GEOGRAPHIA POLONICA
2010, 83, 1, 51–60

DYNAMICS OF THE POLISH COAST EAST OF USTKA

WACŁAW FLOREK, JACEK KACZMARZYK, MAREK MAJEWSKI
Department of Geomorphology and Quaternary Geology,
Institute of Geography and Regional Studies, Pomeranian University in Słupsk,
Partyzantów 27, 76-200 Słupsk, Poland
E-mail: florekw@apsl.edu.pl; kaczmarz@go2.pl; marekmajo@o2.pl

Abstract: The objective of the investigation presented here has been to verify schemes for the development of cliff coasts proposed earlier by Subotowicz (1982). This is *i.a.* justified by observations suggesting greater differentiation to the geological structure and consequent hydrogeological characteristics of the Southern Baltic cliffs than had been assumed by the authors of earlier works. The measurement data for the investigated profiles yielded by the work to date show that:

– the most dynamic zone on the coast is the beach,
– clifftops are the parts least resistant to destruction,
– the strong storms of late autumn 2004 and the 2005/06 and 2006/07 seasons proved capable of activating the cliffs at nine of the ten investigated profiles, though no relationship was found between the lithology of the sediments building the cliffs and rates of erosion.

Key words: coastal zone, cliff, Southern Baltic, extreme storms, erosion.

INTRODUCTION

The Polish coast east of Ustka is of a quite diversified character, though mainly assuming the form of eroded cliff coast. The sub-Pleistocene surface is significantly variable, having been transformed by the exarative action of the ice-sheet. The thickness of the Quaternary layer varies from ca. 120 m near Lake Wicko, via 40 m in Ustka to over 130 m east of the Łupawa mouth. The heights of cliffs in turn vary from 3-5 m at Ustka (km 236-233), via 12-15 m along the Orzechowo-Poddąbie stretch (km 230-225) and 25 m at Dębina (km 222), to 4-5 m at Rowy (km 220-217) (Fig. 1).

Except by the the mouths of the Słupia and Łupawa, the foundation of the cliff is everywhere built of lodgement and flow till, and glaciolimnic sediments formed mainly in the Late Vistulian (after the Pomeranian stage). The lodgement till everywhere contains a large admixture of gravelly and stony material, sometimes weathered strongly (especially the crystalline schist). There are numerous additions of Paleozoic particles, often containing fauna, as well as a distinct joint in the till with prevailing vertical cracking. Above the lodgement till are Late Vistulian limnic sediments and peat, while the top part is usually built of Late Holocene eolian sand with fossil soil.

Numerous seepages and springs are formed on the surface of the cohesive sediments (till and Late Vistulian and Holocene peat), facilitating the generation of falls and sliding and thereby stimulating the development of the cliff. A similar role is played by the presence of the breakwaters of the port at Ustka.

