The southern Baltic Sea — test field for international co-operation

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A b s t r a c t . Selected results of the joint geological investigations of the Southern Baltic are presented, mainly related to geological cartography and environmental geology (e.g., sea bottom contamination). The results of international projects expand the knowledge of bathymetry, seabed sediments in the Polish Exlusive Economic Zone and other data obtained by the Marine Geology Branch of the Polish Geological Institute during its 35 year research activity on the Baltic Sea. The PGI participates in research co-operation with neighbouring Baltic countries (especially Germany, Lithuania, Russia, Sweden, and Finland), but also with geological surveys of Great Britain and the Netherlands conducting joint research in the Polish part of the Baltic Sea.

Key words: *southern Baltic Sea, geological mapping, sea bed sediments, geochemical monitoring, international co-operation*

The Baltic Sea, occupying an area of 415,266 km^2 and with a mean depth of 52 m, is divided into the following seven regions: the Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, Danish Straits, and Kattegat (Fig. 1), the division stemming from the shoreline complexity and seafloor morphology. This division is internationally recognised (Mikulski, 1987). The terms "Southern Baltic" or "southern Baltic area", although not precisely defined, are in common use, particularly in Polish literature, both in monographs and cartographic publications (e.g., Łomniewski et al., 1975; Augustowski, 1987; Mojski et al., 1995).

The Republic of Poland's maritime areas consist of internal waters (a part of the Gulf of Gdańsk with Puck Bay, Puck Lagoon, and the Vistula Lagoon, as well as the Szczecin Lagoon), the 12-nautical-mile-wide territorial sea, and the Exclusive Economic Zone. Poland borders on the Baltic Sea with Germany, Denmark, Sweden and Russia.

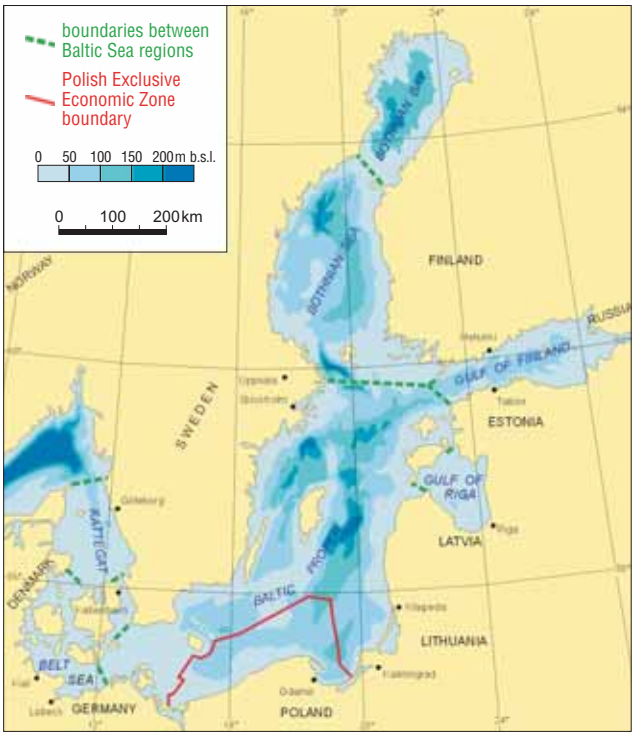

Fig. 1. The location of the Polish Economic Zone on the Baltic Sea

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Profile of the area

The Republic of Poland's maritime areas (excluding the Szczecin Lagoon) cover 30,533 km^2 and include parts of the major deep Baltic basins (the Bornholm Basin, Gotland Basin, and Gdańsk Basin), as well as the Słupsk Furrow (Fig. 2). The basins are separated by sills, the minimum depth of which, recorded on the sill which separates the Bornholm Basin and the Słupsk Furrow, is about 60 m; the depth of the sill separating the Gdańsk and the Gotland Basins is about 85 m. South of the basins there are coastal shallows, characterised by the raised seafloor of the Odra Bank, Słupsk Bank, Czołpino Shallow, and Stilo Bank. The only bank located north of the deep basins, away from the coast, is the Southern Middle Bank, found north of the Słupsk Furrow (Fig. 2).

