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# Distribution and significance of heavy-mineral concentrations along the southeast Baltic Sea coast

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## ABSTRACT

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Heavy mineral concentrations (HMCs) in coastal sands are important from both scientific and practical standpoints. On one hand, they may serve as local sources of iron and other economically important metals, and on the other they are good indicators of hydro-meteorological and sedimentological conditions along the coast. A variety of HMC types have been documented in beach, foredune, and relict dune environments of Lithuania. The study region is located along the Curonian Spit (Nida) and mainland coast (Būtingė). The ocean beach sites range from 25 to 35 m in width and are backed by 5-10 m-high foredunes. The Great Dune Ridge on the Curonian Spit consists of relict (mid-late Holocene) dunes which are the highest coastal dunes in Northern Europe (more than 60 m above sea level). The prevailing westerly winds attain speeds of 4.2 m/s in the summer and 5.5 m/s in autumn and winter. Along the southeast Baltic Sea coast, quartz and feldspars-rich sands contain variable amounts (1-8%) of heavy minerals, such as garnet, rutile, zircon, magnetite, ilmenite, hornblende, and other accessory minerals. On the beach, HMCs typically range in thickness from 0.1 to more than 3.0 cm and represent increased wave and run-up regime. Based on previous studies of coastal morphodynamics and field observations during 2005, 2006, 2008 and 2010 enriched horizons near the foot of the foredune are the result of storm reworking and subsequent aeolian deflation. Similar process concentrates almandine garnet and magnetite along the Curonian Lagoon shoreline, on the opposite side from the Nida beach site. Based on their occurrence in the Great Dune Ridge, we suggest that buried HMCs likely represent periods of increased wind activity (storminess). Due to their relatively high fraction of heavy minerals, HMCs have substantially higher magnetic susceptibility (MS) values than background quartz-rich sands and, where well developed, they can be used for spatial correlation of subsurface horizons. Therefore, the MS method was used as a tool for cataloguing the properties of HMCs in the field and in the laboratory. For documenting lithological differences between exposed heavy-mineral concentrations and background quartz-rich sands, this study focused on coastal environments with different sedimentary regimes: 1) surface profile and shallow trenches through the upper berm at Bating (wave run-up setting along the mainland shoreline); 2) a 40-m-long shore-normal beach profile at Nida on the Baltic Sea shoreline of the Curonian Spit, (mixed wave/aeolian conditions) and 3) a short surface profile along a lagoon beach at the base of the Paranidis Dune (the landward side of the spit). The 2008 and 2010 data were compared to previous studies of the HMCs in relict dunes (exclusively aeolian setting). The spatial and temporal distribution of HMCs in different sedimentary environments is a function of: 1) the initial heavy-mineral content prior to high-energy events and 2) hydro-meteorological and sedimentary conditions during the events responsible for removal of lighter minerals and HMC formation as a lag deposit. The thickness, degree of concentration, and rhythmicity of HMC horizons offer opportunities for quantifying the periodicity and intensity of hydrodynamic processes along sandy coasts.

**ADDITIONAL INDEX WORDS:** *Magnetic susceptibility, Indicator, Dynamic condition*

## INTRODUCTION

Both open ocean inland sea shorelines are characterized by great hydro-dynamic energy fluxes, which determine the timing and magnitude of sediment fluxes and the morphodynamics of beaches and dunes. The dominant sand fraction is differentiated by grain size and density, often culminating in heavy-mineral concentrations (HMCs) that occur in a variety of settings and are preserved in the sedimentary record (Rao, 1957; Woolsey *et al.*, 1975; Dolotov *et al.*, 1982; Komar and Wang, 1984; Tsvetkova-Goleva and Simeonova, 1984; Komar, 1989; Smith and Jackson, 1990; Linčius, 1991; Frihy and Komar, 1993; Hamilton and Collins,1998; Buynevich *et al.*, 2007a,b; Nair *et al.*, 2010).

