Coastal modifications of the Caspian Sea and other central Asian lakes as natural models for coastal responses to the global sea-level rise

A. O. Selivanov

Lomonosov Moscow State University, Moscow, Russia

(Received February 25, 1994; accepted June 1, 1995)

Abstract. The problem of coastal response to recent and anticipated global greenhouse-induced sea-level rise attracts great attention from scholars, decision-makers, and the lay public. Re-modelling and destruction of coastal depositional bodies and erosional scarps will cause the heaviest losses amongst a variety of sea-level rise consequences. The Caspian Sea, Aral Sea, Issyk Kul Lake, and some other giant lakes in Central Asia are extremely sensitive to changes in climate humidity, river runoff, and human activity, and present an exceptional opportunity to observe directly the impact of water-level changes. Coastal morphology, nearshore bottom slope, and the profiles of depositional coastal bodies or erosional scarps, as well as rate and amplitude of water-level changes, appear to be the most important factors in coastal response rates and patterns. Strict analytical prediction of coastal response to a possible future accelerated sea-level rise is yet to be achieved. Various modifications of the Zenkovich-Bruun Rule can be used only as a first approximation in these studies. A comprehensive methodology based on field data and simple quantitative approaches made it possible to present a general overview of future coastal evolution in the former USSR.

1. Introduction

Estimates of global greenhouse-induced sea-level rise in the next century range from a few decimeters to four meters and we have no reliable corroboration to favour one estimate over another. The Intergovernmental Panel on Climate Change (Houghton et al., 1990) agreed unanimously on a 65 ± 35 cm rise in global sea level until 2100. The revised emission scenarios led the members of the Panel to the estimates of 51 ± 37 cm (Wigley and Raper, 1992). Global sea-

Corresponding author: A. O. Selivanov; Lomonosov Moscow State University, Geography Department, Vorobyovy Gory, Moscow, 119899, Russia; e-mail: selivano@glas.apc.org

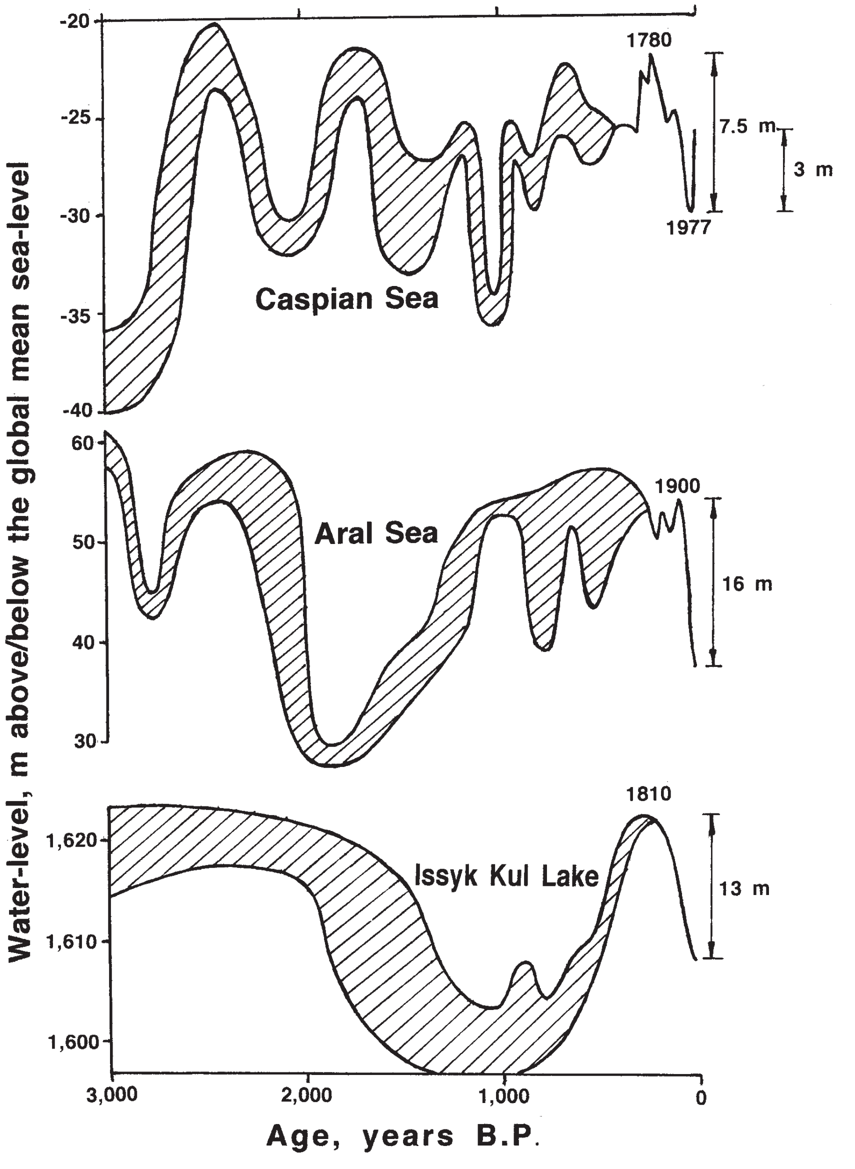

Fig. 1 - Water-level changes in the largest enclosed lakes in Central Asia during the last 3 millennia, after various sources. Hatched area shows a variety of paleogeographical and historical estimates for each lake.

