of wind-blown sand has been found to be clearly dependent on wind velocity and direction, grain size and moisture content of the sediment, vegetation density, and the general character of the dune-barrier relief. Any change in one or more of these parameters can upset the delicate balance within the regime, and thus jeopardize the stability of the dunes and barrier beach.

For example, both a high density of vacationers (approximately 1 person/2m^2/day) and intensive construction decrease vegetation and

Figure 6. Replenished beach developed from embankment material shown in Figure 5 (Photo: Y.D. Shuisky).

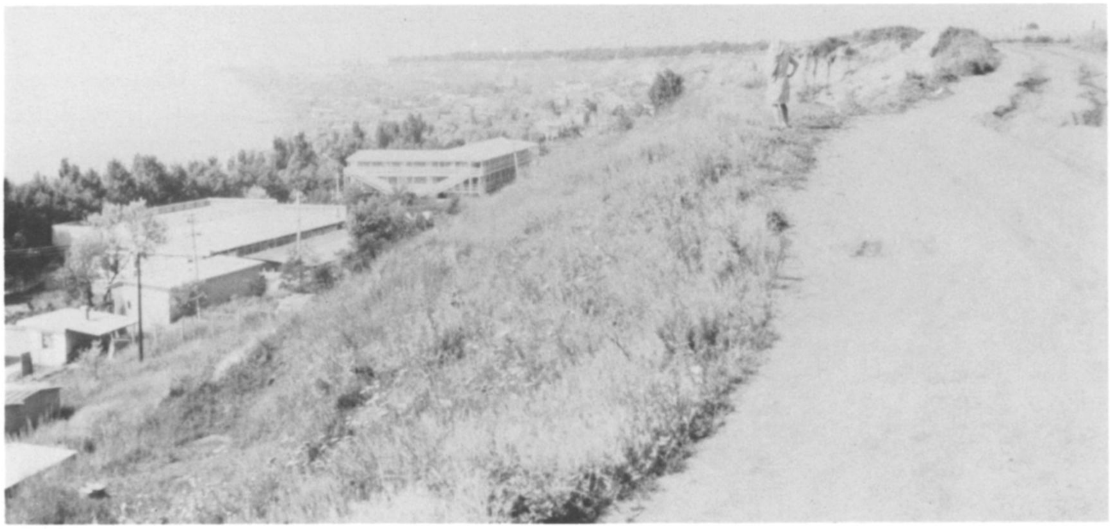

Figure 7. Cliff and barrier at the Dniester liman (Photo: M.L. Schwartz).

lead to deflation and erosion of the dunes and barriers. Typically, the Budaksky liman barrier, from measurements at 48 sites, has had a width varying from 44 to 140 m (the average being 90 m). Where there are very few visitors, at the southwestern end of the barrier, the average width is about 103.5 m; but at the northeastern end, where the density of vacationers is high, the average width is only 80.3 m. The height of the barrier varies from 1.05 m to 3.45 m (average 1.88 m), while the southwest and northeast sectors average, respectively, 2.04 and 1.47 m. The southwestern portion has retreated by 24 m and the northeastern by 39 m within the last 30 years. The same pattern exists at other barrier beaches around the Black Sea coast.

The climate is dry over most of the Black Sea coastal region. Average annual precipitation varies from 150-200 to 300-400 mm, while the mean July temperature is 20-22° C. Therefore, it is necessary to irrigate fertile land near the coast. And yet, irrigation saturates clay rocks, rapidly decreasing their competency, and shore erosion rates subsequently increase.

Due to irrigation of the land southwest of Odessa since 1983, there has been a threefold increase in landslide frequency and shore erosion rates have grown by a factor of 2.5. Water saturation of rockfall cliffs along Jarylgach Bay has increased erosion rates by 3 times. On the central shore sector of Kalamitsky Bay the average erosion rate was 1.26 m/yr between 1974 and 1980, before irrigation, and about 2.7 m/yr between 1981 and 1986, after irrigation was started (SHUISKY, 1981, 1985).