Understanding the spatial and temporal distribution of HMCs is particularly important during high-energy hydro-meteorological events (storms and strong winds), as well as a range of sedimentary conditions and morphodynamic processes. The sandy shoreline of the Baltic Sea presents an ideal opportunity to investigate the present context of HMC occurrence due to the wide range of coastal landforms and energy regimes over a short stretch of coast (Fig. 1).

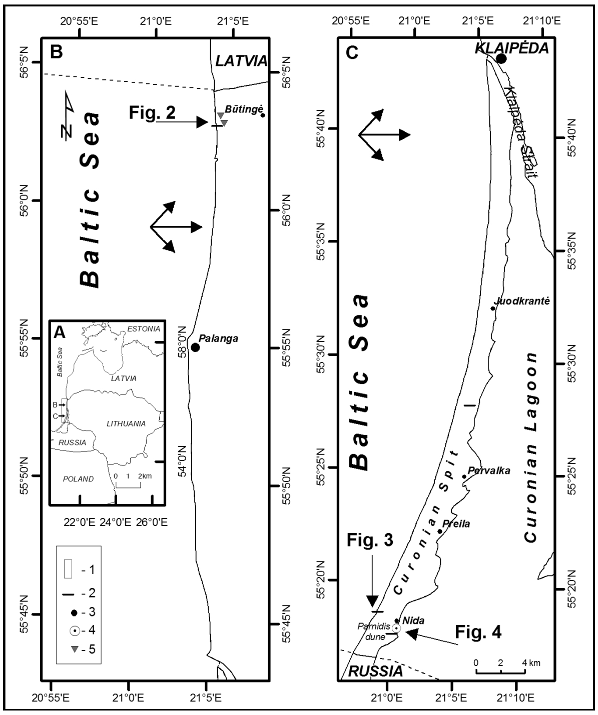

Figure 1. (A) Location of two study areas along the southeast coast of the Baltic Sea: (B) mainland coast from Klaipėda Strait to Lithuania-Latvia state border and (C) the northern part of the Curonian Spit, Lithuania. Arrows in show the direction and speed of prevailing winds (wind direction after Žilinskas *et al.*, 2001). Numbers in legend: 1 – study area, 2 – magnetic susceptibility (MS) profiles, 3 – settlements, 4 – borehole, 5 – trench.

The near lack of tidal influence limits the hydrodynamic factors thereby facilitating the interpretation of specific heavy-mineral concentrations. In addition, subsurface investigation of well-sorted beach and dune sands in this region rely heavily on geophysical imaging (high-resolution georadar) and a strong response of subsurface signal to HMCs requires an understanding of their geological context (Buynevich *et al.*, 2007a).

The present study documents the distribution of heavy minerals and the use of low-field magnetic susceptibility (MS) along surface profiles and in shallow trenches at several contrasting sites along the southeastern Baltic Sea coast, Lithuania. The goals of our research are 1) to compare the morphodynamic states of three beach profiles with the surficial HMC distribution; 2) to assess the distribution of enriched horizons in the shallow subsurface, and 3) to evaluate the possibilities and prospects of this approach to method for rapid evaluation of modern morphodynamic conditions and for reconstruction of past high-energy events.

