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Polygenesis of the Southern Baltic floor relief

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Abstract: On the basis of its bathymetry, two plains, one deep, the other shallow, may be recognised on the floor of the Southern Baltic Sea. Since the disappearance of the last Pleistocene ice sheet about 12.2 ka BP in the west and 12.5 ka BP in the east and north, the deep plain has remainded drowned, either by the sea or by lakes. In contrast, the relief of the shallow plain is a reflection of three different environments: (1) glacial and fluvioglacial (in the period 14.2-12.5 ka BP); (2) subaerial (12.5-7.5 ka BP) when weathering and stagnant or dead ice conditions predominated and (3) marine (since 7.5 ka BP), i.e. since the shallow plain was covered by the *Litorina* transgression. The processes operating during the later evolutionary phases considerably destroyed the older landforms, i.e. those of glacial, fluvioglacial and subaerial origin. This much modiefied relief was then covered by littoral sediment which accumulated when the Baltic attained its present shoreline. The spits, abrasion platforms and steps and cliffs present in the modern landscape have been created by near-bottom and shore currents.

Key words: late Pleistocene, Holocene, morphogenesis, marine transgression

Introduction

Much new evidence for our understanding of the morphogenesis of the Southern Baltic (Polish Economical Zone) floor has been published in recent years, mainly in respect of the publication by the Polish Geological Institute of two cartographic/text publications which cover the Southern Baltic. The first is the 1:200 000 Geological Map of the Southern Baltic Bottom, published in the period 1989-1995; the second is the 1:500 000 Geological Atlas of the Southern Baltic, published in 1995. In both of them much attention is given to the bottom relief. Each sheet of the Map contains a geomorphological sketch and, in the Atlas, one of the 34 tables is a geomorphological map, and another table presents a synthesis of recent sedimentary processes. In the texts of both publications there are separate chapters devoted to the analysis of bottom relief and to its morphogenesis and evolution.

The new data permit new avenues of investigation, e.g. of the interpretations concerning the origins of the Southern Baltic bottom relief. It has long been known that a significant part of the Southern Baltic area was land during the early Holocene and also partly during the Late Glacial period. The *Litorina* transgression in the Atlantic period (the Flandrian transgression along the western coasts of Europe) converted this area into a sea floor; this resulted in a change of the subaerial relief into a marine underwater relief. The whole complex of these phenomena and processes has recently been firmly dated, using the radiocarbon method, and in some cases also the TL method.

General information on the Southern Baltic bottom relief has earlier been given by Rosa (1967, 1987), Pikies (Geological Atlas..., 1979), Mojski (1989, 1991, 1995), Uścinowicz (1996). The evolution of the contemporary coastal zone was investigated comprehensively by Tomczak (1993, 1995, Geological Atlas...,1995); therefore this zone is not discussed in this paper.

Overview of glacial relief generated after the decay of the last Pleistocene ice-sheet

Bathymetrically, the Southern Baltic area consists of two parts, the so-called shallow plain and the deep plain. These are separated by a more or less well defined shallow plain slope. The latter is located at depths not exceeding 40 m, whereas the deep plain lies below 60 m. Such a division was proposed by Czekańska (1927), and is still used today because it reflects very well the principal bathymetric features.

Glacigenic relief, formed essentially by the decay of the last Pleistocene ice-sheet, has developed somewhat differently in both parts of the bottom. In the deep plain, in the bottoms of the present day basins, i.e. the Bornholm, Gdańsk and Gotland Basins (Fig. 1), the ice-sheet decayed in the presence of

