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Sedimentation conditions of marine Prangli and Naissaar sand deposits, the Estonian coastal sea

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Abstract Formation and geological setting of sand deposits located to the south of Prangli and Naissaar islands are discussed. The deposits were investigated in detail in 2003. The accumulation areas of sand have formed on the account of the material eroded in the coastal area of the above islands, which has been carried to the investigation area by wave activity and currents. In Prangli sand deposit mainly very fine (fineness modulus <1) and fine sand (fineness modulus 1.5–2.0) occur. In Naissaar deposit the sand is very fine (fineness modulus 1.0–1.5), but very coarse sand (fineness modulus >3) occurs sporadically in the upper part of the deposit. On the grounds of the investigation results the Commission of Mineral Resources of Estonia registered the active proved reserves which the Port of Tallinn intended to use for building new quays and coal terminal in the Port of Muuga.

Keywords *Estonian coastal sea, Prangli Island, Naissaar Island, sand, grain-size distribution, fineness modulus.*

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INTRODUCTION

In 2003 Prangli and Naissaar sand deposits were investigated in detail to establish their geological setting and sediments composition. On the grounds of the investigation results the Commission of Mineral Resources of Estonia registered the active proved reserves which the Port of Tallinn planned to use for building new quays and coal terminal in the Port of Muuga.

Prangli sand deposit is located ca 1 km to the south of the island of the same name (Fig. 1). The investigations were carried out on an area of 301.3 hectares (Fig. 2a) where the depth of water ranges from 6 to 20 m.

Naissaar sand deposit is located in Tallinn Bay, ca 0.7 km to the south of the island of the same name (Fig. 1). The investigations were carried out on 640 hectares (Fig. 2b), depth of water is 6–30 m. Sand occurs also outside the above deposits, but only as a thin layer.

MATERIAL AND METHODS

The field work was carried out with R/V *Junikon* which has equipment for geophysical investigations and drilling. The geophysical investigations comprised continuous seismoacoustic profiling and echosounding. The upper portion of bottom deposits was investigated by the continuous seismoacoustic profiling in order to