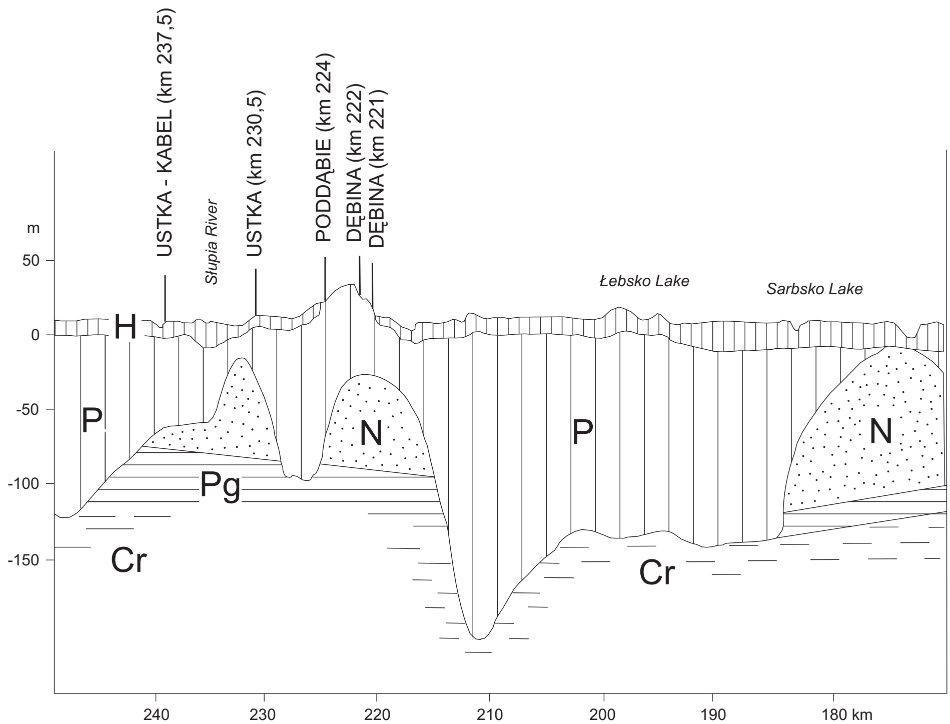

Figure 1. The Rowy-Ustka geological cross-section (after: A. Tomczak 1995); H - Holocene, P - Pleistocene, N - Neogene, Pg - Paleogene, Cr - Cretaceous; Locations of sites monitored are marked.

Comparison of cartographic and cadastral information from the years 1862-1938 showed that, during that period, east of Ustka, the coast retreated 150 m, i.e. at an average rate of about 2 m/year (according to Zawadzka-Kahlau 1994, the rate over the previous 100 years had been 1.6 m/year). What is more, a comparison of cadastral maps from the years 1960 and 1970 with survey maps from 1978 (Salik 1979) showed that the rate of erosion of the cliff east of Ustka was 1.0-2.3 m, and of that near Dębina – 0.2-1.8 m/year (Fig. 2). E. Zawadzka-Kahlau (1994) in turn evaluated the rate of such changes at 2.7 m/year at Ustka and 1.65-2.65 m/year at Dębina. These values are the result of catastrophic losses of the order of 7-8 m (e.g. in 1983), as separated by short periods of cliff stabilisation, sometimes even beach growth. It should be stressed that the largest losses occur at the end of relatively warm winters (e.g. 1913/14, 1982/83, 1986/87, 1999/2000, 2006/07; Fig. 3), when the coast is not protected by ice, and storms are generated by predominating winds from the N-NE sector (E. Florek, W. Florek, Orłowski 1996). Recently, significant erosion has also been observed during late autumn storms (November 2004), and also during the whole of the late autumn/winter storm season (2006/07), with a predominant wind from the NW sector.

Studies published hitherto on the mechanisms and rates of evolution along the investigated stretch of coast have used cartographic and cadastral information, only sporadically supported by geodetic survey material (Mielczarski 1964, Konarski