## PHYSICAL SETTING

The study region is located along the Baltic Sea coast of the Republic of Lithuania, which encompasses 90.66 km of shoreline - 38.49 km of mainland coast, 1.14-wide Klaipėda Strait, and 51.03 km covering the northern half of the Curonian Spit (Žilinskas, 1997; Fig. 1). The latter is a UNESCO World Heritage Site, and is part of a 98 km-long, 0.4-4.0 km-wide barrier Spit (Gudelis, 1998) divided between the Russian Federation in the south and Lithuania in the north. Situated along the landward part of the spit, the Great Dune Ridge consists of relict (mid-late Holocene) dunes which are the highest coastal dunes in Northern Europe (more than 60 m above sea level). The open sea beaches average 25-35 m in width and are backed by 5-10 m-high foredunes. The Būtingė site represents an erosional coast, whereas the western shoreline of Nida is an example of accretionary coastal type (Žilinskas and Jarmalavičius, 2003). The Curonian Lagoon beach site range from 2 to 15 m in width and in many places is bordered by different generations of dunes. The prevailing westerly winds attain speeds of 4.2 m/s in the summer and 5.5 m/s in the fall and winter (Žilinskas *et al.*, 2001). Along this part of the Baltic Sea coast, quartz and feldspar-rich sands contain variable amounts (1-8%) of heavy minerals, such as garnet, rutile, zircon, magnetite, ilmenite, hornblende, and other accessory minerals. Their enrichment beyond the background value (>15-20%) is the focus of the present investigation.

## METHODS

The present study of heavy mineral concentrations and coastal morphodynamics relies on lithological contrast between quartz ($\rho$=2.65g/cm$^3$) and heavy minerals ($\rho$>2.7). The ferromagnetic properties of magnetite ($\rho$=5.2) and paramagnetic nature of other heavy minerals result in a clear low-field magnetic susceptibility (MS) response. This contrast with diamagnetic (slightly negative) MS values of quartz was used to locate and quantify the relative enrichment in the HMCs (Shankar *et al.*, 1996; Buynevich *et al.*, 2007a; Buynevich, 2011). The *in situ* measurements of sand were performed along the surface profiles and shallow trenches at Būtingė (Fig. 2A), surface profile across an exposed Baltic Sea beach at Nida (Fig. 3A), and a short profile across a low-energy lagoon shoreline (Fig. 4A). At Būtingė site, a 22.3-m-long MS profile and down a 0.55-m-deep trench were measured in late October 2010. The latter were compared to the values from a 0.3-m-deep trench excavated in early November 2008 at a nearby site (Fig. 2). A 30-m-long MS profile collected in 2008 at Nida beach is compared to a 44.0-m-long profile obtained in 2010 (Fig. 3B). The shortest 3.3-m-long MS profile was measured on the lagoon beach at the foot of the Parnidis Dune (Fig.4). Depending on the total length of the profile, the MS measurements were taken at evenly spaced intervals varying from 15 cm to 1 m.

Bulk magnetic susceptibility was measured using Bartington MS2K field scanning sensor (relative sensitivity decreases to 50% at surface diameter of 2.5 cm and the depth of 0.3 cm). Given this response decay with depth, the field sensor is ideal for measuring relative MS values on moderately smooth sediment surfaces, particularly where sampling of unconsolidated HMC horizons is problematic (Buynevich *et al.*, 2007a). The assessment of the morphodynamic changes along the coast was performed by the Coastal Research and Management Team of the Coastal Research Department, Institute of Geology and Geography. The annual investigations (repeated leveling) of coast cross-section profile were carried out using an electronic tachometer (TOPCON GTS 229) in Būtingė and Nida. A hand-held GPS system was used along profile and trench locations.