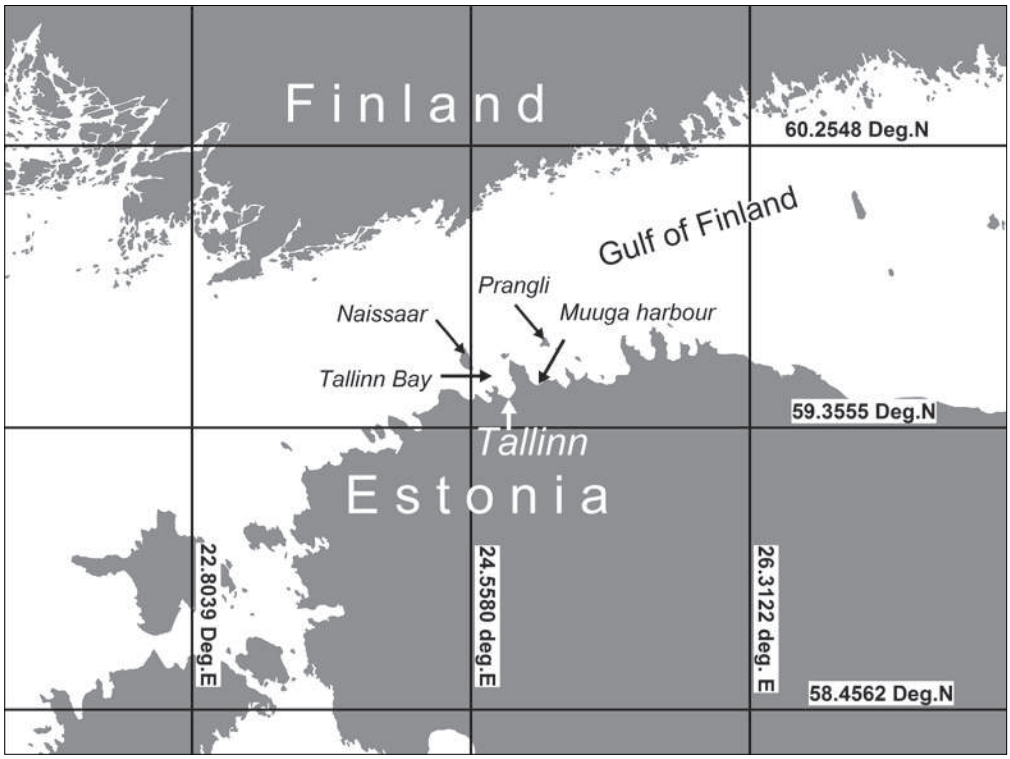

Fig. 1. Location of Prangli and Naissaar sand deposits.

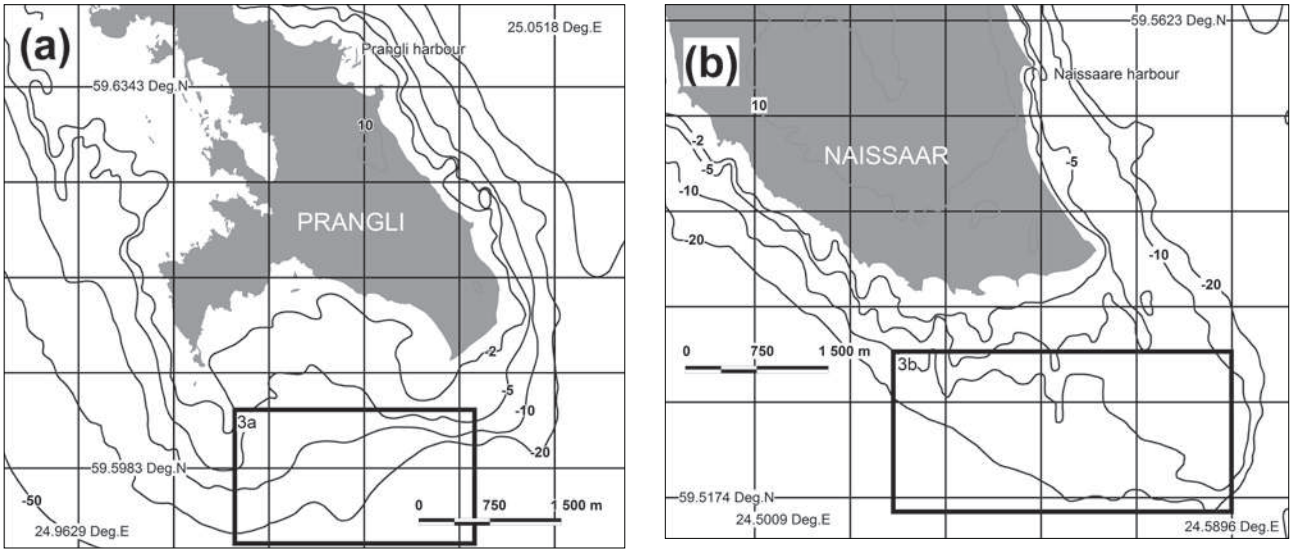

Fig. 2. Location of investigation areas: a – Prangli sand deposit; b – Naissaar sand deposit.

draw the boundaries of the beds of different density (resolution 0.3–0.5 m). The results obtained were interpreted taking into account also the drilling results, and the thickness of sand layer was determined. The continuous seismoacoustic profiling was carried out using underwater hauled device "Shelf". The seismoacoustic waves with a frequency of 5 kHz were generated every 250 milliseconds using a piesoceramic vibrator. The results were registered on electrochemical paper EHB–4 by the recording device INEI. Seismoacoustic profiling was also carried out using Sparker SAK–1. The sounding frequency was 270–1300 Hz.

