# Baltic cliffs and much more

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Seashore — these words carry so many meanings and symbols. So many artists have been enchanted by the magic of this place, where the impetuous sea meets the calm and peaceful land's resistance. For majority of people this is a fascinating place where they eagerly spend their free time. The magic of the Polish Baltic Sea coast is intensified by attractive geology; the easy-to-watch geological structure and great dynamism and variety of active geological processes, such as erosion and accumulation. On the Polish coast time flows in the human pace.

The Baltic Sea is a relatively small sea with 3800 km of developed coastline. The northern (Scandinavian) coast is particularly complex, as it is built of crystal and sedimentary rocks, with fiord and skerry coasts as dominating coast types. The other shores of the Baltic Sea are made of soft or placer rocks which are prone to erosion by which the coastline is leveled in many stretches. This mostly concerns the Polish shore, which has been leveled by the sea by means of coastal erosion in cliff stretches (approximately 80% of Polish coastline) and by accumulating sands on spit stretches (approximately 20% of Polish coastline) (Fig. 1). The accumulating activity of the sea was supported by winds and rivers.

On the Polish Baltic coast there are outlets of two major rivers flowing into the Baltic Sea: the Vistula River and the Odra River. The Vistula River, which changed its outlet in historical times, has had considerable influence on morphological development of the area.

The complicated process of seashore development has been in many places modified by human activity. Anthropogenic influence usually activates the coastal geological processes, creating new opportunities for observation. One of such places is the outlet cone of the Vistula River, which has been developing for the last one hundred years in the area of the river's youngest outlet.

The Polish Baltic shore is built mainly of Holocene and Pleistocene deposits, and only in its eastern part the lower bases of cliffs comprise Neogene sands and silts. All these deposits are prone to marine erosion, as a result of which the coastal zone is supplied by great amounts of sand accumulated on the beaches and spits. In effect, the Polish coast is famous for a large number of sandy beaches.

The pace of erosion, in many places exceeding 1 m/yr, causes new exposures in cliffs which are over several dozen meters high. These exposures reveal a whole spectrum of Pleistocene glacial, fluvioglacial and other deposits, as well as their various forms. In the cliffs in the area of Gdynia and Władysławowo, Miocene brown coal deposits are also visible. In some places on the spits, marine erosion uncovers Holocene peats and aeolian sands with layers of fossil soil. In the area of cliffs, including those inactive ones, there are many slides and other forms of massive land movements. Their kinds and scale are visibly connected with geological structure and local hydrogeological conditions, as well as with anthropogenic activity.

In the case of seashore with Pleistocene deposits with visible presence of boulder tills, one of the most attractive