The main parent formation of the Southern Baltic marine clastic sediments are glacial and fluvioglacial deposits. Holocene marine sediments are residual or are the products of multiple redeposition of eroded Pleistocene deposits. Sediments on the southern Baltic seafloor show strong differentiation especially with regard to grain size. Occurrence of each sediment type shows general regularities, and depends mainly on sea depth and the distance from the shore. Gravel, sandy gravel, gravelly sand, coarse, medium sands occur mainly in the shallow water zone at a depth of up to 30 m. Fine sands cover the seabed at a depth from 30 to 50–60 m in general, and also occur in shallower zone as irregular patches between coarser sediments. Muddy sand and sandy mud occur on the edges of deep water basins, while mud covers the central parts of the basins (Fig. 3). Outcrops of Pleistocene and early Holocene deposits are not very common and are formed in some places by glacial till, interstadial sandy deposits, glacio-lacustrine clay and clays of early stages of the Baltic Sea development. The outcrops of till and clays on the thresholds separating the Basins are covered by a thin (< 0.2 m) layer of recent clayey sands. Ferromanganese concretions also occur with these sediments.

Basic results of the research on the Baltic Sea by the Marine Geology Branch of the Polish Geological Institute

The primary aim of the Marine Geology Branch of the Polish Geological Institute, formed in 1968, was to learn about the genesis and development of the Baltic Sea and to determine the regions in which undersea mineral deposits occur. Since 1970, geological work has been done on the coast and in the Polish Exclusive Economic Zone of the Baltic. As a result, a series of essential cartographic studies