level rise over one meter during the next century is, therefore, less probable, but cannot be totally excluded as yet.

Moreover, even a few decimeters rise in sea level would have substantial negative impact on a global scale. Inundation and storm surges would increase their frequency and heights, saltwater intrusions into estuaries and coastal aquifers would cause problems in water supply and coastal ecosystem survival. Passive coastal inundation would result from a sea-level rise only on a

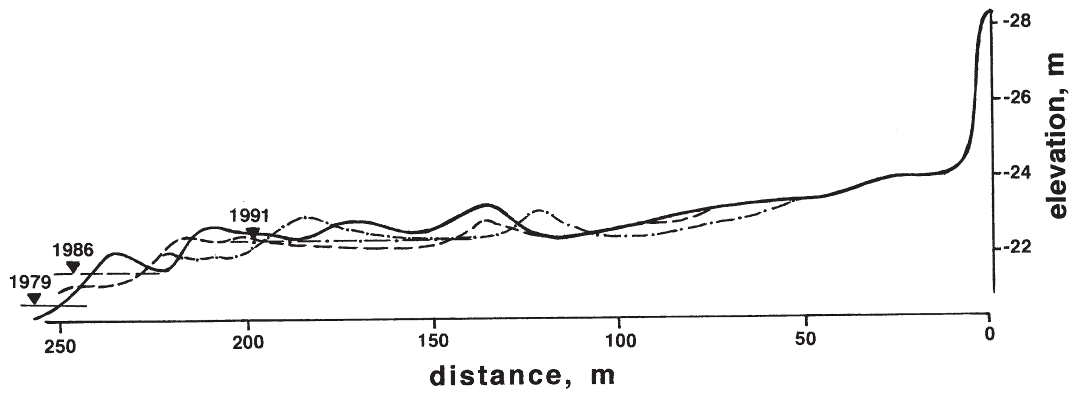

Fig. 2 - Morphological changes in the shoreline-normal profiles near the town of Lenkora, Azerbaidzhan, south-western coast of the Caspian Sea, in 1979-1991.

few coasts: in small semi-enclosed bays and on very gentle-sloping coasts, i.e., where wave energy does not reach the shoreline. In most cases, an active re-modelling of the coastal profile will be inevitable. As a first approximation, coastal reformation due to sea-level rise can be divided into retreat of erosional scarps (sea cliffs), and reformation of coastal depositional bodies, usually combined with a general tendency to their destruction.

2. The Zenkovich-Bruun Rule and its limitations

Shoreline retreat due to sea-level rise is widely believed to be adequately predicted by a law which postulates equality between erosion of sediments on a beach during the sea-level rise and their deposition in the nearshore, together with preservation of the transverse profile. In Russia, this rule was proposed by Zenkovich (1959, 1967) and his successors. American and European scholars involved in related problems denominate a similar model by the Bruun Rule (Schwartz, 1967) after the pioneering studies by Bruun (1962). According to Bruun, horizontal shoreline retreat R after the rise U of relative sea level is given by

$$R = U\,B/D, \tag{1}$$

where B = width of wave-induced bottom zone, and D = its maximal depth.

However, this simple model adequately describes coastal evolution only for a narrow boundary conditions:

(a) slow sea-level rise in comparison to shoreline retreat, i.e., $R >> U$ (Allison, 1980);

(b) general availability of sediments to maintain an equilibrium profile;

(c) exclusively shoreline-normal sediment movement by waves in seaward direction;

(d) existence of a seaward limit of sediment movement by waves or any other factor ("lower