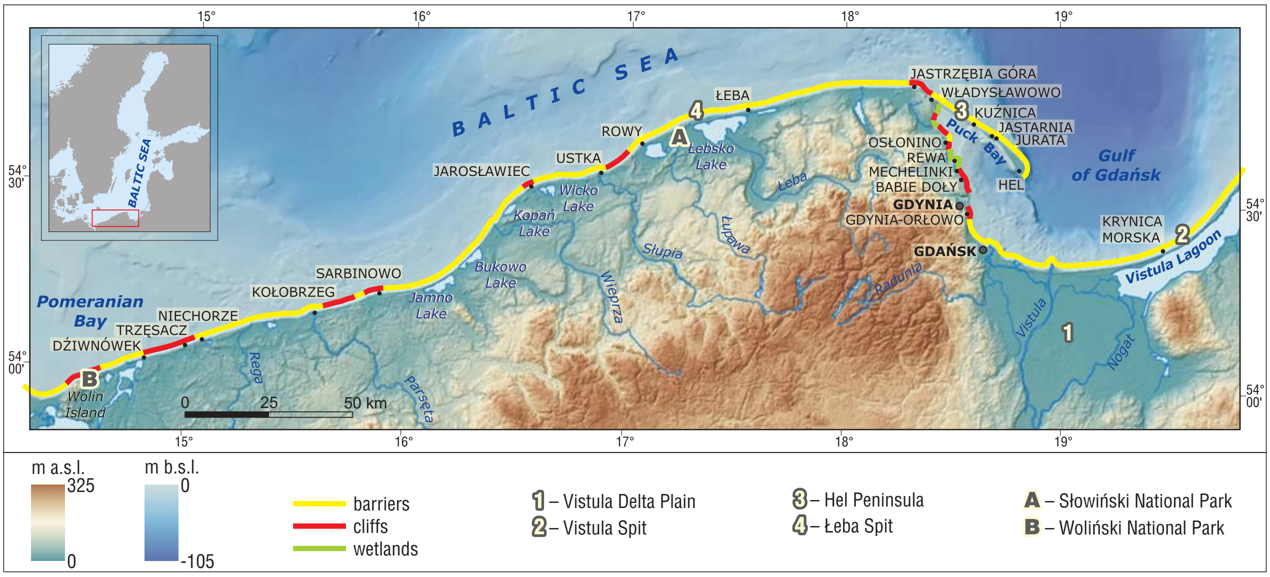


**Fig. 1.** Localization map

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effects of erosion is the abundance of pebbles lying at the foot of the cliffs. These pebbles represent diversified types of rocks of Scandinavia and the Baltic Sea bottom. They are of special interest to collectors of rocks, minerals and fossils. A very special type of mineral found on the Polish beaches is amber (see p. 604).

Accumulation stretches of the Polish seashore are represented mostly by spits. The deposition of sea sands has always been accompanied by aeolian sedimentation. The wind blew the sands out of the beach and, in this way, created dunes which in some places reach 35 m. Most of the dunes have been afforested in many years of human efforts, however, in many places the aeolian processes are still active. These processes can be observed on the largest scale in the Słowiński National Park. The most attractive spits are those separating lagoon lakes from the sea and the Hel Spit (Hel Peninsula) which measures 36 km in length. The spits along with lagoon lakes and large areas of marshes create an exceptional and attractive ecosystem. Special attention needs to be paid to the Vistula River outlet and the accumulation of deposits that it carries.

The large scale of erosion and accumulation on the southern shore of the Baltic Sea, in places caused by human activity, makes it necessary to protect the area subsequently to scientific research (Graniczny et al., 2004b).

## Cliffs

Cliff coasts of total length of 100 km can be found on the western shore of the Gulf of Gdańsk as well as on the following stretches: Władysławowo–Jastrzębia Góra, Rowy–Ustka, Jarosławiec, Sarbinowo–Kołobrzeg, Niechorze–Dziwnówek and Wolin Island (Fig. 1). Among the cliffs we can distinguish inactive (dead) stretches, vegetation stretches and active stretches. These are often steep slopes, several- or several-dozen-meters high, showing clear traces of geodynamical processes. The highest cliff on the Polish Baltic shore is on Wolin Island and reaches 93 m a.s.l. It is characteristic of cliff exposures that, due to abrasion, they are "refreshed" on a current basis and, as a result, we may discover new and unknown elements of the geological structure. It is best to observe the cliff shores in the spring, when the exposures are naturally cleansed by winter-spring storms.