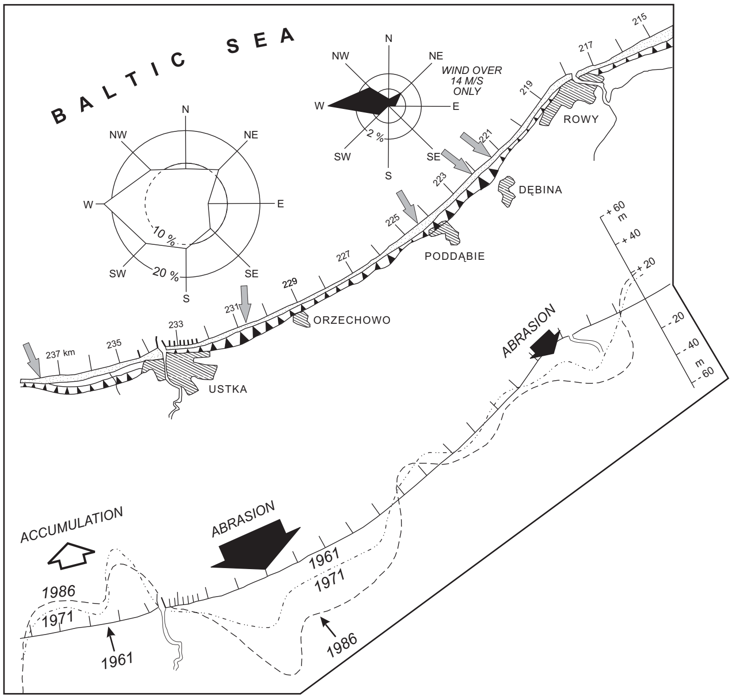

Figure 2. Coastline evolution between Rowy and Ustka. Changes at the cliff foot in the years 1961-1971-1986 (W. Dziedzic, E. Florek and P. Konarski 1994).

Figure 3. The cliff in Poddąbie in the wake of the huge storms of 1924 and 2004.

1981, Dziedzic 1990, Zawadzka-Kahlau 1995, 1999). However, the authors of the present paper have been making systematic measurements several times per year for 8 years now (other than at the Ustka-polygon profile, on which measurements started in 2000) – the subjects being coastal profiles located along stretches of differing cliff height, geological structure and distance from the Ustka breakwaters. These investigations are supplemented by the charting of beach micro-forms and photographic documentation, including via aerial photography (see Florek, Grabowska-Dzieciątko and Majewski 2001). This documentation has allowed for the formulation of first remarks on the morphogenetic differentiation to the investigated cliff stretches, in line with the geological structure and hydro-geological characteristics, exposure of parts of the cliff and meteorological and hydrodynamic conditions, and with the impact of hydrotechnical work at the River Słupia mouth. A quantitative assessment of the influence of extreme storms on rates of erosion also became possible.

The first phase to the investigations presented below was financed from the own funds of the Pomeranian Pedagogical Academy in Słupsk. Later financing has in turn been from Grant PBZ-KBN-086/P04/2003 entitled “Extreme meteorological and hydrological events in Poland (assessment of events and evaluation of their impact on the human environment”, grant leader Prof Jacek Jania – Department of Earth Sciences, Silesian University), and specifically its Task 5.5.8 “Influence of extreme events on the functioning of geosystems of the Baltic Sea coastal zone and of river valleys of near-coast areas”.

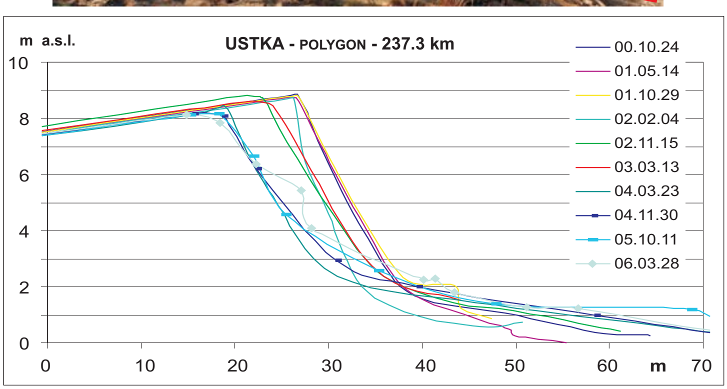

Figure 4. Changes to the cliff profile at the Ustka–polygon station between October 2000 and March 2006.

USTKA – POLYGON STATION (KM 237.5)

The cliff at Wicko, near the point of landfall of the power cable, is formed in the Upper Holocene dune sands, below which, in the western part of the monitored stretch, approximately at sea level, there are peat outcrops (possibly of Holocene origin), and below them a grey base till.

The cliff has retreated steadily, albeit rather slowly, at both profiles investigated along this stretch. At the east profile, located nearly precisely at the point of landfall of the power cable (Fig. 4), retreat was quickened by tourist impacts, which had strengthened over the most recent two–year period following the shift further westward of army checkpoints.