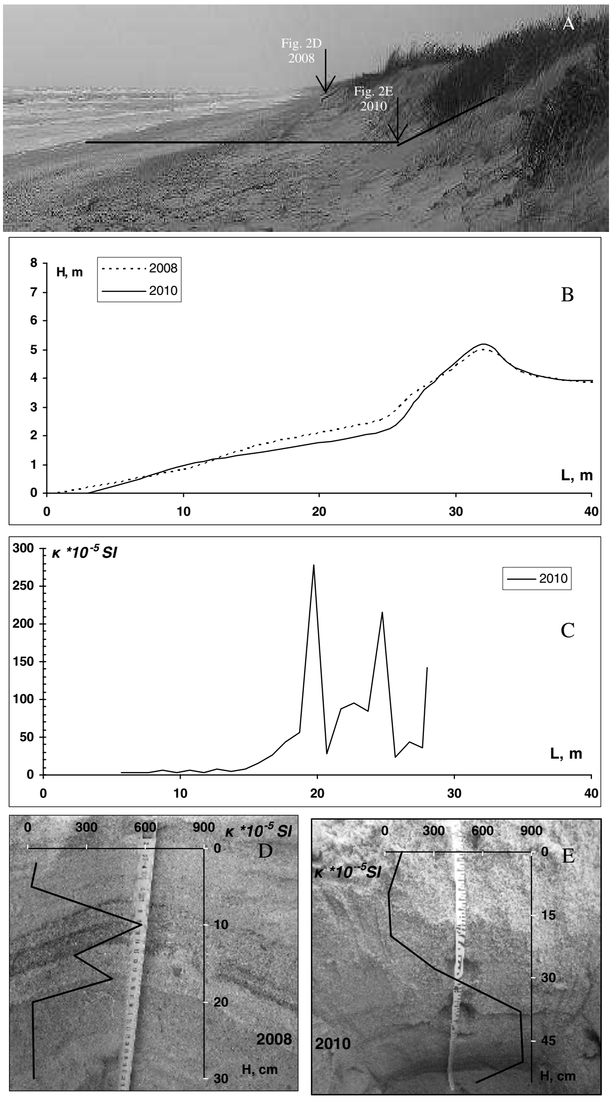

Figure 2. (A) Locations of profiles along Būtingė beach (28 October 2010 topographic and MS profile is 100 m south of the 11 November 2008 topographic profile and trench). (B) topographic profiles at the two sites. (C) Magnetic susceptibility (MS) of sand along the 2010 profile. (D) and (E) are vertical MS profiles in shallow trenches along the upper part of the berm collected during 2008 and 2010, respectively.

## RESULTS

Following the Ervino (Erwin) storm of January 2005 (Žilinskas *et al*., 2005) and a winter storm in 2007, the 2008-2010 period was relatively calm, as presented by annual investigations (repeated leveling) of topographic profiles (Figs 2B and 3B). Būtingė beach mainly underwent retreat, whereas Nida beach accreted due to influx of sand via longshore transport from the south.

At the Būtingė site, bulk magnetic susceptibility ($\kappa$) values along a beach-foredune profile range from 2.6 (dimensionless, x10$^{-5}$SI units) for quartz-rich sand to 277.5 for heavy-mineral enriched horizons (Fig. 2C). In shallow trenches, MS reaches 581.4 and 848.2 for the November 2008 and October 2010 trenches, respectively (Fig. 2E, 2D). Along the Baltic Sea beach at Nida, the background values of 0.0-5.0 contrast with >20 for the HMCs (Fig. 3C). In the Parnidis profile, the MS shift is similarly dramatic, from $\kappa$=2.4-3.7 to 680.3-725.5 (Fig. 4C). Even where the up-dip end of the buried inclined HMC was observed to reach the surface, a distinct signal ($\kappa$=34.1) was measured at the surface (see the labelled horizon at 1.65 m mark in Fig. 4). Similar values were observed in previous studies of buried slipface strata enriched with HMCs within the Great Dune Ridge (Buynevich *et al*., 2007a).