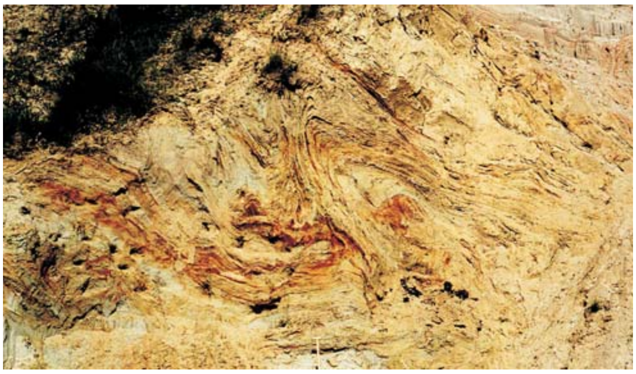

**Fig. 2.** Glaciotectonical disturbances of sand and silt deposits. Cliff in Gdynia-Orłowo. Photo by L. Zaleszkiewicz

In the cliffs of the Gulf of Gdańsk and in the areas of Jastrzębia Góra and Jarosławiec we can observe the geological structure of moraine uplands made mainly of glacial and fluvioglacial deposits. The uplands' surface is built of a layer of boulder till visible in the upper parts of cliffs, which gives a false impression of geological structure homogeneity. Under the clays there lie lithologically and genetically diversified deposits (e.g., glacial and fluvioglacial sands, silts and clays), which are in many places glaciotectonically disturbed, as noticeable in the exposures. Glaciotectonical disturbances are visible on a large scale in cliffs which cut the uplands in the place of their contact with furrows and ice-marginal valleys. This can be observed in Gdynia-Orłowo (Fig. 2), in Babie Doły, as well as on the western part of the coast, for instance in Jarosławiec. Fluvioglacial deposits are quite common, in some places deposits of cleft forms and kames are exposed (e.g., in Mechelinki, Wolin Island). In the cliff of Osłonino — north of Gdynia — fluvial interglacial deposits are periodically visible. The Pleistocene deposits located in the lower parts of the cliffs and quickly covered by deluvia and coluvia are neither well--exposed nor well-known. In some places, on the level of beaches, old dark gray glacial tills prepared by marine erosion are exposed. In regions where those clays have greater thickness, characteristic headlands and spurs are created.

**Fig. 3.** Headland made of glacial till. Cliff in Gdynia-Orłowo, southern view. Photo by D. Kaulbarsz

The most famous headland is located in the area of the picturesque cliff in Gdynia-Orłowo (Fig. 3). The headland is built of glaciotectonically uplifted cracked glacial till, what facilitates rockfalls and deposit falls (Kaulbarsz, 2005). The height of the headland is currently 18 m a.s.l. The Orłowo cliff is located in one of the oldest Polish reserve, which main object is the protection of beech forests and Swedish mountain ash trees.

In case of the cliffs which cut moraine uplands from the side of the Gulf of Gdańsk (Gdynia-Orłowo, Babie Doły) as well as in the area of Władysławowo, there can be found, apart from Pleistocene deposits, older subsoil deposits. These are mostly snow-white sands, in places with brown coal ash and coal from the Miocene period — approximately 5 million years old (Grabowska, 1987). Their tops are at various heights, e.g., the Gdynia-Orłowo cliff top is at the level of 20 m a.s.l. and on a several-hundred-meter stretch they fall below sea level. In Babie Doły, the snow-white color of sands visibly contrasts with rust-colored gravel, creating in effect a picturesque combination. (Fig. 4). The longest outcrop of these deposits on the Polish coast is in the area of Władysławowo and reaches the length of 3 km (Kramarska, 2002; Wagner, 2007). Since the beginning of 1859, coal deposits among the sands have been exploited, however, the exploitation was ceased due to limited and low quality resources.

**Fig. 5.** Cliff between Rowy and Ustka — glaciotectonically disturbed deposits of end moraine. Photo by D. Kaulbarsz

Cliffs situated in the middle part of the coast, on the stretch between Rowy and Ustka, cut the end-moraine zone, related to the last ice sheet recession (Petelski, 1985; Rotnicki, 1995). Going west of Rowy, we may observe the geological structure of the end-moraine zone, starting with moraine background deposits, passing the culmination zone of elevations — here the deposits are also glaciotectonically disturbed to a large extent, and moving onto their foreland deposits, including ice-marginal deposits (Fig. 5). Moreover, the presence of aeolian sheet on glacial deposits is very characteristic of this cliff stretch (Fig. 6). These are yellow sands, in some places with overstratification of peat and fossil soil, which were formed around 7000 years ago. A similar geological situation can be observed in the Wolin Island cliff where, next to