Drilling was carried out by vibratory and rotary method. For vibratory drilling a 4.6 m long tube 108 mm in diameter furnished with two valves was used. The core was recovered from the tube with the help of the inside plastic membrane pipe. The vibratory drilling points (total 30 in Prangli and 46 in Naissaar sand deposit) were selected on the grounds of seismoacoustic profiling results. In case the base of sand deposit was not reached by vibratory drilling, the rotary drilling was used. The latter was performed by rotary drilling rig URB–2 through a special opening in the vessel's hull. The drill pipe was 9 m long, furnished with a ball valve. The drilling was continued down to the base of

the sand deposit. The base of the sand deposit was in Prangli area varved clay which formed kind of a "plug" to the drill pipe.

By bulk sampling method 70 samples were taken from Prangli and 64 samples from Naissaar sand deposit. The positioning was carried out by the navigation system of r/v Junikon (precision 1 m).

The grain–size distribution of the samples collected was determined by sieve analysis on the board of R/V *Junikon* and at the Laboratory of the Geological Survey of Estonia. The sieving was carried out according to the requirements of Annex 5 of the regulation of the Minister of the Environment of Estonian Republic No 29 of 22 June, 1995 "Guidelines for applying the requirements of mineral exploration for sand and gravel". The following set of sieves was used (size of sieve in mm); 10; 5; 2.5; 1.25; 0.63; 0.315; 0.16 and 0.05. The fineness modulus of sand was calculated with the equation: Fm=(A2.5+A1.25+A0.63+A0.315+A0.16)/100, where Fm is fineness modulus and A2.5 etc. is the fully retained mass of sand on the sieve.

The classification of sand applied is based on fineness modulus:

Class of sand	Fineness modulus
very coarse sand	>3.0
coarse sand	2.5–3.0
medium sand	2.0–2.5
fine sand	1.5–2.0
very fine sand	1.0–1.5
extrafine sand	<1.0

The application for extraction permit was compiled on the grounds of the investigations carried out according to the above Guidelines. The Guidelines also establish that the fineness modulus of building sand must be 1.3 or more and the share of <0.05 mm fraction must be less than 10%. If the sand does not meet the above requirements it cannot be classified as building sand.

GEOLOGICAL SETTING

In the region of **Prangli Island** the crystalline basement is covered by the sandstones of the Kotlin Stage (Vendian) (Suuroja *et al.* 2002). The Vendian sandstones form the cores of almost all islands and banks in the area. The Kroodi Formation of the Vendian is represented by weakly to medium–cemented yellowish–grey sandstone. At different levels up to 1 m thick interbeds of argillaceous siltstone (reddish–brown, with yellowish and greenish–grey blotches) are found. In places at the lower boundary of the Kroodi Formation there is a basal bed up to 2 m thick, consisting of coarse-grained sandstone, gravellite, fine conglomerate or mixtite. In the upper part of the Kroodi Formation up to 8 m thick Kannuka Member is distinguished, comprising weakly to medium–cemented coarse–grained siltstone to medium sandstone.

In the region of **Naissaar Island** the bedrock is represented by the terrigenous complex of the Vendian (Upper Proterozoic) and Cambrian. The Vendian rocks are mainly sandstones and aleurolite with argillaceous interbeds, while the Cambrian rocks are represented by the clay of the Lontova Stage.

The formation and distribution of sand deposits are related to the Quaternary deposits covering the seafloor in the surroundings of Prangli and Naissaar (Suuroja *et al.* 2002). The oldest Quaternary deposits (greyish–brown till with crystalline pebbles) are spread in small areas only. They are found also in the depressions eroded into bedrock. On Naissaar and Prangli the till is covered with glaciofluvial deposits. The oldest tills are overlain by the till of the Järva Formation, thickness of which is variable. The tills in the region under discussion are basin tills characterised by big share of pelite fraction, small share of coarse–grained fraction (the latter is well–rounded) and equal percentage of sand and silt. The Järval Formation is divided into two parts by the glaciofluvial (Naissaar) or glaciolacustrine (Prangli) deposits.