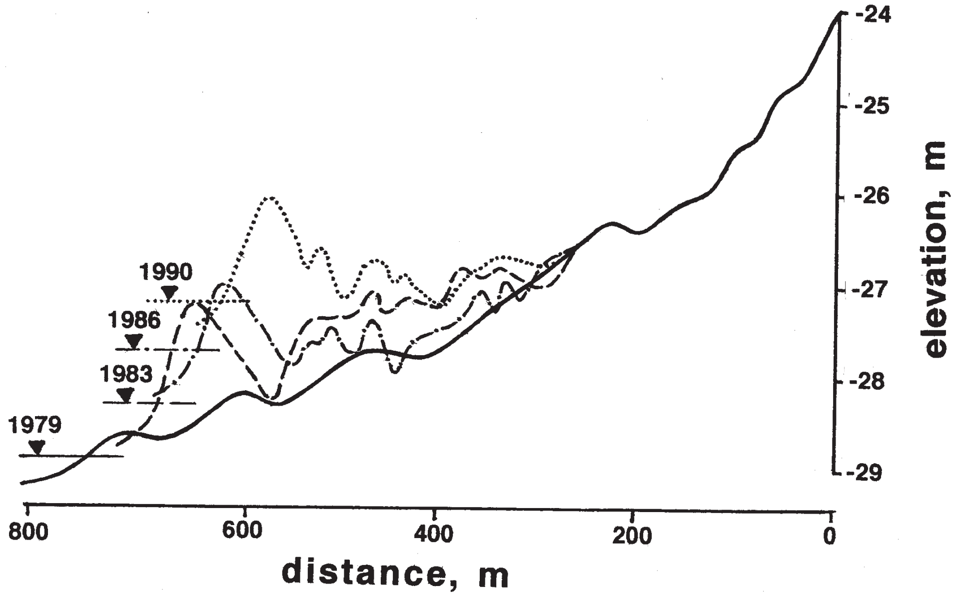

Fig. 3 - Morphological changes in the shoreline-normal profile 15 km south to the entrance to the Kara Bogaz Gol Bay, Turkmenistan, south-eastern coast of the Caspian Sea, in 1979-1990.

limit of an underwater coastal slope", or "wave base") (Dean, 1990; SCOR Working Group, 1991).

Therefore, determination of the "wave base" becomes an important problem and depends upon wave parameters. According to various authors, the "wave base" varies from 1.5 to 3.5 heights of 5% waves beyond the breaking zone (Zenkovich and Popov, 1980; Bruun, 1988). Generally, over 90 percent of longshore sediment transport occurs above this "wave base".

To account for the possible variety of parameters mentioned in (b)-(d), as well as for other processes involved into reformation of the coastal zone, different modifications of the Bruun Rule were developed (see: Selivanov, 1993, for the review).

If waves break at offshore submerged ridges, an inclination of their seaward slope should be included into the Eq. (1) (Dubois, 1977). Sedimentary movement from shoreface to backshore can be indirectly taken into account if an elevation, e, of a coastal dune is included into the traditional Bruun equation (Weggel, 1979):

$$R = U\,B/(D+e). \qquad (2)$$

Oppositely, an aeolian offshore transport of sediments was quantified in the "modified" Bruun Rule by Edelman (1970). He postulates a decrease in elevation of a coastal dune in proportion to the value of sea-level rise:

$$R = B1\ \ln[(D+e)/(D+e-U)], \qquad (3)$$

where $B1$ = width of an active coastal zone, from the seaward limit of an underwater coastal

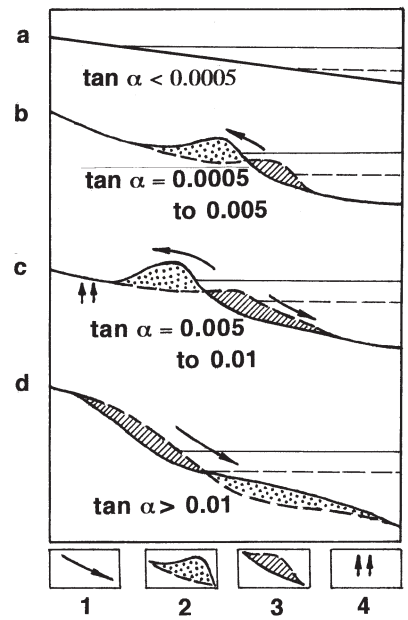

Fig. 4 - Different types of coastal zone natural evolution during sea-level rise. Differences in schemes (a)-(d) are caused mainly by inclination (tan a) of the underwater coastal slope. Dotted lines show profiles before the sea-level rise; solid lines - profiles after the sea-level rise. (1) Dominant direction of the transverse movement of sediments; (2) deposited part of the profile; (3) eroded part of the profile; (4) rise in the underground water level.

slope to the crest of a coastal dune.

The so-called "generalized" Bruun Rule (Dean and Maurmeier, 1983) allows us to account for sediment washover to the lagoon:

$$R = U(B1+W+B2)/(h1+D+e-h2-D2), \tag{4}$$

where $h1$ = elevation of a beach berm, $B2$, $D2$, and $h2$ = respective parameters of a landward (lagoon) slope of the barrier island, W = its width.