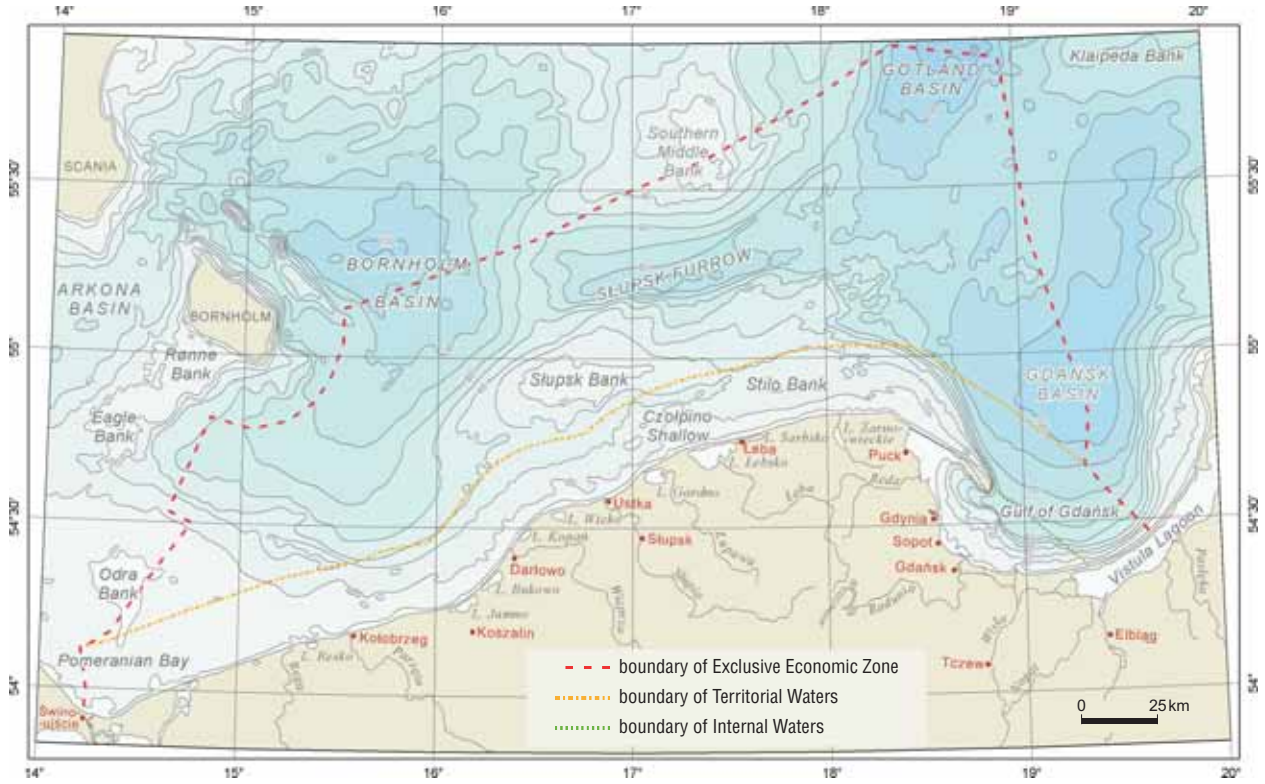

Fig. 2. The bathymetry of the Southern Baltic

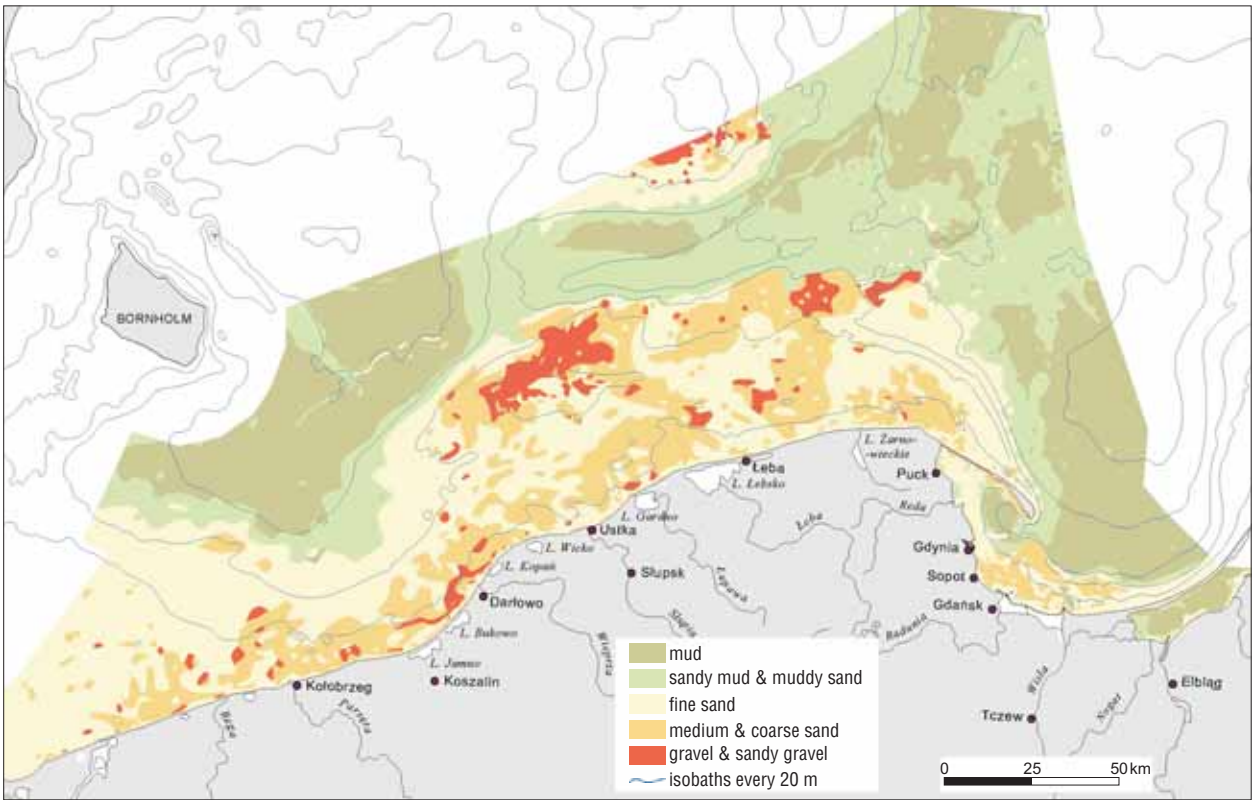

Fig. 3. Surface sediments of the Southern Baltic

was developed, such as *The Geological Map of the Baltic Sea Bottom* in 1 : 200,000 scale (Mojski, 1989–1994), *The Geochemical Atlas of the Southern Baltic* in 1 : 500,000 scale (Szczepańska & Uścinowicz, 1994), *The Geological Atlas of the Southern Baltic* in 1 : 500,000 scale (Mojski et al., 1995), *The Geochemical Atlas of the Vistula Lagoon* (Uścinowicz & Zachowicz, 1996), *The Geological Map of the Baltic Sea without Quaternary Deposits* in 1 : 500,000 scale (Kramarska et al., 1999).

Parallel to the cartographic work, the prospecting and documentation of aggregate deposits was performed. Natural aggregate, i.e., gravel, sandy gravel and gravelly sand, which form deposits in the seabed are the most thoroughly investigated mineral resources in the Southern Baltic.

Up to the present day, three deposits; the Słupsk Bank, Southern Middle Bank and Koszalin Bay have been documented with total resources of ca. 160 million tonnes. Since 1990, investigations of sand resources for beach nourishment have also been carried out.

Between 1995 and 2003, the research focused on the area of broadly understood coastal zone — an area which is very important for the national economy and extremely sensitive to any interference in the natural environment. As a result, a very detailed (1 : 10,000) map was developed, which covers the land and the sea sections and presents geological issues, the area development and use, as well as the main geodynamic hazards.

Bilateral and international projects