USTKA STATION (KM 230.6)

Along this stretch, directly on the base till and with no visible sedimentation boundary, there rest clay-till sediments of flow till. These are of variable grain structure and, in depressions, have a varved structure. On top of the clay there is a 2-45 cm thick layer of peat with a significant participation of *Betula nana* particles (dates: 11 800±115 years BP, Lu-763, 11 850±115 BP, Lu-763A, 11 100±140 years BP, Gd-122; Marsz and Tobolski 1993).

Depressions in the terrain have limnic sediments resting on the peat, in the form of sandy and muddy calcacerous gyttja with macroparticles of flora and fauna. Above that is non-calcacerous detritus gyttja.

Still higher, there is sand with 1-5 horizons of moss peat. There is fossil soil on the surface of this series of sediments, and it is dated at 2 980±60 years BP (Gd-5368), and covered with eolian sediments, among which there are soils dated at 1 590±60 years BP (Gd-5728), 1 050±50 years BP (Gd-5366) and 1 030±80 years BP (Gd-4307) (Marsz and Tobolski 1993, Tomczak 1993, Fig. 5). The ceiling of the sediments is formed by a row soil, built of alternating humus layers and sand blown over from the beach.

On the surface of the cohesive sediments (till and Late Vistulian peat) there are numerous effusions and springs facilitating the development of landslides. This in turn stimulates the development of the cliff, which is also strengthened by the presence of the Ustka breakwaters.

The behaviour of the Ustka cliff was seen to be relatively stable during the period of investigations. Significant changes

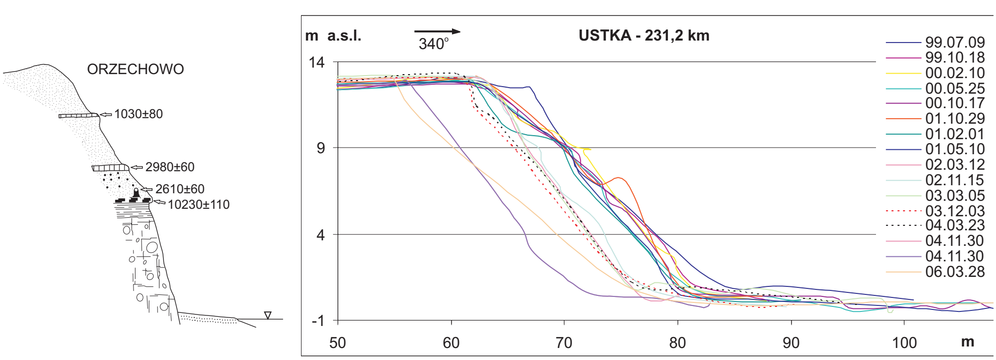

Figure 5. Geological structure of the cliff at Ustka-Orzechowo (after A. Tomczak 1993, 1995) and changes to the cliff profile between July 1999 and March 2006.

had occurred at both stations in the upper part of the cliff, above the horizon of the Sub-Atlantic podsol soil. These entailed a sliding of the overlying eolian sand and row soils. The sliding occurred between July and October, i.e. during a period of strong drying of that layer, as well as a significant impact exerted by vacationers, which went down to the beach along that profile. This resulted in the formation of a mound at the cliff foot. The beach height changed cyclically: it increased between spring and summer, before being decreased in the autumn and winter by storm action (see Fig. 5).

PODDĄBIE STATION (KM 224)

The Poddąbie station is in the area of formation of a large landslide generated after the disastrous 1916 storm, this decided about the look and behaviour of the coast until quite recent times.

At the western profile (km 224.4), located west of the stairs leading down to the beach, the cliff is of medium height (slightly exceeding 19 m above sea level) and is marked by a small landslide. After a distinct but parallel retreat of the upper part of the cliff in the spring of 1998, there followed a gradual lowering. In the beach part, cyclical, seasonal changes in beach width and in the thickness of the beach sediment layer were to be observed.