**Fig. 4.** Outcrop of Miocene deposits in the Babie Doły cliff. Photo by D. Kaulbarsz

**Fig. 6.** Cliff between Rowy and Ustka — aeolian cover on glacial deposits. Photo by D. Kaulbarsz

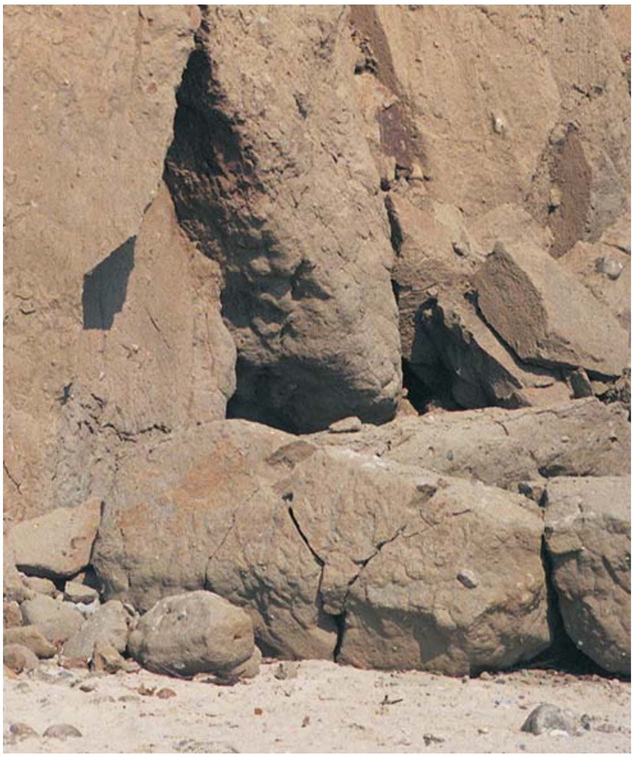

**Fig. 7.** Rockfall. Cliff in Gdynia-Orłowo. Photo by L. Zaleszkiewicz

kame deposits, there are end moraine deposits, locally covered by aeolian sands.

Cliffs are places where you can observe geological history and current processes of abrasion. The coasts are particularly intensely eroded during spring and autumn storms. The waves cut the steep slopes, activating the processes of deposit sliding and slipping. In case of harder deposits such as glacial clays, the waves groove in them deep wave-cut grooves, which leads to rockfalls (Fig. 7). It is common that at the foot of such slopes we can observe great numbers of rocks and pebbles washed out from the coast. The beaches at the foot of the cliffs are usually narrow and stony.

In the last years, the processes of erosion have intensified on the southern coast of the Baltic Sea. It is related to natural factors, such as the increased frequency of high storm swellings, or sea level rise due to climatic changes, as well as to anthropogenic factors (Zawadzka-Kahlau, 1999). The coastal zone is endowed with exceptional touristic predispositions, and its climatic and curative properties encourage interest in its recreational and sanatorium resources. Due to this interest, there is great necessity for integrated management of the coastal zone, including seashore protection (Zachowicz & Dobracki, 2003; Dubrawski & Zawadzka-Kahlau, 2006).

The beginnings of seashore protection in Poland date back to the $19^{th}$ century. Initially, the shores were protected against abrasion with groins counteracting the waves energy and with sea-walls fortifying the seashore. Nowadays, this protection is in many places executed by means of supplying beaches with sand, building protective sea-walls, or complete building up of cliff slopes to stabilize sliding processes (Zawadzka-Kahlau, 1999). In some cliff stretches, it is necessary to carry out draining works on the slopes in order to protect the developed areas. One of such examples is the cliff in Jastrzębia Góra, where the structure of deposits (sloams) and lack of draining system often led to slides which posed danger to the buildings situated at the top of the cliff. Stone-and-earth structure was built there, but unfortunately, it did not manage to stop the erosion process. Its intensified effects can still be seen on both sides of the construction (Fig. 8).