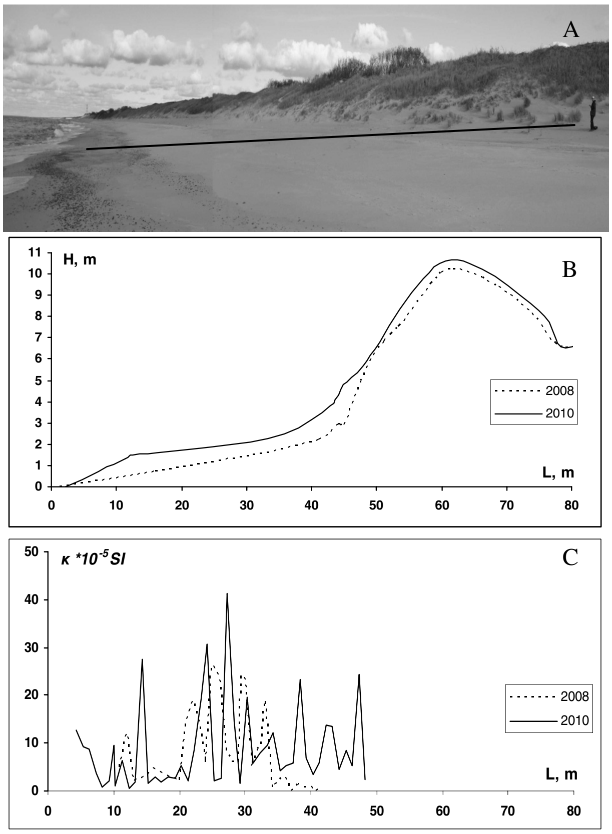

Figure 3. (A) Location of the monitoring profile along Nida beach, Curonian Spit. (B) Morphodynamic changes of Nida profile in 2008 and 2010. (C) surface MS measurements along the profile collected on 13 November 2008 and 27 October 2010.

## DISCUSSION

The results of the HMC analysis and morphodynamic context of the three study sites during fair-weather conditions, indicate that heavy minerals tend to concentrate on relatively stable, from the hydro-dynamic point view, berm crest of the Baltic Sea shoreline and the low-energy Curonian Lagoon beach (Kirlys and Stauskaitė, 1982), as well as along the upper berm/basal foredune region on the high-energy erosional shoreline (Linčius, 1991). Similar to other coastal settings, HMCs at the Baltic sites are related to episodic storm wave regime and increased wind activity, resulting in a sequence of buried HMC layers at the base of the foredune (Fig. 2D, 2E; Rao, 1957; Woolsey *et al*., 1975; Komar, 1989; Smith and Jackson, 1990; Linčius, 1991; Žaromskis, 1982; Frihy and Komar, 1993; Hamilton and Collins, 1998). In different coastal settings, HMCs typically reflect the dynamics of onshore and reverse flow of wave run-up and subsequent aeolian winnowing (deflation). These factors operate individually or in succession, the onshore and alongshore (foredune-parallel) aeolian transport requiring low moisture content above the level wave swash. Observed surface HMCs are often ephemeral because any substantial change in energy conditions (storm wind, wave run-up) either concentrate or erode these horizons. However, their preservation in beach and dune sediments attests to their high preservation potential given a net accretionary trend (Figs. 2D, E and 4B; Komar, 1989; Smith and Jackson, 1990; Buynevich et al., 2007a, b).