The till of the last glaciation (Järva Formation) and fluvioglacial deposits are covered with late-glacial varved clays and post-glacial clays, which contain hydrotroilite. The topmost layer of seafloor deposits is represented by deep-water pelite and silt formed during the Litorina and Limnea Sea stages.

In the area of Prangli and Naissaar sand deposits the seafloor is covered with sand of various grain sizes, under which lie varved clay and till.

Bedding conditions of the sand deposits

In **Prangli sand deposit** a narrow stripe of very coarse to fine sand spreads around the outcrop area of till (drill holes 6–1, P–6, P–20, 7–1, P–5 and 4–1; Fig. 3a). In drillhole 7–1 there is a layer of coarse sand (0.5 m) and in drill holes P–5 and P–6 of very coarse sand (0.3 m and 0.2 m respectively), which overlie extrafine sand. The thickness of sand deposit increases towards Prangli Island (Fig. 4a, cross-section A–B). Along the cross-section glaciolacustrine varved clay forms the base of sand. In the part of the cross-section closer to Prangli Island a lens of sand with a fineness modulus of >1.3 occurs, its thickness increasing towards the island. In the seaward part of the cross-section (beginning from drillhole P–19), on the surface of varved clay there is a lens of sand with a fineness modulus <1.3, which wedges out. The thickness of sand deposit is the biggest in the northernmost drillhole P–5, where the thickness of extrafine sand is 7.8 m.

The base of **Naissaar sand deposit** (Fig. 4b, cross-section C–D) is till or glaciolacustrine varved clay, irregular alternating within the investigation area. Till or varved clay are overlain mainly with sand with a fineness modulus <1.3. The thickness of the latter varies greatly, reaching 9.7 m (the biggest in the investiga-

tion area) in drillhole No. 39 (Fig. 3b). The sand with a fineness modulus <1.3 is spread sporadically (as lenses, not forming a continuous layer), in drill holes Nos. 29 and 47 it is missing. Within Naissaar deposit the sand with fineness modulus <1.3 is covered with the sand with fineness modulus >1.3, the biggest thickness of the latter is 8.8 m (drillhole 58). The biggest total thickness of sand complex is 11.2 m (drillhole 58).

Grain-size distribution of the sediments forming the sand deposits

Sand's main quality indicators are fineness modulus and the content of fraction with a diameter <0.05 mm (silt and pelite).

In **Prangli sand deposit** (Figs 5, 6) extrafine (fineness modulus <1) and fine sand (fineness modulus 1.5–2.0) dominate. Medium and very coarse sand form 6.2% (3.1% each) of the samples collected and the share of coarse sand is 1.5%.

In **Naissaar deposit** (Figs 5, 6) the sand is very fine (fineness modulus 1.0–1.5), but very coarse sand (fineness modulus >3) occurs sporadically in the upper part of the deposit.

The sand's fineness modulus is the biggest (4.23) in drillhole No. 21 (north-western part of the investigation area), where very coarse sand lies on till. The smallest fineness modulus of sand of the whole investigation area (0.22) is recorded in drillhole No. 41. Coarse and