Another example of futile battle of man with the forces of Nature is the cliff in Trzęsacz and the ruins of a gothic church from the $14^{th}/15^{th}$ century standing on its edge. The temple was originally built in the distance of 2 km from the seashore. Today we can only see a part of the church's southern wall standing on top of the cliff — the rest has been damaged in the process of abrasion (Fig. 9). A man attempted at protecting the church against the phenomenon of abrasion already in the $18^{th}$ century. This place is connected with another curiosity — through this place passes the line of 15° meridian of eastern longitude, which marks central European time.

Many stretches of the coast are in the precincts of scenic parks or reserves. If it does not pose any danger to developed areas, these stretches of coast are left to natural development, which allows observation of the course of hydrodynamic and geodynamic processes. This concerns the aforementioned cliff in Gdynia-Orłowo and the Wolin Island cliffs, which constitute a natural element of the Wolin National Park.

**Fig. 8.** Stone and ground structure around the cliff in Jastrzębia Góra. Photo by P. Domaradzki

**Fig. 9.** Ruins of a gothic church in Trzęsacz. Photo by L. Zaleszkiewicz

**Fig. 10.** Uncovering tree trunks on the beach. Photo by L. Zaleszkiewicz

## Barriers

Barriers constitute around 80% of the Polish coastline, and their total length is approximately 380 km. They level the coastline in many places cutting off coastal lakes and coastal lowlands from the sea. Such spits are in the precincts of the following lakes: Jamno, Bukowo, Wicko, Kopań, Łebsko, and the Vistula Lagoon. Another form which has the features of a spit is the Hel Peninsula going into the Gulf of Gdańsk. The main characteristic of a spit is the accumulation of sands on the beaches and the presence of aeolian processes. They change their location, moving towards south, just like other stretches of the coast. During withdrawal, the spit beaches remain only with dead trees and uncovering peats (Fig. 10).

The accumulation of sand in the spits of the middle and western coast of the Baltic Sea is a result of sand movement influenced by seashore current from west to east, while on the Vistula Spit — from east to west.

**The Vistula Spit** encompasses the southern part of the Gulf of Gdańsk. It measures around 100 km in length, with 80 km of Polish coastline (Topolska, 2001). In this place, in the early Holocene period, there used to be a fluvial plain with peat bogs present in depression. In later periods, marine deposits were accumulated with amber redeposited from the area of Sambia. Traces of phase development of the spit are visible in the terrain relief, namely in three dune zones: brown, yellow and white. Brown dunes developed 4300–3500 years ago, the yellow ones 2200–1800 years ago, and the white dunes have been developing today (Tomczak et al., 1989; Tomczak, 1995a). The highest dune, named "Wielbłądzi Garb" (Camel Hump) is located east of Krynica Morska and reaches around 50 m a.s.l. The basis for separation of dune-formation periods are fossil soils. The dunes originally used to be covered by forest, however, as a result of overexploitation of natural resources, the forest was grubbed out, and later planted again.

The Vistula Spit in its current form began its formation during the Atlantic transgression. Most probably, it was developing simultaneously on its whole length, widening towards the sea, along with the development of the Vistula River Delta.

**The Vistula River,** the longest river in Poland and the biggest in the Baltic Sea basin, enters the Gulf of Gdańsk after its long way of 1047 km, and its waters become the inseparable part of the Baltic Sea. Here, the river offers Neptune what its current gathered on its way in different areas of the country.