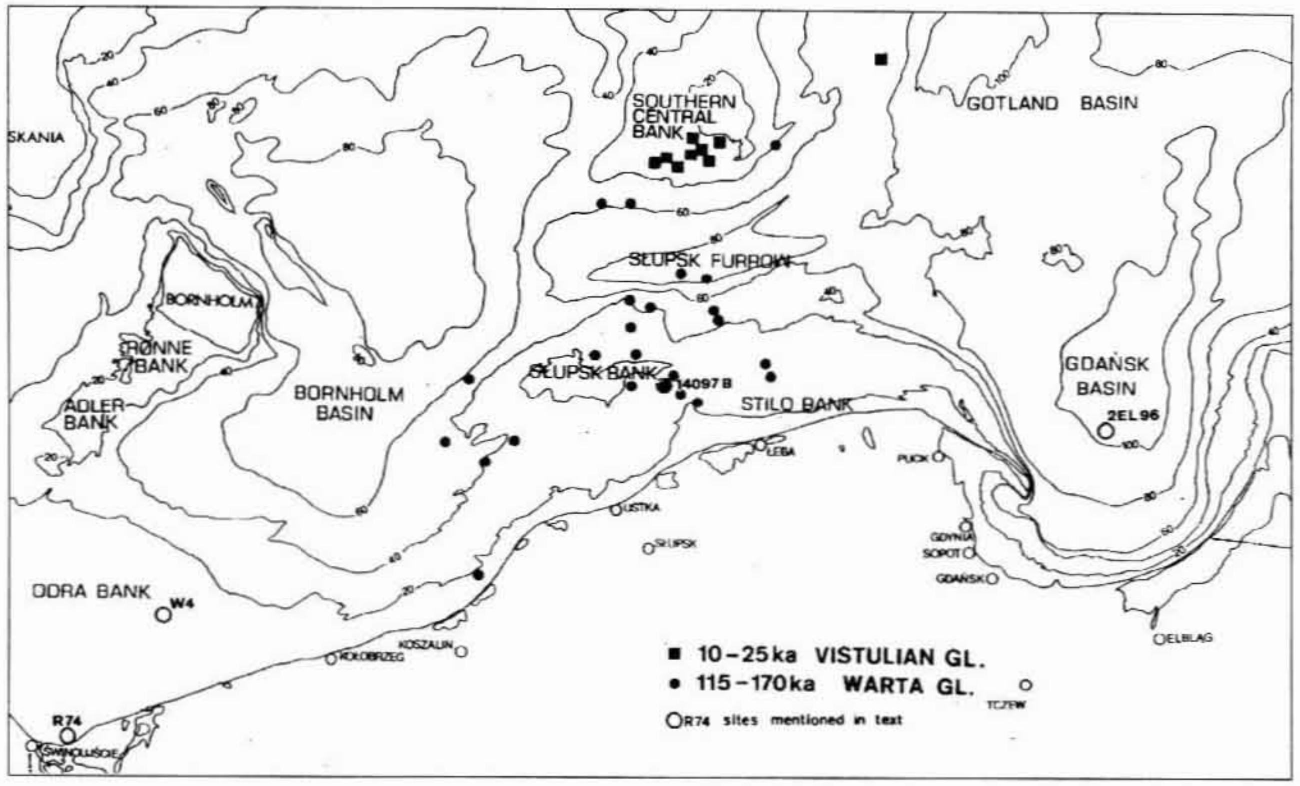

Fig. 1. Bathymetry, sites location and thermoluminescence dating, mainly of till and fluvioglacial deposits (after Kramarska & Zachowicz in: Geological Atlas..., 1995, Plates XVII and XVIII).

extensive water bodies. The postglacial relief there was formed (Pikies - Geological Atlas..., 1995) by subaqueous moraine plains, and, to a smaller extent, by low hills formed from that moraine. The single end moraine, present in the western part of the Gdańsk Basin is quite exceptional. The several dozen kilometres long sandy esker in the southern part of the Bornholm Basin is a distinct form. Its azimuth is about 240°, which corresponds well with the direction of movement of the last Pleistocene ice-sheet in this area suggested by many authors.

Nearly the whole area of the glacial relief of the deep plain is covered by Late Glacial and Holocene marine and lacustrine deposits, with no trace of hiatuses. In general, this cover does not permit us to obtain a more accurate knowledge of the glacigenic relief, which, additionally, is made more difficult due to its atypical development (the cover was formed in subaqueous conditions). An example of this marine and lacustrine sequence is shown in Figure 2.