At Chernomorka Village, near Illichevsk, a combination of factors has caused the shore to erode at a rate of 1.5 m/yr, such that a large segment of the coastal road here has disappeared within the last 8 years. The rapid beach erosion has been attributed to both the nearshore mining of sand and the increase in groundwater accompanying rapid growth in the local population.

A few further observations concerning the southern and western coastal sectors of the Black Sea are as follows. The Black Sea coastline of Turkey is 1,701 km in length and consists mostly of cliffs. Three low areas prograding into the sea are the Yesilirmak, Kizilirmak, and Sakarya deltas (EROL, 1985). While these deltas are prograding (BIRD, 1985b), there is erosion in other sectors on the west and east (BUACHIDZE, 1974). On the Black Sea coast east of the Bosporus, the shore between Cape Baba and Cape Kerempe is eroding, with the sediment being transported offshore or drifting

Figure 8. Shore retreat at one of the barrier beaches in the northwestern part of the Black Sea (Photo: Y.D. Shuisky).

eastward. The coast is also retrograding near Trabzon. Farther east, the Coruh River supplies 3 million tons of sand and gravel to the coast each year. Some of this enters a submarine canyon, but the rest of the sediment enters a drift cell with terminal deposition at the port of Batumi. Human impact may soon have an effect on the resort beach at Mamaia, north of Kostanza. A long docking jetty, associated with an industrial petrochemical complex 5 km to the north of Mamaia, will be interferring with the southerly net shore-drift (CHARLIER and JULIO, 1985). Considering that the Black Sea coast of Rumania is only 245 km in length, this is a significantly endangered site. For the 378 km-long Bulgarian coast, SIMEONOVA (1985) documents widespread erosion by landslides and rockfalls in cliffed sectors and wave action at beaches: near Cape Shabla retreat is 0.01 m/yr in limestone cliffs and 8 m/yr at places in cliffs with exposed underlying clays; between Blacik and Varna stratified cliffs are retreating at up to 1 m/yr; and north of Burgas the Sarafavo landslide in Cenozoic clays forms a lobe that is cut back more than 20 m^3/m/yr by wave action. Elsewhere on the Bulgarian coast, SIMEONOVA attributes coastal erosion to human interference by the construction of ports and resorts, shore protection facilities, and by beach and nearshore mining of sediment.

CONCLUSIONS

As shown here, human activity along the Black Sea coasts may, as on other coasts of the world, have different impacts. In some cases it is harmful to the shore zone, while in others it can help to both develop and preserve valuable coastal sites. Impact of the latter kind can only be achieved when the coastal region has been well studied and the projects are both economically and scientifically well-grounded with respect to the local environment.

There have been many projects that have caused a site-specific deficit of sediment in the shore zone. Such developments either concentrate wave energy towards erosion of the shore or speed up the erosion already in progress by hindering the transport of sediment along the shore. Other forms of human activity decrease the stability of cliffs on barrier beaches, further facilitating increases in the rate of shore erosion and loss of property.

In the first half of the 20th century and earlier many settlements, roads, and other structures were built on the Black Sea coasts without proper consideration of the processes operating in the coastal zone. Subsequently, it turned out that many of these facilities had been located in unfavorable places, where the danger of erosion was quite high. As a result, substantial investments are now being required for the protection of these works from wave action and related processes (*i.e.*, eolian, fluvial, etc.).

Studies carried out in different countries bordering the Black Sea, as well as on the coasts of other seas and oceans, have shown that the negative impact of shore erosion can be mitigated in the following ways:

(1) After detailed studies of regional coastal processes, locate future development at sites where it will not be detrimental to the shore.
(2) Replenish beach sediment where development has interfered with the natural sediment transport.
(3) Minimize or abandon such activities that deplete the supply of sediment in the shore zone.
(4) Avoid practices which decrease the stability of cliffs along the coast.
(5) Monitor drift-cells in order to predict changes in the sediment budget which may have a detrimental effect upon coastal property.

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