International co-operation is focused on cartographic work and on environmental geology. The Marine Geology Branch of the Polish Geological Institute took part in a number of international — multi- and bilateral — initiatives aiming at a synthesis of national cartographic studies and the publication of geological maps. In the 1990s, three important research projects were implemented regarding the environmental problems of the Baltic Sea.

Co-operation in Geological Cartography of Maritime Areas. Bilateral Polish-German co-operation dates back to the beginnings of the Marine Geology Branch. The first research voyage to the Odra Bank took place in 1972 on the m/s *Bereitschaft* owned by the Geological Institute in Berlin. In 1976, the first joint study of the concentration of heavy minerals in the sands of the Odra Bank was performed. As early as in 1975, scientific co-operation with the Geological and Paleontological Institute of Kiel University was established, whose result was joint research on late- and postglacial sediments of the Gdańsk Deep from the deck of the German ship, the s/b *Meteor* (Kögler et al., 1985).

The co-operation on geological cartography established in the early 1990s between the Marine Geology Branch and the Baltic Sea Research Institute in Warnemünde (Germany) and the Atlantic Branch of the Institute of Oceanology of the Russian Academy of Sciences in Kaliningrad resulted in jointly developed geological maps of the Baltic sea bed.

The first effect of the scientific co-operation was *The Map of the Sediments of the Western Baltic*. The map was published in 1994 by the Department of Navigation and Oceanography of the Ministry of Defence of the Russian Federation in Saint Petersburg, in 1 : 500,000 scale. This map is a two-board publication; it presents surface sediments (the 0–5 cm layer), while the second board shows the Quaternary sediments of the Western Baltic (sediments below the 1 m layer) (Emelyanov et al., 1994a, b).