The glacial relief forms in the shallow plain area, i.e. those on the Odra, Słupsk, South Central and the Stilo Banks are much better developed and clearly visible, though very much degraded. The relief in the Odra Bank area is that most degraded. Hillocks of the marginal zone occur on the Słupsk Bank, which are traces of end moraines of the Słupsk Bank phase. They are up to 5 m high, and form an elongated zone with azimuth 220° (they are parallel with the present Baltic coastline). They are built from sand, gravel and boulders. Low hillocks of old end moraines also occur in the lower part of the shallow plain slope at the southern edge of the Bornholm Basin. End moraines are relatively easily distinguished in the relief and in the geological structure of the bottom.

The flat morainic plain is quite extensive. In the lower lying places it was at least partly formed by subaqueous processes. Small morainic mounds are sometimes present in this area.

Outwash fans and ice-marginal lake plains occur in the shallow plain area. Outwash fans are present on the surface of the South Central Bank, most probably in two horizons, separated by a distinct sill which is several metres high. The surfaces of the outwash fans slope to the south and east. In the Słupsk Bank area, the outwash fan forms the south-east forefield of the end moraines of the Słupsk Bank phase, and denotes the traces of eastward outwash flow from this marginal zone.

Ice-marginal lake plains were formed on the southern slope of the Słupsk Bank, and on the Stilo Bank. These are flat plains with undulations not larger than 10 m.

Peat and post-lacustrine plains of varying size are present on the Odra Bank and also in the bottom of the Puck Lagoon. They comprise fine mineral deposits, gyttja and peat. These plains started to form almost immediately after the ice-sheet receded from the area (Fig. 3); much earlier, on the Odra Bank (14.06 ka BP, Jurowska & Kramarska - Geological Map... 1995) in the present coastal zone (e.g. on the Gardno-Łebsk Lowland, 13.8 ka BP, Rotnicki & Borówka, 1994), an somewhat later - 12.2 ka BP (Uścinowicz & Zachowicz Geological Atlas..., 1995) along the southern edge of the Gul of Gdańsk, where lacustrine formations lie in the Late Glacia deltaic cover of an earlier Vistula channel. About a dozen othe geological stations document other areas of peat and post-lacustrine plains, dated using the radiocarbon method as forming between 12.01 ka BP and 7.24 ka BP (Kramarska - Geological Atlas..., 1995), i.e. taking at least 4 800 years to form. The upper age limit, i.e. the 7.24 ka BP date, was obtained from peat from the Pomeranian Bay floor near Wolin Island. This peat is covered by fossiliferous marine sand. Therefore, with some approximation, it may be reasoned that this date is the extreme upper age limit for when subaerial conditions prevailed in the Southern Baltic area. The sea entered onto the new land part of the coastal zone a little later, for example in the northern part of the Vistula delta after 6.33 ka BP.

Inundation of the Southern Baltic land by the sea started a consecutive cycle of sediment accumulation and of littoral relief formation. The distribution of these forms depended to a large degree on the distribution of the older glacigenic and subaerial forms of relief. Accretional, erosional/accretional and erosional plains began to be formed on the sea bottom. Today, they form at least 50% of the Southern Baltic shallow plain and there is a distinct predominance of erosional/accretional plains. These plains are present not only on the surface of the shallow plain, but also on its slopes to 60 m water depth, and in some places even deeper. Erosional terraces were formed in many places, marking consecutive steps which maybe reflect older forms of glacigenic origin and younger forms of unknown genesis. These are grouped mainly at the southern edge of the Bornholm Basin, in depths of 15 to 50 m. Traces of accumulative coasts, probably coastal embankments and small spits, are much less common. At present, they are much eroded owing to progressive transgression by the sea. Their occurrence at depths between 20 and 40 m on the Odra Bank and Słupsk Bank slopes, as far as the southern boundary of the floor of the Gulf of Gdańsk, may indicate a longer stabilisation of the coastline at this depth zone of today.

Special attention should be given to the extensive landform which was created by the *Litorina* transgression along the south-western boundary of the Gdańsk Basin - the Hel Spit. This was formed at a depth of at least 50 m; it marks the northernmost reach of the coastal zone, which is presently at least 20 km offshore at the base of the spit. It is the product of accumulation predominantly of Upper Holocene age, and is at least 100 m thick in its south-eastern part. The calculated rate of sea level rise was then 1.7 cma^{-1} (Tomczak, 1993; Tomczak - Geological Atlas..., 1995).