The cliff at the east profile (km 224.3), located east of the western path to the beach and a small spring, has two ”steps”. The upper part is formed by a landslide trough, which changes into a landslide tongue. The lower part of the tongue is active, a fact that

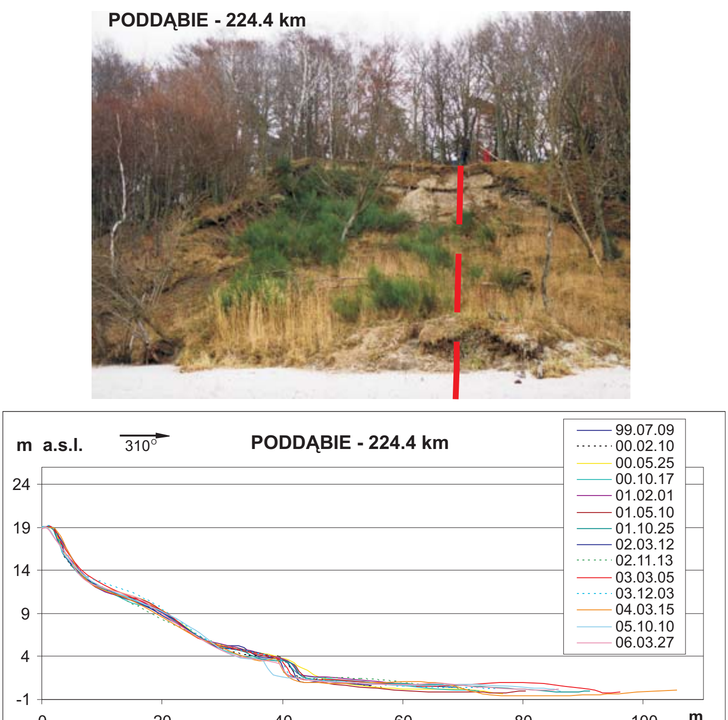

Figure 6. Changes to the cliff profiles at the Poddąbie station between July 1999 and March 2006.

is confirmed by changes in the longitudinal profile of the tongue over the last eighteen months. The end part of the tongue has been destroyed by marine erosion. The inter-seasonal stability of the profile in its beach part would seem to be worth noting (Fig. 6).

The 5-8 m thick ceiling layer in both profiles is sand, which rests on a several metre-thick layer of grey sandy clay with mica, with clayey sand interbeddings. These formations of meltwater, or perhaps ice dam lake origin, as enriched with Paleogenic and Neogenic material, rest on sandy or clayey till, or on sand. This fact attests to significant glaciodynamic disturbance of the sedimentation order.

interbeddings and lenses of various ages. The cliff top is built of Late Vistulian slope and eolian sediments (Subotowicz 1982), as well as Upper Holocene row soil.

The west profile (km 222.25, Fig. 7) is regular, with a steep cliff face, though directly east of this there is a slowly if steadily developing landslide. Over the six years the profile changed only slightly, and then solely in its upper part – the postglacial sandy deposits. Significant changes, i.e. falls and reworking of the material by marine erosion, took place during the winter storms of the last two storm seasons: 2005/06 and 2006/07. Changes to the beach mainly entail seasonal variations in width.

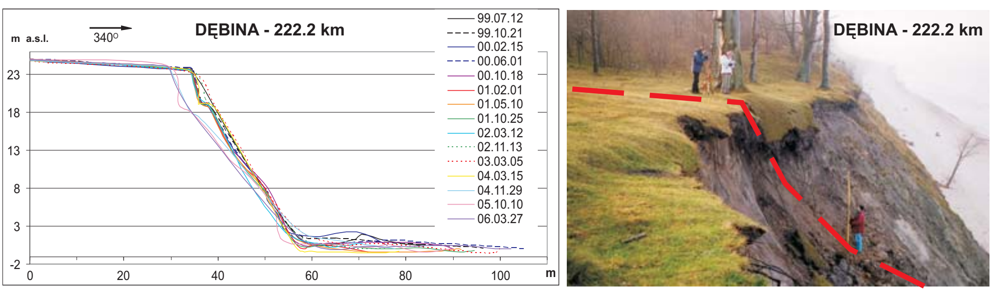

Figure 7. Changes to the selected cliff profile at Dębina-west between July 1999 and March 2006.