The last model postulates raising of a barrier island in proportion to sea-level rise and maintenance of its width. Hands (1983) was the first to account for possible outflow of fine particles in suspension under storm conditions to the offshore and lower shelf zones:

$$R = UB(1+F)/D, \tag{5}$$

where F = portion of fine particles (usually less than 0.005 mm) in surficial coastal sediments.

Models (2)-(5) usually bring higher estimates of shoreline retreat than those based on the traditional Bruun Rule. Three-dimensional modifications of the Bruun Rule (e.g., Bruun, 1988) require for the variety of parameters difficult to obtain.

Moreover, field studies in many coastal areas reveal that under special conditions coastal evolution patterns differ significantly from the above model and can hardly be predicted by any

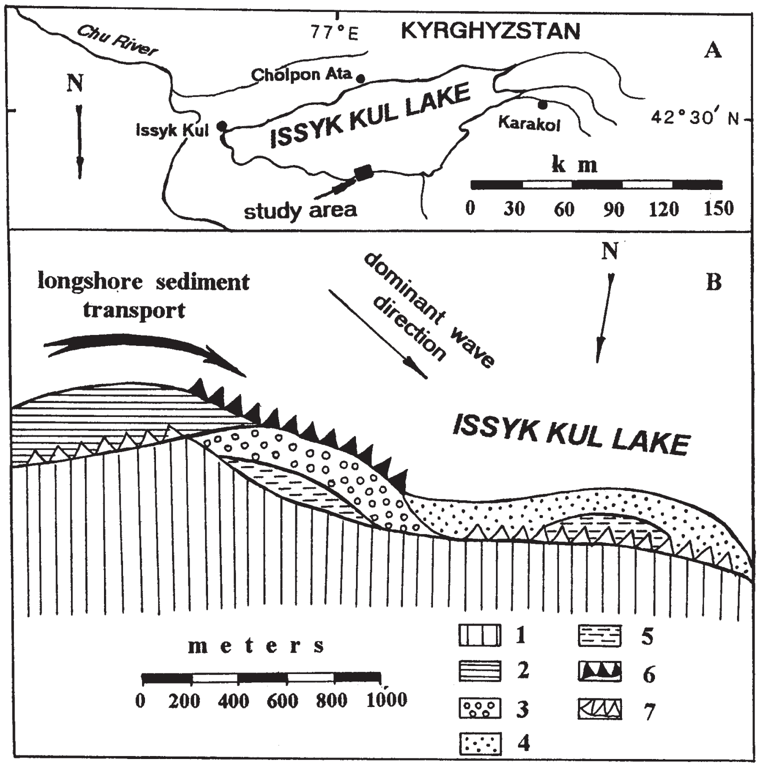

Fig. 5 - General position (A) and present situation (B) in the study area on the south coast of the Issyk Kul Lake: (1) mid-Holocene sandy coastal terrace; (2) late-Holocene loamy coastal terrace; (3) gravel coastal barrier; (4) sandy coastal barrier; (5) lagoon; (6) active cliff; (7) inactive cliff.

analytical approach (Pilkey and Davis, 1987; Dean, 1990; Leatherman, 1990; Healy, 1991; SCOR Working Group, 1991).

3. Central Asian lakes as "natural laboratories" of coastal response to water-level changes

The Caspian Sea, the Aral Sea, the Issyk Kul Lake, and some other giant "sea" lakes in arid and semi-arid Central Asia show significant water-level changes on every time scale, representing changes in climatic humidity, river runoff, and human activity (see Selivanov, 1997, for the review on this problem). Changes in their water levels on a century-to-century time scale are as high as 15-20 m (Fig. 1). The Caspian Sea water-level, for example, has risen at a rate of over 10 cm/year since 1978, after a period of intensive water-level fall in the 1930s-1970s. Agricultural and recreational areas, a number of towns, villages, and industrial structures have fallen in danger of inundation and erosion during the last two decades. The Aral Sea water-level has fallen by over 15 m since the 1900s. Its water surface area has decreased three-fold, leaving arable land, settlements, and harbours without water, and changing the regional climate significantly. Water-level of the Issyk Kul Lake has fallen by 13 m during the last two centuries.

Table 1 - Shoreline retreat (m) in the shore-normal profile near the town of Lenkoran, Azerbaidzhan (see Fig. 2).