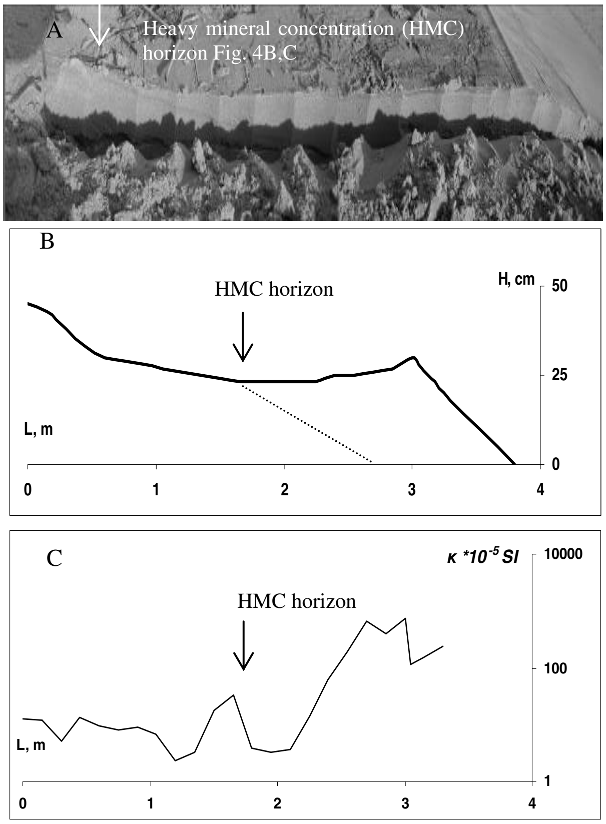

Figure 4. (A) Photograph of a trench through a narrow beach along the Curonian Lagoon shoreline, at the base of Parnidis Dune (See Figure 1 for location). (B) Cross-section of the trench highlighting a prominent dipping HMC. (C) Magnetic susceptibility values of surface sediment show an increase at the 1.65 m mark that coincides with the dipping HMC. Exposed HMCs forming on the beachface (2.7-3.0 m interval) produce even higher MS response (note the logarithmic Y-axis).

Magnetic susceptibility values, which are primarily a function of magnetite and paramagnetic mineral content, reflect both the general trends in heavy-mineral fraction and the "hotspots" related to shore-parallel or dipping HMCs (Fig. 4). Based on exposed beach profiles, there is periodic alternation of granulometric properties of surface sands and an overall difference in mean grain size between the two sites, with $\kappa$=50-270 for the coarser-grained upper berm at Būtingė and $\kappa$=20-40 at Nida. However regardless of the mean grain size, heavy minerals are typically found in the finer fraction of a particular sand horizon (Komar, 1989).

The high MS values of the fine-grained lagoon beach are likely derived from the adjacent Parnidis Dune, with hydraulic sorting by small waves within a non-tidal lagoon. Minor MS peaks coincide with the near-surface expression of a buried "paleo-HMC", whereas direct measurements of actively forming dark sand layers are higher by at least one order of magnitude (Fig. 4C). Less than 100 m from the measured magnetite-rich ("black sand") section of the beach (Fig. 4), several sections of the beachface had a distinct predominance of almandine garnet ("purple sand"), a trend that will require further investigation.

## CONCLUSIONS

The present study demonstrates that the distribution of heavy-mineral concentrations is a good indicator of increased energy conditions even during periods lacking substantial storm activity. Due to the ferri- and paramagnetic properties of many heavy minerals, in contrast to diamagnetic nature of quartz, low-field magnetic susceptibility offers a rapid and effective means of locating, mapping, and quantifying HMCs along the surface, in trenches, and in sediment cores. Future studies will focus on assessing the thickness, degree of concentration, and rhythmicity of HMC horizons to quantify the periodicity and intensity of hydrodynamic processes along sandy coasts.

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## LITERATURE CITED

Buynevich, I.V., 2011. Heavy minerals add weight to neoichnological research. *Palaios,* 26, 1-3.

Buynevich, I.V., Bitinas, A., and Pupienis, D., 2007a. Lithological anomalies in a relict coastal dune: geophysical and paleoenvironmental markers. *Geophysical Research Letters*, 34, L09707, doi:10.1029/2007GL029767.

Buynevich, I.V., FitzGerald, D.M., and Goble, R.J., 2007b. A 1,500-year record of North Atlantic storm activity based on optically dated relict beach scarps. *Geology*, 35, 543-546; doi: 10.1130/G23636A.1.

Dolotov J. S., Žaromskis R. B. and Kirlys V. I., 1982. Differentiation and Stratification of Near-shore Sediments Material**.** Science Moscow. 182.

Frihy O.E, Komar P.D., 1993. Long-term Shoreline Changes and the Concentrations of Heavy Minerals in Beach Sands of the Nile Delta, Egypt. *Int. J. Mar. Geol*, 115, 253-261

Gudelis V., 1958. Curonian Lagoon Sediments and its Lithological Characteristics (In Lithuanian). *Scient. Report. Geology and Geography*, 8, 12-20.

Gudelis V., 1998. Lithuanian Coastal Region (in Lithuania). Vilnius, Lithuanian Acad. Sci. Monogr., 442.