DĘBINA-WEST STATION (KM 222)

This station is located at the place where the Dębina cliff is highest (about 25 m at its edge). Descriptions of the geological structure here differ significantly. Fine sand with clay and mud interbeddings is present at sea level. Probably the sand contains glaciotectonically disturbed Paleogenic or Neogenic sediments (Petelski 1985). According to the newest (and in the opinion of the authors of this paper, the most realistic description from Jasiewicz (1998), the Dębina cliff, in its above-water-level part, is built of disturbed glacilimnic sediments, with till

The east profile, located exactly at km 220.0, is dominated by a large landslide beginning in the 1970s. For many years this landslide was stable, gradually becoming covered by young beech trees. However, the two most recent storm seasons (2005/06 and 2006/07) saw the landslide become active again. Its lower part is presently subject to marine erosion.

DĘBINA-EAST STATION (KM 221)

Ordinates of the cliff edge at the Dębina-east station (km 221.0) are only a little over +10 m msl. The geological structure of this part of the cliff was described by Petelski

(1975, 1985), and recently by Jasiewicz (1998). At sea level, there is a boulder till present defined by Petelski as brown till (while Florek (1996) had it as grey, and Jasiewicz as black). This is highly compressed, with numerous boulders up to 1 m in diameter. The till is very much disturbed. Winter storms (e.g. that of 1995/96) cut out of it steeply southward-sloping, scaly structures, appearing along lengths of several hundred metres (Florek 1996), (Jasiewicz 1998). On top of that till there is brown (according to Jasiewicz brown-grey) sandy boulder till, which in places has interbeddings of tilly sand and gravel. On top of this till, in the eastern part of the cliff (i.e. near the measurement profiles), there rests a light brown (according to Jasiewicz a red) sandy boulder till, with numerous boulders of diameters up to 50 cm. In Petelski's interpretation (1985) this till comes from the transgressive Gardno Phase. Between these till levels occur zones of glaciodynamic disturbances.

After a distinct parallel retreat in 1998, the west profile (km 221.25), remained stable, with the exception of the beach, whose sediment layer varied markedly in width and thickness. The profile became active again in the 2006/07 winter season.

On the east profile (km 221.0), sliding of the sandy upper part of the cliff crown was generated in 1999 by vacationers. Later storms removed the colluvium. The profile was relatively stable, also in the beach part, until 2004. The cliff became significantly rejuvenated during the 2005/06 winter, and significantly eroded by sea in the 2006/07 winter.

CONCLUSIONS

The investigations of the variability to cross-shore profiles of cliffs in Poland's Ustka region, started by the authors of this paper, are planned to last many years. The objective is to verify the schemes for the development of cliff coasts proposed earlier by Subotowicz (1982). This is *inter alia* justified by observations of the Southern Baltic cliffs indicating that the differentiation to their geological structure, and to the resultant hydro-geological characteristics, is greater than has been assumed by the authors of earlier work.

The measurement data obtained along the investigated profiles thus far show that:

- the most dynamic coastal zone is the beach, which is subject to cyclical changes, i.e. an increase between spring and summer and a decrease due to marine erosion in the autumn and winter months,
- the top of the cliff is the part least resistant to destruction. Most often the latter is built of eolian sands, which are readily made subject to downward spilling, especially in the summer when holiday-makers play an active part in the process. The material sliding from the top of the cliff collects at its foot in the form of mounds or taluses,
- the lower parts of earlier-formed landslide tongues at Poddąbie and Dębina are now being gradually eroded away by the sea, while the landslide at Dębina became active again in the winters of 2005/06 and 2006/07,
- the strong storms of late autumn 2004 and the 2005/06 and 2006/07 seasons resulted in activation of the cliffs at nine of the ten investigated profiles, with no relationship being found between the lithology of the sediments building the given cliffs and the rates of erosion observed.