Years	Field data	Bruun rule (Eq. 1)	"Modified" Bruun rule (Eq. 3)
1979-1986	20-25	130-150	90-105
1986-1991	30-40	80-95	55-65

Therefore, these giant water bodies can serve as excellent "natural laboratories" for studying the impact of sea-level rise. Comparison of tendencies in coastal evolution during the periods of water-level fall and rise in the Caspian Sea confirms a limited applicability of the Zenkovich-Bruun Rule. During the water-level fall by over 3 m in 1930-1977, shallow nearshore bottom zones in the North Caspian basin (Kizlyar and Komsomoletz Bays) and in the south-western corner of the sea (Kirova Bay) emerged at a rate of over 100-150 m/year. The water surface area of the Kara-Bogaz-Gol Bay decreased by 30%, and a 3-meter waterfall formed in the inflow channel from the main Caspian Sea water body.

In general, depositional processes prevailed on the Caspian coasts during that period. Many depositional coastal bodies (beaches, dunes, spits, and barriers) increased their sizes and volumes. The Agrakhan Spit doubled its width and increased in length by 3-4 km (Ignatov et al., 1993). In the delta fronts of the Volga, Urals, and Terek rivers, shorelines advanced by 150-600 m each year. In the Kura and Sulak River deltas, shoreline advanced strongly until the middle 1950s. However, hydraulic engineering including reservoir construction in the middle river reaches, has resulted in a drastic reduction of sedimentary discharge to deltas of the Sulak, Samur, and Kura rivers (by 25-75%), and in intensive erosion of delta fronts since the late '50s.

Under the recent water-level rise, most depositional shorelines have undergone shoreward migration and erosion. The pattern of their response to water-level rise vary from one coastal segment to another. Where nearshore bottom slope and beach slope is very gentle (usually lower than 0.0005), passive inundation of coastal lowlands occurs. Over 20,000 sq. km have already been inundated on the coasts of the North Caspian basin. Depositional coastal bodies on the coasts with relatively gentle nearshore bottom slope retreat landward without significant re-modelling. A case study area in the south-western corner of the Caspian Sea, near Lenkoran City in Azerbaidzhan, represents an excellent example (Fig. 2). This coastal segment is characterized by the presence of three to four sand beach ridges, medium nearshore bottom slope (0.003-0.005), and a roughly shoreline-transverse dominant wave direction. During water-level rise periods, a system of beach ridges migrate landward, preserving their general dimensions. The shoreline retreat in 1979-86 totaled 20-25 m, whereas different modifications of the Bruun equation lead to the estimates of 100-125 m (Table 1). "Modified" Bruun Rule (Eq. (3)) can serve as a best approximation In the subsequent period (1986-1991), the shoreline retreat intensified, possibly due to exhaustion of bottom sedimentary sources and acceleration of water-level rise. This response pattern is a characteristic feature of coastal segments with relatively gentle nearshore bottom slopes (usually 0.0005-0.005) and ample sediment supply. On several coastal segments of this type, where sedimentary nourishment from adjoining rivers or eroding coastal scarps is extremely high, the shoreline continues its advance notwithstanding the water-level rise. Kilyazi

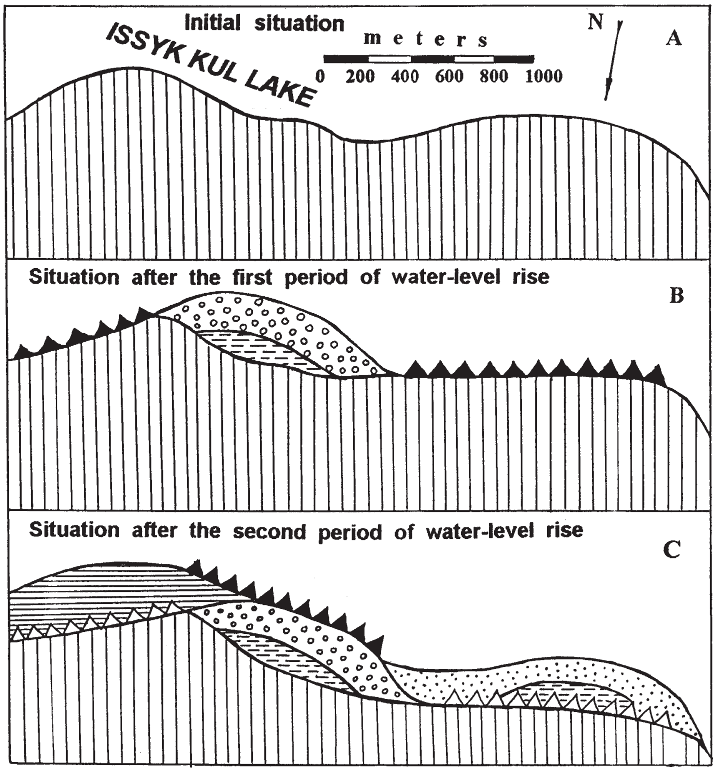

Fig. 6 - Geomorphological changes in the study area on the Issyk Kul Lake (see Fig. 5) during the last 3500 years: (A) before the first period of water-level rise (approximately 3500 B.P); (B) after the first period of water-level rise (approximately 2000-1500 years B.P); (C) after the second period of water-level rise (the last 150 years). See Fig. 5 for an explanation of the geomorphological units.