Between 2002 and 2004, a joint Polish and German *Cross-border Map of the Pomeranian Bight Sediments* was developed. The map of surface sediments of the Pomeranian Bight covers the German and Polish parts of the Pomeranian Bight and the adjacent areas — the eastern part of the Arkona Basin and the southern part of the Bornholm Basin, the Eagle and Rřnne Banks. The area of the map is limited by the coastline to the south, by the latitude 55°20' to the north and by the 13°30' and 16°00' meridians to the west and to the east, respectively. The number of samples of the German data set involved in the presented map is 5428 and 1553 samples were taken by the Polish Geological Institute. The major difficulty in combining grain size data from varying sources is the utilisation of unequal sequences of size fractions at the different laboratories and/or operators while measuring grain size data. This causes incompatible results. Tauber (1995) presents a method to solve this problem. A Fermi function with two parameters, "median" and "sorting", is used to approximate the empirical cumulative grain size distribution. ArcGIS 8.2 was used to combine all the data presented in the map (Fig. 4) (Bobertz et al., 2004a, b).

Between 1995 and 1998, two maps in 1 : 500,000 scale were developed together with the Lithuanian Geological Institute, Geological Survey of Lithuania, Geological Survey of Sweden and the Swedish Maritime Administration: *The Bathymetric Map of the Central Baltic Sea* (Gelumbauskaite, 1998) and *The Bottom Sediment Map of the Central Baltic Sea* (Repecka & Cato, 1998). The maps

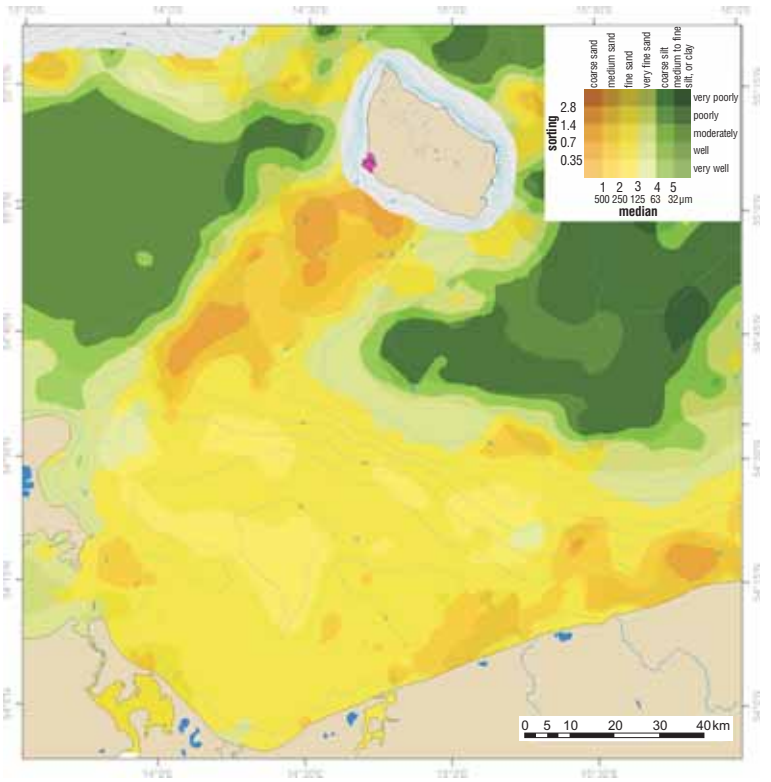

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Fig. 4. Surface sediments of the Pomeranian Bight (after Bobertz et al., 2004b, in press)

complete with the descriptions are available both in hard copy and in ArcInfo digital format.

Co-operation in Environmental Geology of Maritime Areas. The primary aim of work on the environmental problems of the Baltic Sea was to determine the geochemical condition of the sediments and to establish the bases for the monitoring of the environment based on the changes occurring in the sediments.