The present delta of the Vistula River is characterized by forms and deposits connected with three outlets of the river (Fig. 11) (Graniczny et al., 2004a). Until 1840 the

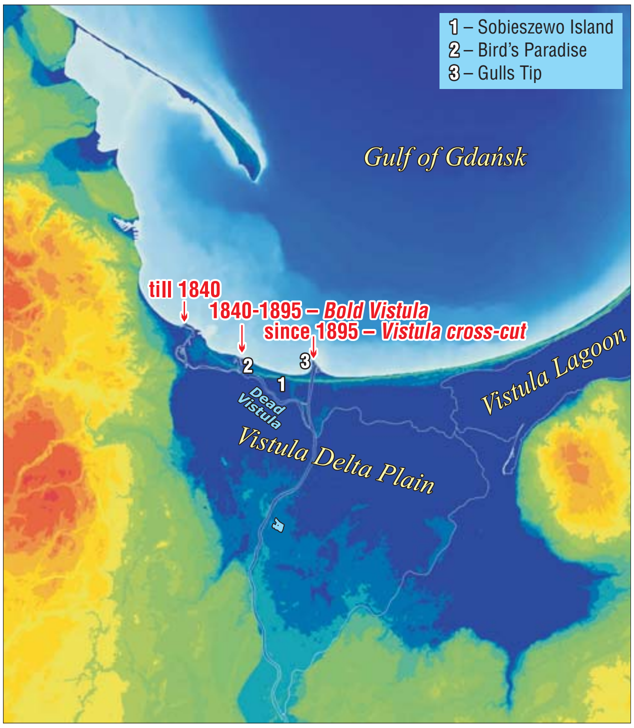


**Fig. 11.** The Vistula River outlet in historical times

**Fig. 12.** The Vistula cross-cut. Vistula's outlet to the Gulf of Gdańsk. Photo by M. Ostrowski

Vistula's outlet had been located near Gdańsk. In the winter of 1840 four factors appeared simultaneously: high water level of the Vistula River, the presence of a large ice block in its outlet, heavy storm on the Baltic Sea and high water level of the Gulf of Gdańsk. The sandbanks and dunes of the spit separating the Vistula River bed from the sea were destroyed. The river grooved a new outlet which was named the Wisła Śmiała (the Bold Vistula), and the stretch between the old and the new outlet, later cut off by sluices, received the name of the Martwa Wisła (the Dead Vistula). However, the new riverbed of the Bold Vistula was not capable of taking in such great amounts of water. This led to floods which caused considerable damage and posed a threat to the whole region. In 1888 the parliament of Prussia decided to build a cross-cut for carrying a part of the waters of Vistula into the sea. This cross-cut was opened in 1895 and measured 7 km in length. Since then, the outlet cone of the Vistula has been developing northward from the 3000-meter-wide spit (Fig. 12).

On both sides of the Vistula's riverbed, the newest generation of riverside forms, situated between the white dunes and the waterline, is built of low (up to 1.5 m) banks separated by marshy areas. In the older part of the cone, white dune banks dominate, reaching heights up to 5–6 m. In the land area of the outlet cone there are present small water reservoirs — lagoons. The largest lagoon developed on the eastern side of the outlet cone. In the last century, large amounts of sandy deposits have accumulated in the Vistula's outlet. A set of accumulation forms of the delta's front has developed. Sedimentation of these deposits, additionally supplemented by materials carried by the riverside current caused by winds, results in hampered outflow of river waters and ice in particular. In order to ensure free outflow of waters, people have built special stone piers on both sides of the river. The sandy material accumulating in the Vistula's outlet creates vast shoals, sandbanks and periodically also sandy islands which change their location. The outlet cone of the Vistula River is made of front delta deposits mainly in sandy facies, and locally in muddy facies. The thickness of sandy deposits of the outlet cone is 11–15 m.