Spit in Northern Azerbaidzhan, and the Turkmenian coast north of Krasnovodsk Spit can serve as examples.

Different situation occurs on the depositional segment of the east Caspian coast, south of Kara-Bogaz-Gol Bay in Turkmenia, where nearshore bottom slope is higher (0.006-0.008) (Fig. 3). A low-energy sand depositional terrace up to 600 m in width formed there during the water-level fall in 1930-1977. Under the recent water- level rise since 1978, a sand ridge of up to 1.5-1.8 m in elevation and 40-60 m in width has emerged on the beach. The rise in underground water-level resulted in lagoon formation behind the ridge. The beach ridge migrates landward from year to year, and the total width of the beach decreases due a shoreline retreat, whereas the water surface area of the lagoon increases. However, rates of shoreline retreat are lower than those predicted by the Bruun approach (Table 2). "Generalized" Bruun Rule (Eq. (4)) leads to the best-fit estimates. Such an evolutionary pattern is typical of coastal segments with moderate nearshore bottom slope (usually 0.005-0.01).

On steeper coasts, presumably in Dagestan and Azerbaidzhan, rates of coastal destruction and shoreline retreat are higher. In places they exceed the Bruun Rule-based estimates. A significant portion of sediments on these coasts is cast ashore and washed over to the landward slope of an depositional feature. Other portions may be drawn into a longshore current or moved down the bottom slope to depths where waves do not act.

Therefore, as was first stated by Pavel Kaplin (1989), the nearshore bottom slope determines not only shoreline retreat values, according to the Bruun Rule, but also the very patterns of coastal evolution (Fig. 4). The model was further elaborated by Kaplin and Selivanov (1995). The similar model of coasatal evolution depending upon the nearshore bottom slope was independently proposed by Ignatov et al. (1993).

Erosional coasts are also seriously affected by reverses in water-level change. During the water-level fall period, inactive cliffs composed of Paleogene and Miocene sands and clays in shoreline concavities on the eastern Caspian Sea coast (Mangyshlack and Cheleken Peninsulas) and near Manas in Dagestan were protected by wide beaches, and erosion occurred only on capes or under storm surge conditions. Under the recent water-level rise these beaches are subject to inundation and erosion, thus activizing cliff retreat. On some coastal segments, the rate of this latter process has increased by a factor of between 3 to 5 since 1978.

4. Special effects in the coastal response to water-level rise

Under conditions of substantially oblique wave directions, longshore sediment movement, and changes in shoreline contour can result in unequal coastal responses during two successive periods of water-level rise. A visual demonstration of this phenomena was found on the Issyk Kul Lake (Fig. 5). Two generations of coastal sand barriers, 11-12 and 7-8 m in elevation, flank a high (20-25 m) terrace, and separate small ancient lagoons from the lake. Inactive and active erosional scarps in coastal barrier and high lake terrace slopes indicate the spatial positions of eroded coastal segments. It appears that a sort of "rotation" of the coastline contour occurred from one high water-level period, dated 2,985 ± 380 years B.P. by the C-14 method, to another one (450 ± 120; 470 ± 130 years B.P). Accretional segments of the coastline became erosional ones, and vice-versa. I call this phenomena coastal intransitivity. A similar process of shoreline "rotation" was demonstrated for barrier islands on the US Atlantic coast (Dolan et al., 1989).

However, the water-level rise since 1978 has not significantly affected general evolutionary patterns of many river deltas in the Caspian Sea. The Kura, Sulak, and Samur river deltas continue their erosion caused primarily by human intervention. Passive inundation of low-lying areas remains the primary evolutionary process in the Volga River delta. A possible reason for this lies in higher water and sedimentary discharges of the Volga River (by 20-30%) due to the wetter climate of the Russian Plain in the 1980s.

Rate and amplitude of water-level rise serve as other important factors influencing coastal response patterns. Over time scales of hours and days (i.e., single storms or wind surges) rates and values of shoreline retreat on many segments of the Caspian Sea coasts appear to be proportional to the elevation and duration of the water-level rise episode. However, as was first stated by Allison (1980), the Bruun Rule can be applied only to small water-level changes relative to the width of the equilibrium coastal zone profile. The necessary assumption of an equilibrium pattern for all coastal modifications severely limits application of the Bruun Rule. The possible

Table 2 - Shoreline retreat (m) in the shore-normal profile south to the entrance to the Kara Bogaz Gol Bay, Turkmenistan (see Fig. 3).