The main characteristics of the genesis of the deposits, as described above, and of the forms of Southern Baltic bottom relief (especially those of the shallow plain) lead to the conclusion that the main hiatuses in sediment deposition and in the generation of forms of the relief occurred in the period from 14.2 ka PB to about 7.24 ka BP (Fig. 3), and also from 14.2 ka and 12.5 ka BP, when freshly-shaped glacigenic relief was being destroyed by wash-out water. The second occured after 7.24 ka BP, when small forms of bottom relief were generated, conditioned by near-bottom and coastal currents. Larger forms developed at that time only as spits along the present coastal zone.

The degree of destruction of glacigenic relief on the shallow plain

It would appear that there were two main stages of destruction of the glacial relief on the shallow plain: an older episode, occurring directly after the relief appeared from under the ice-sheet, and a younger one, from the beginning of the *Litorina* Sea transgression in the Atlantic period.

The older stage was characterised by the destructive action of outwash. At many locations, it led to at least partial, and sometimes to complete destruction of the glacial deposits and relief. Only the coarse, gravelly and gravel/boulder deposits with small additions of sand remained in some places. Locally, only sand remained. Postglacial morainic plateaux of that time were probably destroyed through the retreat of the cliffed coasts

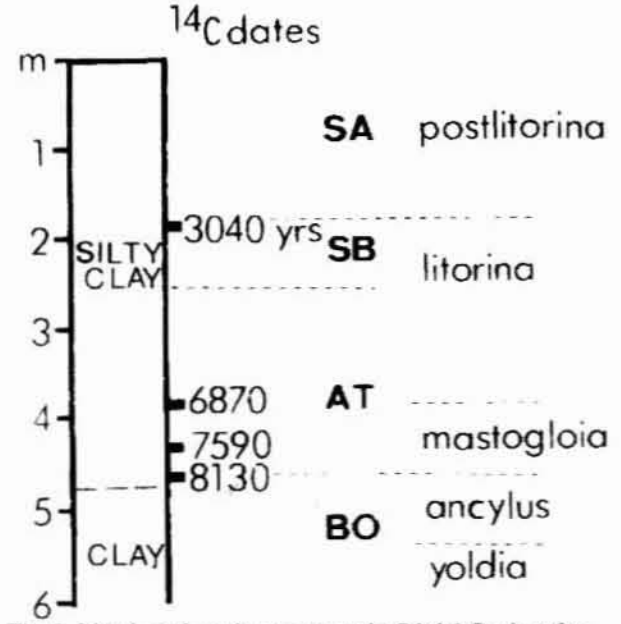

Fig. 2. Limnic and marine sequence in Gdańsk Basin (after Witkowski and Zachowicz in: Geological Atlas..., 1995, Plate XVIII).