The first project called *Contaminants in the Baltic Sea Sediments* was carried out under the auspices of the International Council for the Exploration of the Sea and the Helsinki Commission. Marine sediments provide a possibility to assess the changes in the environment in a consistent manner. Not only the present-day distribution of contaminants, but also at the same time the depositional history of the sampling site can be exposed, provided certain hydrochemical and biological conditions are met. The baseline study of the concentration of contaminants in the Baltic Sea surface sediments was carried out in 1993. All the sub-areas of the Baltic Sea were covered. The trace element concentrations in the surface samples revealed high concentration of Cd, Cu, Zn, Ag, Ni and Co in the central deep basins, and very high concentration of As in the Bothnian Bay. For Pb, Cd, and Hg, apparently anthropogenically influenced distribution patterns were found in the deep basins, with high concentration in the Western Baltic and the Gulf of Gdańsk, in the eastern part of the Gulf of Finland and in the Bothnian Bay (except for lead). The highest total concentration of carbon and nitrogen are found in the central deep part of the Baltic proper. The concentration at similar bottoms in the Bothnian Bay and Bothnian Sea is about 1.5 to 2 times lower (Perttilä, 2003). As a result of the study, 14 sites were selected as suitable for sediment monitoring at 5 and 10 year intervals. The sampling equipment and methods as well as the scope of chemical analyses were recommended.

Between 1993 and 1995, National Geological Survey of the Netherlands, in close co-operation with the Polish Geological Institute's Marine Geology Branch, conducted a geological and geochemical sea bed monitoring programme in the Gulf of Gdańsk. The general objectives of the programme were to gain insight into the historical build-up of sea bed sedimentation and contamination, and in particular to analyse the sea bed quality with the intention of identifying "hot spots" and also recognising the thickness of polluted layers and the concentration of the pollutants. A total of 41 locations were chosen to include sites with varying sedimentological composition and also potential "hot spots". The seismic survey was carried out over 25 sampling locations. The samples were described, and sub-samples were taken for organic and inorganic analyses and X-ray photography. Five possible "hot spots" were found (Fig. 5) (Pashier et al., 1997; Uścinowicz et al., 1998; Ebbing et al., 2002).

The *Marine Environmental Assessment and Monitoring Gdańsk Gulf Basin MASS* project was the continuation of the commenced work. It was implemented between 1997 and 1999 by the geological surveys of the Netherlands and Great Britain, as well as the Polish Geological Institute and the Lithuanian Institute of Geology. The project's aim was to develop a standardised approach to marine environmental assessment and monitoring, including appropriate data management, applicable to both western and eastern Europe. In order to achieve this aim, the following aspects of marine monitoring in the Polish and Lithuanian sectors of the Gdańsk Basin were considered: site selection and sampling procedures, laboratory procedures, data management, and the provision of analytical reference materials (Fig. 6).

Studies of down core profiles show the beginning of metal contamination in muddy sediments at depths between 16 and 10 cm, but the patterns of variations differ in detail for each core and depend on the sedimentary environments (Fig. 7).

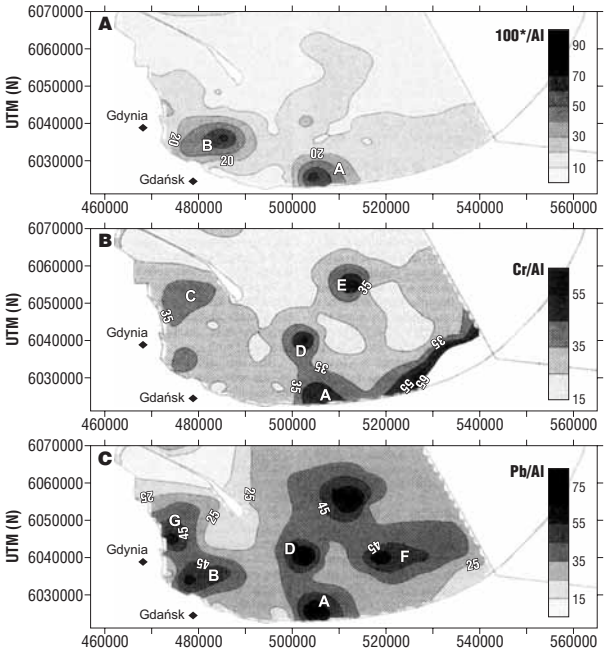

Fig. 5. The location of "hot spots" in the Gulf of Gdańsk — the result of a Dutch-Polish project (after Ebbing et al., 2002)