Years	Field data	Bruun rule (Eq. 1)	"Modified" Bruun rule (Eq. 4)
1979-1983	70-80	90-110	60-75
1983-1986	40-50	115-140	75-90
1986-1990	25-30	105-125	70-85

sea-level rise over the next century may reach significant rates and turn coastal evolution into essentially disequilibrium patterns. Shoreline migration would lag behind sea-level rise. SCOR Working Group members (1991) believe the time lag to be the primary reason for the fact that shoreline migration values on wave-dominated ocean coasts after single storms are usually 3 to 6 times lower than those predicted by the Bruun Rule.

Coastal barrier islands, spits, and similar detached depositional bodies represent specific coastal features which would be certainly among the most sensitive under the anticipated sea-level rise. Only slow sea-level changes favour the formation of depositional coastal barriers (Zenkovich, 1959; Leontyev, 1960; Dolotov, 1992). According to Leontyev (1960), coastal barriers do not form at all if the sea level changes faster than 2.5 mm/year, whereas in the next decades the rate of greenhouse-induced sea-level rise could possibly become as high as 10 mm/year. The correlation in intensity of seaward slope erosion and landward migration depends upon various factors. Instrumental data for sand barriers, primarily on the US Atlantic coast, prove that landward migration generally does not exceed 5-7 m/year. According to Shuisky and Vykhovanetz (1989), under the present sea-level rise, coastal barriers on the north-west Black Sea coasts maintain their width by migrating at similar rates. However, in the 21st century retreat of seaward slopes of many coastal depositional bodies can possibly accelerate to 10-15 m/year. Therefore, narrowing of depositional bodies would become inevitable. It would take only a few decades for most of them to narrow to the critical widths, 100-200 m. Later, they would suffer from multiple fracturing and become islands or totally disappear. One can monitor these processes of sand barrier destruction on the Caspian Sea. It has taken only one decade of water-level rise, since 1978, for Kura Spit and Sara Spit on the south-western coast to be broken in their proximate segments and turned into fast-disappearing islands.

The above data comprised an important part of the comprehensive methodology applied to the elaboration of the first small-scale predictive map of coastal USSR evolution under a possible future greenhouse-induced global sea-level rise, and a series of medium-scale maps for the Black Sea and the Sea of Azov (Kaplin et al., 1993), the Baltic Sea, the Bering Sea, etc.

5. Conclusions

Strict analytical prediction of coastal response to accelerated sea-level rise is yet to be developed. Coastal morphology, nearshore bottom slope, and profiles of depositional coastal bodies and erosional scarps, as well as rate and amplitude of water-level change, appear to be the primary factors influencing coastal response rates and patterns. Various modifications of the Zenkovich-Bruun Rule, as well as recent and ancient natural analogs can be used only as a first approximation in these studies. Boundary conditions for each quantitative model should be thoroughly studied. Where possible, longshore sediment drift and sediment washover onto the landward slope of a depoisitional coastal features should be accounted for. Natural analogs from the giant Central Asian lakes, which are extremely sensitive to climatic changes, make it possible to demonstrate obviously important coastal response processes and patterns.

Acknowledgements. This study was supported by the Russian Foundation for Basic Research (grant No. 95-05-14925a). A fellowship from the University of Trieste made a comparison of results with those obtained in the North Adriatic Sea possible. Special thanks are extended to Prof. Antonio Brambati and Dott. Sandro DeMuro ("Dipartimento di Scienze Geologiche, Ambientali e Marine", University of Trieste).

References

Allison H.; 1980: *Enigma of the Bruun Formula in shore erosion.* In: Fisher J. J. and Schwartz M. L. (eds), Proc. Per Bruun Symp. UGU Comm. on Coastal Environment,Western Washington Univ., Bellingham, pp. 67-78.

Bruun P.; 1962: *Sea level rise as a cause of shore erosion*. ASCE J. Waterways and Harbour Div., **88**, WW1, 117-130.

Bruun P.; 1988: *The Bruun Rule of erosion by sea-level rise: A discussion on large-scale two- and three-dimensional usages.* J. Coast. Res., **4**, 627-648.

Dean R. G.; 1990: *Beach response to sea-level change.* In: Mehaute B. and Hanes D. M. (eds), The Sea, Vol. 9, John Wiley Publ., Chichester, New York and London, pp. 197-225.

Dean R. G. and Maurmeier E. M.; 1983: *Models for beach profile responses.* In: Komar P. D. (ed), Handbook of Coastal processes and Erosion, Coastal Research Center, Boca Raton, Fl., pp. 151-166.

Dolan R., Trossbach S. and Buckley M.; 1989: *Patterns of erosion along the Atlantic coast.* In: Magoon O. (ed), Barrier Islands: Process and Management. Proc. Coastal Zone '89 Conf., Charleston, S. C., pp. 111-126.