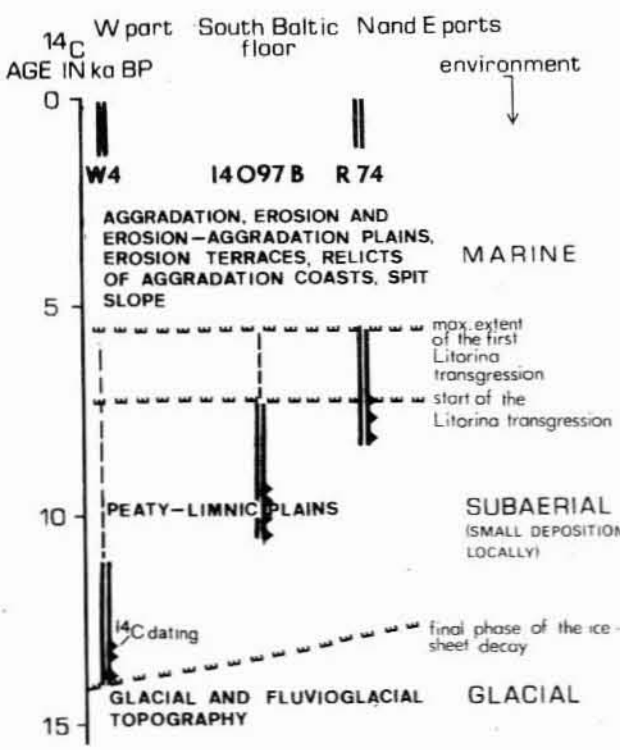

Fig. 3. Schematic picture of the deposition and break sequence in the Southern Baltic banks.
W4, 14097B and R74 - borehole profiles, location at Figure 1.

through marine erosion, and, finally, the remaining parts of the plateaux were inundated. Lower lying places, e.g. valley bottoms, were covered by water earlier. Sites where the till which is older than 20-15 ka BP (such as the till of Pre-Grudziądz stadial, e.g. profile W4 on the Odra Bank, acc. to Jurowska and Kramarska - Geological Map..., 1995, or of Warta age, e.g. profile 14097 B, acc. to Uścinowicz & Zachowicz - Geological Map..., 1995) is overlain by organic, or organic-mineral deposits of lacustrine origin which still formed in Late Glacial times are the evidence of destruction processes. Profiles in which marine *Litorina* deposits rest on the eroded surface of peat and lacustrine deposits are another example (e.g. profile R74 on the Odra Bank; Jurowska & Kramarska - Geological Map..., 1995). The youngest dates from these last profiles therefore indicate the lower age limit for the beginning of the transgression.

It should also be noted that there is a distinct differentiation in the age of the youngest glacigenic forms which remained after periods of shallow plain destruction. Over most of the Słupsk Bank, both glacial horizons of the last glaciation were destroyed, i.e. of the Wisła stage, and, because of this, the near-surface till still present there is of the Warta stage age, i.e. 17-11.5 ka BP. On the South Central Bank, the youngest till was formed during the last advance of the Vistulian ice-sheet, because its age is 25-10 ka BP (Fig. 1). The question then arises as to why there is such a large difference in the age of tills comprising the surface of the two banks. The answer should be sought in a possible glacio-isostatic rising of the South Central Bank. During the development of the *Litorina* transgression, that bank was at first in a much lower position than the Słupsk Bank. Therefore it became inundated earlier and during a shorter time than the surface of the Słupsk Bank.

When the Southern Baltic area became inudated by the *Litorina* transgression, the process of destruction of the bottom became slower, and gradually an increasing role in that process was taken over by near-bottom currents. However, we do not know enough about them to be able to evaluate quantitatively their influence on the shaping of the bottom relief. Assessments by Uścinowicz (Geological Atlas..., 1995) indicate that, at present, in the shallow plain area redeposition of sand and sand-gravel sediments prevails. Such processes are not favourable to the survival of forms of the older relief. Much of the shallow plain surface has become covered with fine sand, and, in effect, the older relief gradually disappears. On the Słupsk Bank and along the coast, an eastward direction of sand transport predominates. In places on the deep plain, clay and silt are deposited at a rate of 0.15 to 2.04 mma^{-1} (Pempkowiak, 1991; Szczepańska & Uścinowicz, 1994). This has lead to a further smoothing of the seabed.

The whole complex of morphogenetic processes, all active at present on the seabed, leads to the generation of increasingly distinctive small forms of underwater relief in the littoral zone, shaped in the environment of the very shallow non-tidal basin of the Baltic Sea.

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Karst areas in Poland and their changes by human impact

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Abstract: The karst areas of Poland occur mainly in the uplands of the southern parts of the country. The karst is evidently polygenetic, with forms produced in the tropical climates of the Tertiary, side by side with those produced in the Pleistocene cold periods. The karstified limestones are often mineralised and they produce large amounts of reliable drinking water and other resources which are extensively exploited (mineral mining, rock quarrying, groundwater abstraction, etc.) Many of Poland's karsts lie within or adjacent to the large industrial conurbations; in such regions, the karsts are under constant anthropogenic pressure. This paper discusses the effects of this human impact on the present evolution of the karst systems.