The area which was created between the Bold Vistula outlet and the Vistula cross-cut is called Sobieszewska Island (Fig. 11). The island is mainly covered by forests, with beautiful dunes and vast beaches which were still full of ambers pretty recently. On Sobieszewska Island, next to the Bold Vistula outlet, there is a nature reserve "Ptasi Raj" (Bird's Paradise), with a scientific and didactic path along which one can admire beautiful scenery: alder tree stands, rushes, Karaś Lake, pine trees, Ptasi Raj Lake and dunes where you can see Sea Holly (*Eryngium maritimum*). Thanks to its fauna assets, the reserve is of international importance.

The Vistula River's outlet cones are on the way of water-mud birds' migrations on the southern Baltic routes, being one of the most attractive places for ornithologists in Poland. Practically every bird-lover could find something for himself here, especially from July to September, when birds stop here on their route. The area of the inflow cone and appearing and disappearing sandbanks is a great location for breeding colonies of rare bird species. For birds, the most appropriate are open spaces — the beaches, the breaker line, coastal sandbanks, new islands and peninsulas as well as dunes in their initial phase of development. Next to the outlet, on the stretch of the cross-cut, the Mewia Łacha (Gulls Tip) Ornithological Reserve was created (Fig. 11). The reserve's indirect object is to maintain open landscape in the largest possible part of the outlet cone. The outlet cone of the Vistula cross-cut is one of the few stretches of the Polish coast where a continuous process of fluvial, maritime, aeolian and organic accumulation process can currently be observed.

The Vistula Spit is a natural barrier separating the depression of the Vistula River Delta from the Baltic Sea. Moreover, the delta's depression areas are protected by means of a complicated system of banks and drainage ditches.

**The Łeba Spit** is situated in the central part of the Polish coast and is famous for the most diversified and developed dune system. The spit screens the lakes and coastal lowlands (Rotnicki, 1995). Its width reaches 1.5 km, and length around 70 km. This environment undergoes continuous changes, which is reflected in layers of locally uncovering fossil soils (Tobolski, 1995). On the Łeba Spit, there is the highest dune in Poland — the Czołpińska dune, which measures 56 m a.s.l. We can find here the following dune forms: moving coastal barchan dunes reaching 40 m height, barchan-arc dunes, parabolic dunes, linear dunes as well as irregular hills (Borówka, 1995; Borówka & Rotnicki, 1995; Piotrowska, 1997). The biggest dunes move from west to east, approximately 4 to over 10 m/yr, resembling vast desert landscapes (Fig. 13). In the background of the moving dunes, there are deflation fields and rifts measuring several hundred meters in length (Fig. 14).

Moving dunes cover forests, settlements, even lakes and river mouths. Aeolian processes are very intensive in this area due to the abundance of sea sands accumulated on the beach. In some places, the dunes are covered by vegetation, especially in their lower parts, while their ridges are absolutely bare (Fig. 15). In historical times, mobile sands covered the Łeba River outlet and forced it to change its riverbed flow. At present, the location of the city of Łeba is its new location. The previous Łeba, known as the Old Łeba, was situated west from the present city, next to the

**Fig. 13.** A vast dune desert. Photo by P. Przezdziecki

**Fig. 15.** *Elymus arenarius* covering the dunes. Photo by L. Zaleszkiewicz

**Fig. 14.** Deflation field. Photo by P. Przezdziecki

**Fig. 16.** Ruins of a church in Old Łeba. Photo by L. Zaleszkiewicz

old river outlet (Bohdziewicz, 1970). In the 15th and 16th centuries the river's outlet was covered by mobile sands, which forced the inhabitants to move to a safer place. The remains of the church which used to stand in the center of the settlement are the only remains left of the Old Łeba (Fig. 16). Presently, the ruins are situated several dozen meters from the beach, which reflects how the spit has moved inland. In the area of the Łeba Spit, Słowiński National Park was established (Ostrowski & Simonides, 1994).