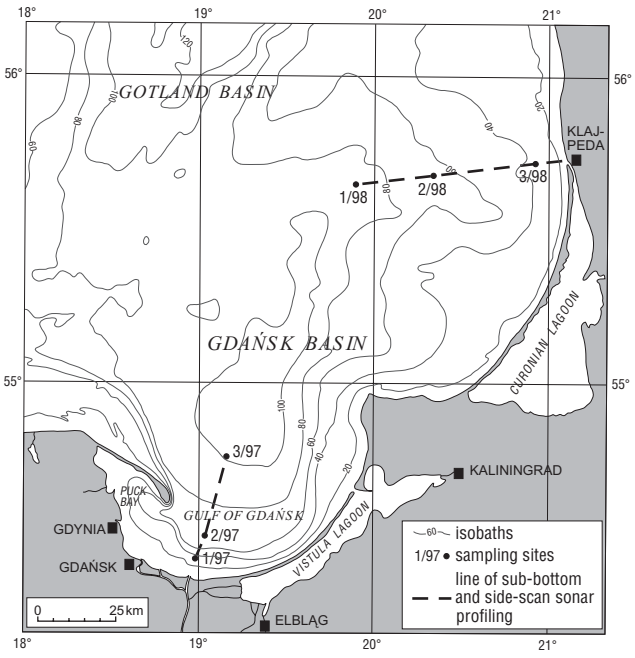

Fig. 6. Documentation map of the work in the Gdańsk Basin within the *MASS* project