Key words: cave, harst, human impact

Introduction

The karst areas of Poland have formed in various limestone formations. Precambrian and Palaeozoic marbles are karstified in the Sudety and Holy Cross Mountains, Mesozoic limestones and dolomites in the Cracow-Częstochowa Upland, Tatra and Pieniny Mountains, Mesozoic chalk in the Lublin Upland and Tertiary halite and gypsum in the Nida Basin and the Wieliczka and Bohnia areas of the Carpathian Foreland. The outcrops of these formations are not collectively very large (about 3% of the total area of Poland), but those areas where carbonates are covered by only thin unconsolidated sediments of Tertiary or Quaternary are much more important in respect of the preservation of karstic features (20%). Moreover, the same formations have formed the foundation for palaeokarst developments at other times when a continental regime affected Poland, in the Upper Keuper and Upper Cretaceous, for example. There is no doubt that much of the modern karst

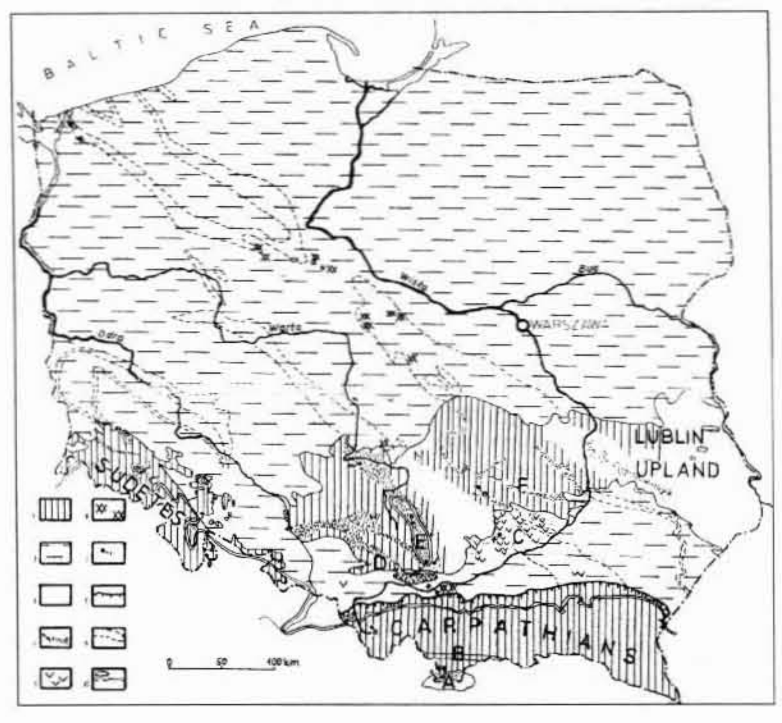

Fig. 1. Karst phenomena in Poland (after Głazek, *et al.*, 1982).
A - Tatra Mountains, B - Pieniny Mountains, C - Nida Basin, D - Silesian Upland, E - Cracow-Wieluń Upland, F - Holy Cross Mountains. 1 - Pre-Neogene non-karst areas, 2 - Neogene clay-sand deposits overlying karst rocks and other rocks, 3 - karst rocks, 4 - surface carbonate karst, 5 - surface gypsum karst, 6 - gypsum-salt diapirs, 7 - the more important caves: in the West Tatras: Śnieżna, Miętusia, Mroźna and Mylna (both opened for tourists); in Beskidy Mountains: W Trzech Kopcach (flysch cave); in the East Carpathian Foreland: Kryształowa in Wieliczka (developed in rock-salt); in Nida Basin: Skorocicka (in gypsum); in Sudety Mountains: Niedźwiedzia in Kletno (open for tourists), Radochowska, Jasna in Wojcieszów; in Cracow-Wieluń Upland: Wierzchowska Górna (open for tourists), Łokietka (open for tourists), Głęboka, Ewy (open for tourists); in Holy Cross Mountains: Raj (open for tourists), 8 - boundary of Carpathian overthrust, 9 - outline of karst rock limits under Neogene sediments, 10 - maximal extent of Pleistocene glaciation.