Dolotov Yu. S.; 1992: *Possible types of coastal evolution associated with the expected rise of the world's sea level caused by the greenhouse effect*. J. Coast. Res., **8**, 719-726.

Dubois R. N.; 1977: *Predicting beach erosion as a function of rising water level*. J. Geol., **85**, 470-475.

Edelman T.; 1970: *Dune erosion during torm conditions.* In: Proc. 12th Int. Conf. Coastal Engineering. Am. Soc. Civ. Eng., New York, 1305-1307.

Hands E. B.; 1983: *The Great Lakes as a test model for profile responses to sea level changes.* In: Komar P. D. (ed), Handbook of Coastal Processes and Erosion, Coastal Research Center, Boca Raton, Fl., pp. 167-189.

Healy T.; 1991: *Coastal erosion and sea-level rise.* Z. Geomorphol., Supplementbd., **81**, 15-29.

Houghton, J. T., Jenkins G. J. and Ephraums J. J. (eds); 1990: *Climate change*: *The IPCC scientific assessment*. Cambridge Univ. Press, Cambridge, 364 pp.

Ignatov E. I., Kaplin P.A., Lukyanova S. A. and Soloviova G. D.; 1993: *Influence of the recent transgression of the Caspian Sea on its coastal dynamics*. J. Coast. Res., **9**, 104-111.

Kaplin P. A.; 1989: *Shoreline evolution during the twentieth century*. In: Ayala-Costanares A., Wooster W. and Yanez-Arancibia (eds), Oceanography 1988, Mexico Auton. Univ., Mexico City, pp. 59-64.

Kaplin P. A. and Selivanov A. O.; 1995: *Recent coastal evolution of the Caspian Sea as a natural model for coastal responses to the possible accelerated global sea-level rise.* Mar. Geol., **124**, 161-175.

Kaplin P. A., Porotov A. V., Selivanov A. O. and Yesin N. V.; 1993: *The north Black Sea and the Sea of Azov coasts under a possible greenhouse-induced global sea-level rise.* In: Magoon O. and Kosyan R. (eds), Coastlines of the Black Sea: Coastlines of the World, Amer. Soc. Civ. Eng., Middletown, CA, pp. 316-354.

Leatherman S. P.; 1990: *Modelling shore response to sea-level rise on sedimentary coasts.* Progr. Phys. Geogr., **14**, 447-464.

Leontyev O. K.; 1960: *Types and formation of lagoon on present sea coasts.* Morskaya Geologiya (Marine Geology), **1**, 186-194 (in Russian).

Pilkey O. H. and Davis T. W.; 1987: *An analysis of coastal recession models*: *North Carolina coast.* Soc. Econ. Paleontol. and Miner. Spec. Publ., **41**, 59-68.

Schwartz M. L.; 1967: *The Bruun theory of sea-level rise as a cause of shore erosion.* J. Geol., **75**, 76-91.

SCOR Working Group '89; 1991: *The response of beaches to sea-level changes: A review of predictive models.* J. Coast. Res., **7**, 895-921.

Selivanov A. O.; 1993: *Modelling response of accumulative coasts to the possible future sea-level rise: General approach and examples from the former U.S.S.R. coasts.* In: Proc. Int. Workshop Sea Level Changes and their Consequences for Hydrology and Water Management, Noordwijkerhout, The Netherlands, April 1993, pp. 1Y.63-1Y.74.

Selivanov A. O.; 1997: *Fluctuations of water level in the Caspian Sea over different time scales as an indicator of climatic changes.* Palaeogeogr., Palaeoclimatol., Palaeoecol., in press.

Shuisky Yu. D. and Vykhovanetz G. V.; 1989: *Exogenic processe in evolution of accumulative coasts in the north-west Black Sea. Nedra Publ*., Moscow, 198 pp. (in Russian).

Weggel R. J.; 1979: *A method for estimating long-term erosion rates from a long-term rise in water level.* Coastal Eng. Techn. Aid. No.79-2. Coastal Research Center, Boca Raton, Fl., 72 pp.

Wigley T. M. L. and Raper S. C. B.; 1992: *Implications for climate and sea level of revised IPCC emissions scenarios.* Nature, **357**, 293-300.

Zenkovich V. P.; 1959: *On the genesis of cuspate spits along lagoon shores*. J. Geol., **67**, 269-277.

Zenkovich V. P.; 1967: *Processes of Coastal Development.* Oliver and Boyd, Edinbourgh and London, 738 pp.

Zenkovich V. P. and Popov B. A. (eds); 1980: *Sea Coastal Zone: Terminological Glossary*. Mysl' Publ., Moscow, 200 pp.