**The Hel Peninsula's** base is in the farthest northern part of the Polish coast. It has an incredible form of spit origin. The peninsula is 36 km long and its shape resembles a bent club (Tomczak, 2002). Its width at the base reaches only 150 m, and on the eastern end — around 3000 m. The relief of the peninsula is diversified by sand dunes, with heights from 5 m to the maximum 20 m a.s.l. In some places, the line of dunes is similar to the old coastal lines. From the open seaside, the form's shore has a mild character of descending sandy bottom (Fig. 17).

The Hel Peninsula is a bipartite form, as far as geological structure and shape evolution are concerned. The western part of the peninsula is genetically continental. Around 6500 years ago biogenic terrestrial deposits began developing in this area. In the last phase of the Atlantic transgression they were covered by 10 m sheet of marine deposits, which later, in the upper part, underwent aeolian modification. In the eastern part of the peninsula, in the period of Late Glacial and the Holocene, a 100-meter-thick layer of sediments was formed, in which the influence of Baltic's development phases can be observed (Tomczak, 1995a, 1995b).

The peninsula in its contemporary form began shaping after the Atlantic transgression, when sea level stabilized at 1–2 m below today's level. The peninsula grew from the side of Władysławowo, elongating gradually. Around 5600 years ago the Hel Peninsula reached Jurata. Every old coastal bar visible in the terrain relief indicates next zones and ranges of its development. The Peninsula reached its final shape 1000 years ago, as a result of sea level rise of about 1.5 m and overflowing of its coastal parts (Tomczak, 1995a, 1998; Tomczak & Domachowska, 1998). The evidence of this is the visible presence of a 1000-meter-wide characteristic shelf called the Długa Mielizna (the Long Shallow) on the side of the Gulf of Gdańsk. The development of the Hel Peninsula is connected with the development of another spit, meeting the Hel Peninsula in the vicinity of Kuźnica. This second spit is an underwater sandy bar crossing Puck Bay, from Rewa to Kuźnica and it is called Rybitwia Mielizna (the Seagull Shallow) (Kramarska et al., 1995). Periodically, this bar stands out above the sea level (Fig. 18).

**Fig. 17.** Hel Peninsula. Photo by P. Domaradzki

**Fig. 18.** Seagull Shallow. Photo by M. Ostrowski

Similarly to every stretch of the sea coast, the spits also undergo the process of abrasion. As a result, the problem of protection becomes a serious issue. A great example of spit coast

**Fig. 19.** A bunker on the beach of the Hel Peninsula. Photo by L. Zaleszkiewicz

protection is building various types of structures such as retaining walls, sea-walls and breakwaters like those on the Hel Peninsula. In order to stop coastal erosion, palisade spurs reaching several dozen meters deep down the sea are used. Superstructuring of the shore may also happen as a result of silting up. On the Łeba Spit, apart from the National Park, the main problem are mobile sands. To counteract them, grass is planted, fence systems are fixed and branches are spread on the dunes.

The Polish spits used to be places of special military importance during the World War II (Fig. 19). Łeba dunes were the field of military practice of Africa Corps group under command of Erwin Rommel. Experiments with V1 launchers were carried out here, too. On the Hel Peninsula, tourists can visit one of the biggest artillery posts from the World War II.

## Summary

Geotouristic assets of the Polish coast attract an increasing number of people, who become interested in walks in fresh sea air as well as in the surface they are walking on and what they can see around them. Looking at the cliff slopes, sands and rocks, their position and number, tourists start to ask themselves the question where it all came from and how it is possible that land grows or diminishes, and that in each place you can see different phenomena.

Branches of the Polish Geological Institute — Marine Geology Branch in Gdańsk and Pomeranian Branch in Szczecin for many years have been popularizing the geotouristic assets of the Polish coast by publishing folders and maps (e.g., Kocyła & Rumiński, 2004). Furthermore, every year, the staff of the Marine Geology Branch organizes a science picnic on the beach in Gdynia-Orłowo during the Baltic Science Festival.

*Translated by Agnieszka Kamińska*

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