The formulation of more in-depth conclusions as to the influence of extreme storms on the rate and character of abrasion will be possible after consideration has been given to the 2006/07 storm season - an exceptional one with respect to the number of strong storms and their duration. The evidence thus far available suggests that rates of abrasion are at present at exceptionally high levels not observed for many years now.

REFERENCES

Dziedzic, W. (1990), Geodynamika brzegu morskiego w rejonie Ustki [Geodynamics of the sea coast in the region of Ustka], *Materiały i Studia Oceanologiczne,* 55: 87-106.

Dziedzic, W., Florek, E., Hondo, A., Konarski P. (1994), *Coastline evolution in the Ustka area in modern times,* in Rotnicki, K. (ed.), *Changes of the Polish Coastal Zone*, Adam Mickiewicz University, Poznań, 124-126.

Dziedzic, W., Florek, E., Konarski, P. (1994), *Stanowisko Ustka. Zmiany linii brzegowej na odcinku Ustka-Rowy w świetle map dawnych i współczesnych materiałów geodezyjnych* [Site Ustka. Changes of the coastline between Ustka and Rowy in the old maps and contemporary geodetic measurements], in: *2 Konferencja „Geologia i geomorfologia Pobrzeża i południowego Bałtyku", Słupsk, 23-25 czerwca 1994, Streszczenia wystąpień i przewodnik wycieczki* [2nd Conference "Geology and geomorphology of the Baltic coast and the South Baltic Sea bottom", June 23-25, 1994. The abstracts and the excursion' guidebook], Słupsk, 76-79.

Florek, E., Florek, W., Orłowski, A. (1996), *Budowa geologiczna i ewolucja strefy brzegowej w okolicy Ustki* [Geological structure and the coastline evolution in the region of Ustka], in Florek, W. (ed.), *45 Zjazd Polskiego Towarzystwa Geograficznego, Słupsk-Ustka 18-21 września 1996. Przewodnik wycieczek* [45th Congress of the Polish Geological Society, Słupsk-Ustka, September 18-21 1996. The excursions' guidebook], Słupsk, 47-52.

Florek, W. (1996), *Nizina Gardnieńsko-Łebska – część zachodnia* [Gardno-Łeba Lowland – west part], in: *45 Zjazd Polskiego Towarzystwa Geograficznego, Słupsk-Ustka 18-21 września 1996. Przewodnik wycieczek* [45th Congress of the Polish Geological Society, Słupsk-Ustka, September 18-21 1996. The excursions' guidebook], Słupsk, 53-75.

Florek, W., Florek, E. (1995), *Man versus the eustatic impact on shoreline development at Ustka (Poland)*, in M.G. Healy and J.P. Doody (eds.), *Directions in European Coastal Management*, Samara Publishing Limited, Cardigan, 243-251.

Florek, W., Grabowska-Dzieciątko, A., Majewski, M. (2001), *Dynamika zmian nadbrzeża morskiego na wschód od Ustki* [Changes of the Baltic offshore to the east of Ustka], in Florek W. (ed.), *Geologia i geomorfologia Pobrzeża i południowego Bałtyku* [Geology and geomorphology of the South Baltic Sea Coast and the bottom] 4, Słupsk, 125-135.

Florek, W., Marsz, A.A., Orłowski, A., Tobolski, K., Tomczak, A. (1994), *Stanowisko Ustka. Budowa geologiczna i wiek osadów budujących odcinek klifowy Ustka-Rowy* [The Ustka site. Geological structure and age of sediments forming the Ustka-Rowy cliff section], in: *2 Konferencja „Geologia i geomorfologia Pobrzeża i południowego Bałtyku"*[2nd Conference "Geology and geomorphology of the South Baltic Sea Coast and the bottom"], Słupsk, 73-76.