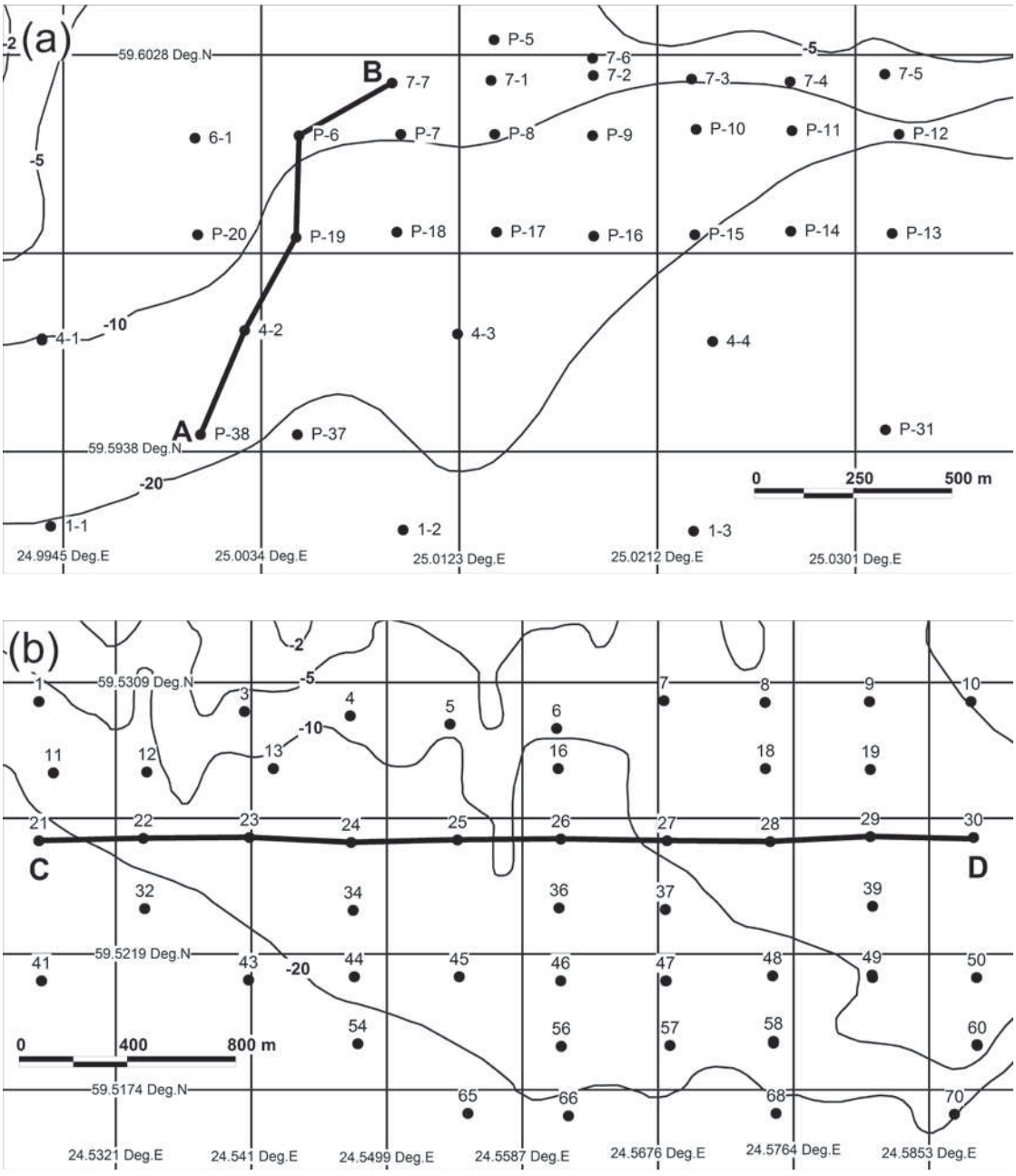

Fig. 3. Location of drill-holes and cross-sections: a – Prangli sand deposit; b – Naissaar sand deposit.

very coarse sand are distributed in the central part of the investigation area, fine to extrafine sand dominate in its south-western part.

FORMATION OF SAND DEPOSITS

The above-described sand deposits have formed as a result of the wave erosion in the coastal zone of Prangli and Naissaar islands. During this process the coarse-grained material of till (pebbles, cobbles and boulders) remained in the coastal zone, while waves and currents carried finer particles (gravel, sand and silt) to the south.

On **Prangli Island** in the west and north the coastal zone is mainly covered with pebble and cobble pavement. In these areas the influence of wave erosion is insignificant, the sea floor is only weakly eroded and sediment transport is small. On the eastern coast of Prangli there are several sandy beach sections, but at the same time in the deeper underwater part of these sections pebbles and cobbles are found as well. The capes formed on the south-eastern and south-western coast of Prangli Island prove that sediment flow occurs from the north to the south.