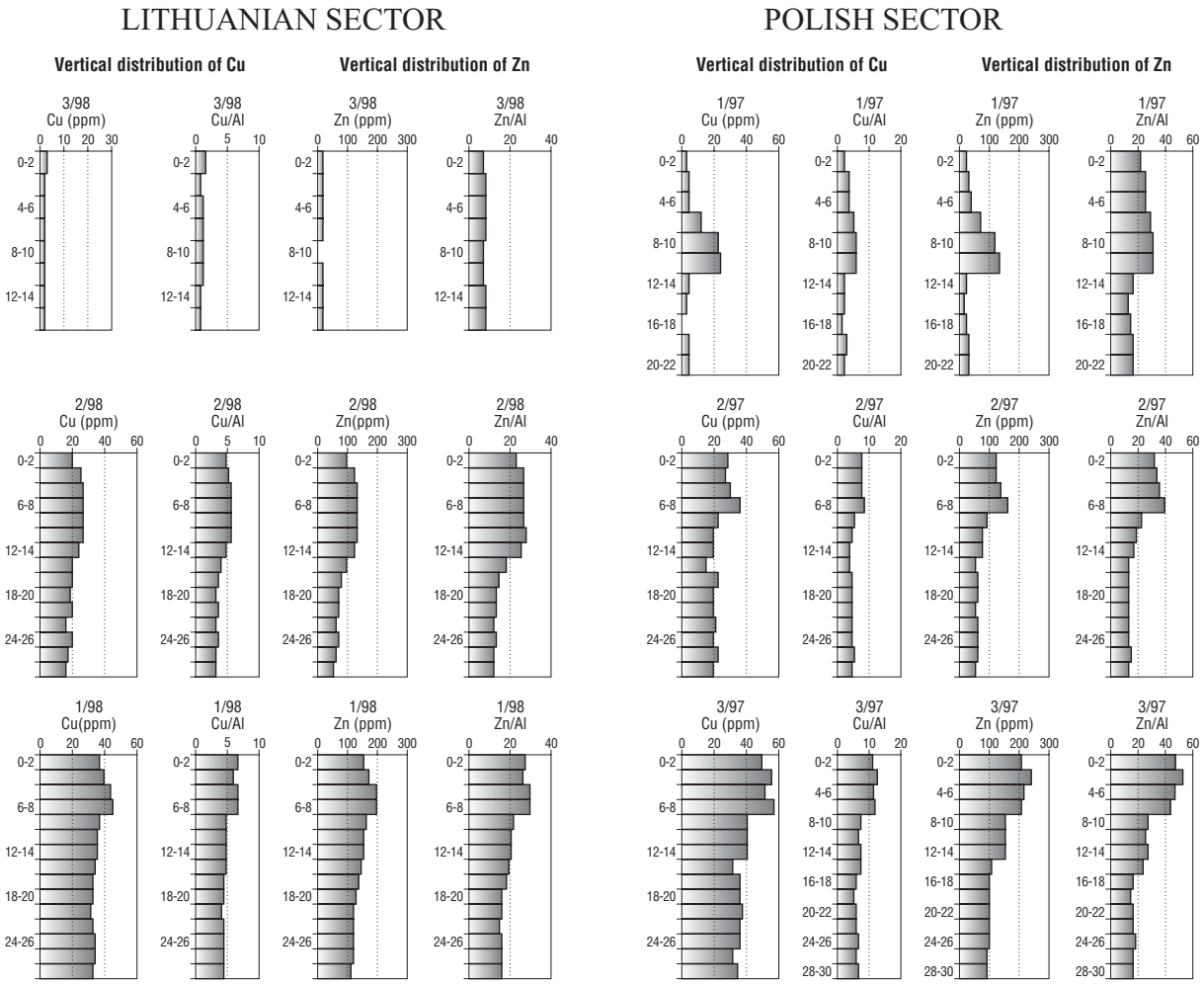

Fig. 7. Vertical variation in the content of selected metals in the Gdańsk Basin sediments

In all cores of muddy sediments, the topmost 2 cm show a decline from maximum metal levels. This probably represents a genuine diminishing of metal loads.

The topmost layer of sediments in the Gdańsk Basin is enriched with phosphorus and organic carbon. This indicates that processes of eutrophication are still going on.

The northern part of the Gdańsk Basin (the Lithuanian sector) seems to be less contaminated by metals and polychlorobiphenyls and also less eutrophicated than the southern part (the Polish sector). This is mainly due to the Vistula river discharging directly to the Gulf of Gdańsk. The second big river — the Nemunas — discharges to the northern part of the Gdańsk Basin via the Curonian Lagoon. Conversely, the muddy sediments in the Lithuanian part of the Gdańsk Basin are polluted by mineral oils and polycyclic aromatic hydrocarbons. Only sandy sediments from the Polish part, located in front of the Vistula river mouth, contain more mineral oils and some PAH than the sands from the Lithuanian sector.

Five cores were taken in each sampling site for tests of intra-site variability and sampling repeatability. Intra-site variability is generally smaller in the lower part of the cores than in their topmost parts. Only in the case of a few samples the differences can exceed analytical errors and indicate genuine differences between samples. The reason for major variations, especially for the 0–2 cm layer, could in fact represent intra-site differences or the coring technique effect on topmost soft sediments.

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The international co-operation of the Marine Geology Branch of the Polish Geological Institute goes far beyond the confines of geological cartography and environmental geology of maritime areas. Between others, Marine Geology Branch of the PGI takes part in the development of the principles of rational management of deposits and the assessment of the results of prospecting and exploitation of raw material from the sea bed. Polish Geological Institute participate in the work of the ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT). The international co-operation also covers wide-ranging exchange of experience in fundamental research of the world ocean. The Polish Geological Institute has been commissioned to work on the EU Centre of Excellence REA *Research on Abiotic Environment* project, within which the Marine Geology Branch carries out the work package regarding the abiotic maritime environment. This gives us an opportunity to develop the international co-operation established so far and to make new academic contacts.

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