Jasiewicz, J. (1998), *Stop 10 - Dębina. Till stratigraphy and glaciotectonic style of the Gardno Phase end moraine*, in: *Field Symposium on glacial geology at the Baltic Sea coast in Northern Poland, 13-19 September 1998. Excursion guide*, Warsaw, 59-64.

Konarski, P. (1981), Zmiany w przebiegu podstawy wydmy lub klifu Zatoki Słupskiej w okresie 1961-1979 w świetle pomiarów geodezyjnych [Changes of the dune or cliff base line on the Słupsk Bay coastline], *Inżynieria Morska,* 4/5: 134-135.

Marsz, A.A., Tobolski, K. (1993), *Osady późnoglacjalne i holoceńskie w klifie między Ustką a ujściem Potoku Orzechowskiego* [Late Glacial and Holocene deposits in the cliff between Ustka and Potok Orzechowski mouth], in Florek, W. (ed.), *Geologia i geomorfologia Pobrzeża i południowego Bałtyku* [Geology and geomorphology of the South Baltic Sea Coast and the bottom], Słupsk, 201-250.

Mielczarski, A. (1964), Wyniki badań i studiów nad morfometrią, rejonizacją brzegów Bałtyku od Rozewia do Świnoujścia [Results of research studies on morphometry and regionalization of the Baltic coast between Rozewie and Świnoujście], *Materiały do monografii polskiego brzegu morskiego* [Materials for the monograph of the Polish coastline] 6.

Petelski, K. (1975), O budowie geologicznej gardzieńskiej moreny czołowej w odsłonięciach klifu między Dębiną a Poddąbiem na Pobrzeżu Zachodniopomorskim [On geological structure of a Gardno terminal moraine as seen in the cliff exposures between Dębina and Poddąbie in West Pomerania], *Zeszyty Naukowe Wydziału Biologii i Nauk o Ziemi Uniwersytetu Gdańskiego, Geografia,* 7, 169-180.

Petelski, K. (1985), Budowa geologiczna moreny czołowej i niecki końcowej lobu gardzieńskiego [Geological feature of Gardno lobe front moraine and end thought], *Biuletyn Instytutu Geologicznego,* 348: 89-119.

Salik, K. (1979), *Wpływ abrazji na zmiany brzegowe Bałtyku na przykładzie badań klifu Ustka - Orzechowo* [Influence of the erosion on changes of the Baltic coastline; the Ustka-Orzechowo cliff case study], Unpublished paper, Instytut Morski, Gdańsk.

Subotowicz, W. (1982), *Litodynamika brzegów klifowych wybrzeża Polski* [Lithodynamics of Polish cliff coasts], Gdańsk, Ossolineum.

Tomczak, A. (1993), *Datowane metodą ^{14}C wychodnie utworów organicznych na brzegu morskim między Rowami a jeziorem Kopań* [The ^{14}C age of the organic deposits in the outcrops at the Baltic coast between Rowy and the Kopań Lake], in Florek, W. (ed.), *Geologia i geomorfologia Pobrzeża i południowego Bałtyku* [Geology and geomorphology of the South Baltic Sea Coast and the bottom], Słupsk, 187-199.

Tomczak, A. (1995), *Budowa geologiczna strefy brzegowej* [Geological structure of the coastal zone], in Mojski, J.E. (ed.) *Atlas geologiczny południowego Bałtyku* [Geological atlas of the South Baltic], Państwowy Instytut Geologiczny - PAE, Sopot-Warszawa.

Zawadzka-Kahlau, E. (1994), Determination of changes of the South Baltic spits and cliffs, *Bulletin of the Maritime Institute* 21, 1: 41-59.

Zawadzka-Kahlau, E. (1999), Trends in the South Baltic coast development during the last hundred years, *Peribalticum* 7: 115-136.