Sediment pattern in the coastal zone of Naissaar Island is similar. Near the western coast the deeper underwater part of the coastal zone is covered with pebble and cobble pavement, but the backshore is covered with sand, which is carried to the sea during high water stand and intense wave activity. On the northern and southern coast of the island sodden till shores occur, which are eroded less by waves. On the eastern coast of Naissaar in the coastal zone the material is of variable grain size – from sand to boulders. In two places abrasion scarps in till and ancient dunes are found. To the east of Naissaar large areas on the seafloor are

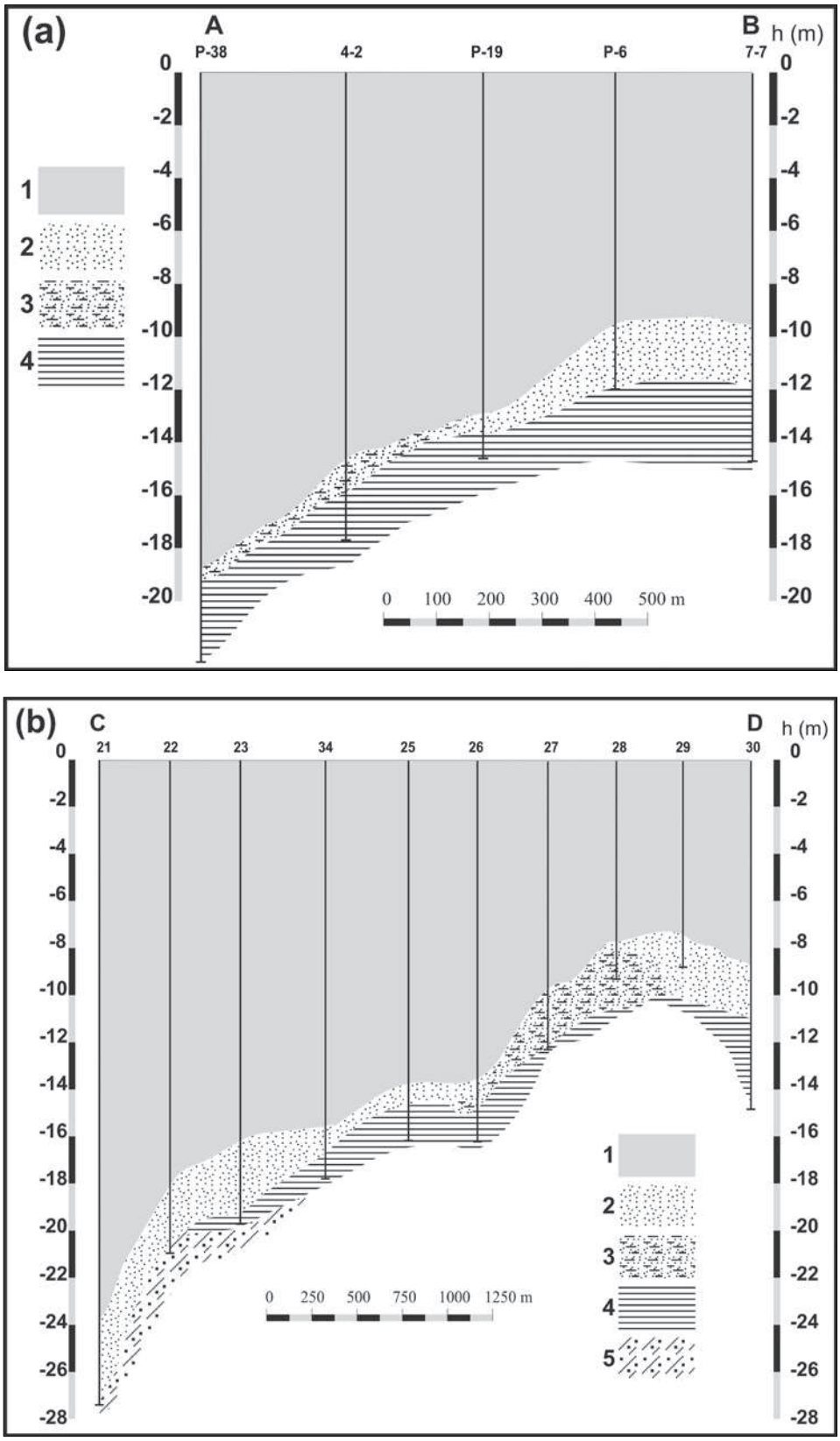

Fig. 4. Geological cross-section of Prangli (A–B) and Naissaar (C–D) sand deposits (for location see Figure 3). Legend: 1 – water; 2 – sand, fineness modulus >1.3; 3 – sand, fineness modulus <1.3; 4 – glaciolacustrine varved clay; 5 – sandy loam till.

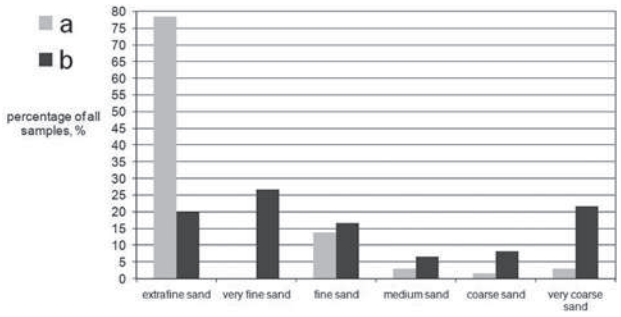

Fig. 5. Distribution of sand fractions in the samples: a – Prangli sand deposit; b – Naissaar sand deposit.

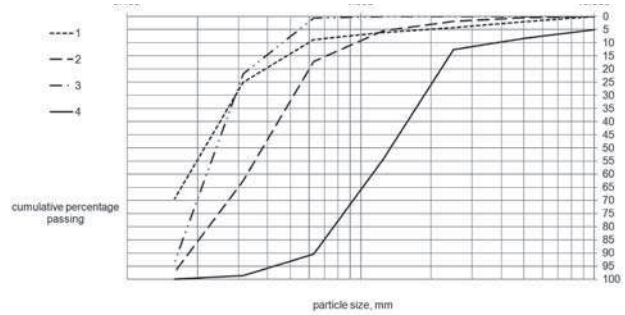

Fig. 6. Characteristic grain-size distribution curves of the sand of Prangli and Naissaar sand deposits. Legend: 1 – extremely fine sand of Prangli sand deposit; 2 – fine sand of Prangli sand deposit; 3 – very fine sand of Naissaar sand deposit; 4 – extremely coarse sand of Naissaar sand deposit.