Hamilton, N.T.M., and Collins, L.B., 1998. Placer formation in a Holocene barrier system, southwestern Australia. *Journal of Coastal Research*, 14, p. 240-255.

Kirlys V., Stauskaitė R. 1982. Granulometric Composition and Distribution of Near-shore Sand Deposits in the NW Part of Kuršių marios Lagoon. *Geographical Yearbook*, 20, 113-122.

Komar, P. D., 1989. Physical processes of waves and currents and the formation of marine placers. *Reviews in Aquatic Sciences, 1, 393-423.*

Komar, P.D and Wang., C., 1984. Processes of selective grain transport and the formation of placers on beaches. *Journal of Geology*, 92, 637-655.

Linčius A., 1965. Heavy Mineral Grain Size and Distribution on the Beach of Curonian Lagoon (In Russian). *Proccedings of the Institute of Geology,* 3, 44-51.

Linčius A., 1966. Mineralogical composition of the beach placers in the South-east Coast of the Baltic Sea (In Russian). *Proceedings of the Science Academy of Lithuania. Series B,* 1, 33-42.

Linčius A., 1991. Beach Placers in the South-east Coast of the Baltic Sea as a Result of Long-term Natural Processes (in Lithuanian). *Geographical Yearbook*, 27, 122–127.

Nair, R.R, Buynevich, I.V., Goble, R.J., Srinivasan, P., Murthy, S.G.N., Kandpal, S.C., Vijaya Lackshmi, C.S., and Trivedi, D., 2010. Subsurface images shed light on past tsunamis in India. *Eos Transactions*, AGU, 91(50), 489-490.

Pustelnikov O., Stauskaitė R., 1979. Suspended Drifts of the Transit Section of the South-East Part of the Baltic Sea Coast (2. Granulometrical and Mineralogical Composition of the Drifts at the Calm and Stormy Sea). *Proceedings of the Science Academy of Lithuania. Series B,* 1(100), 133-152.

Rao B., 1957. Beach Erosion and Concentration of Heavy Mineral Sands. *Journal of Sedimentary Research*, 27, 143-147.

Shankar R., Thompson R., Prakash T. N., 1996. Estimation of Heavy and Opaque Mineral Contents of Beach and Offshore Placers Using Rock Magnetic Techniques. *Geo-Marine Letters*, 16, (4), 313-318.

Smith, A.W. and Jackson, L.A., 1990. Assessment of the past extent of cyclone beach erosion, *Journal of Coastal Research*, 6, 73-86.

Tsvetkova-Goleva V., and Simeonova G., 1984. Accumulation of Heavy Minerals in Landslides in the Burgas Area of the Black Sea Coast. *Marine Geology*, 54(3-4), 309-318.

Woolsey J.R., Henry V.J, and Hunt J.L., 1975. Backshore Heavy-mineral Concentration on Sapelo Island, Georgia. *Journal of Sedimentary Research*, 45(1), 280-284. DOI: 10.1306/212F6D39-2B24-11D7-8648000102C1865D

Žaromskis R., 1982. Structural features and determinants of the Baltic Sea beach deposits (in Lithuanian). *Geographical Yearbook*, 20, 82-88

Žilinskas G., 1997. The lenght of the Lithuanian Shore of the Baltic Sea (in Lithuania). *Geographical Yearbook*, 30, 63-69.

Žilinskas G., Jarmalavičius D. 2003. Trends of Lithuanian Coast Dynamics (in Lithuanian). *Geographical Yearbook*, 36(1), 80-88.

Žilinskas G., Jarmalavičius D. and Pupienis D., 2005. Assessment of the effects of hurricane 'Ervin" on the Lithuanian marine coast (in Lithuanian). *Geographical Yearbook*, 38(1), 49–65.

Žilinskas G., Jarmalavičius D. and Minkevičius V. 2001. *Eolian processes on the Shore* (in Lithuanian). Vilnius, Inst. of Geogr. 283.