covered with sands of various grain sizes. In the southeastern part of Naissaar there is a prominent accumulation area of sand – Hülkari cape. Very likely its core is a till ridge, running towards the southeast. Waves and currents have carried the sand fraction of eroded material to this area. Due to active hydrodynamic processes large amount of the material eroded in the coastal zone has deposited on the seafloor to the southeast and south of Naissaar. The WWII shell cases buried at a depth of several metres in sand evidence this.

CONCLUSIONS

Sand deposits located to the south of Prangli and Naissaar islands in the coastal sea of the Estonian Republic were investigated in detail in 2003. In the areas under discussion the bedrocks are represented by the Vendian and Cambrian terrigenous deposits – sandstone with inderbeds of clay, and "blue clay". The Quaternary deposits are represented by tills of different glaciations, glaciolacustrine varved clay and marine sand.

In Prangli sand deposit the sand is mainly extrafine (fineness modulus <1) and fine (fineness modulus 1.5–2.0). In Naissaar deposit the sand is very fine (fineness modulus 1.0–1.5), but very coarse sand (fineness modulus >3) occurs sporadically in the upper part of the deposit.

The Prangli and Naissaar sand deposits have formed on the account of material eroded in the coastal zone of Prangli and Naissaar islands and carried to its present location by waves and currents. Near the western and northern coast of both islands the seafloor is covered with pebble-cobble pavement, which considerably reduces further erosion of seafloor.

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