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The Provenance of Beaches on the Estonian Islands of Hiiumaa, Saaremaa and Muhu

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ABSTRACT

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Sand and gravel beaches on the emerging Estonian islands occur at and down-drift of sectors where glacial and glacifluvial drift deposits intersect the coastline and extend out across the sea floor. Similar relationships existed along the coastlines of the early Holocene Ancylus Lake and the Litorina and Limnea Sea stages, which now stand at various higher levels around the tilting islands.

ADDITIONAL INDEX WORDS: *Baltic Sea, emerging coasts, glacial and glacifluvial drift, erosion, progradation.*

INTRODUCTION

During the past fifty years, under the Soviet regime, the coasts of the eastern Baltic republics were closed to foreign research workers, but recent political changes have made it possible for western scientists to study the coasts of such countries as Estonia, which is once again independent (Figure 1). The present paper is the outcome of field studies on the Estonian Baltic islands, in association with members of the Estonian Academy of Science in a joint effort to bring current knowledge of the region into the English literature.

BALTIC BEACH SEDIMENTS

Beach sediments on the coasts of the Baltic Sea generally consist of sand or gravel (shingle) or mixtures of the two. Their petrographic and granulometric characteristics are related to the nature of the geological material from which they were derived, and also to the environments of transportation to, and deposition on, the beach (MARKOV, 1955; RAUKAS and HYVÄRINEN, 1992). Some beach materials have been supplied from erosion of coastal cliffs and foreshore rock outcrops; others have been carried to the coast by rivers; and others have been washed in from the sea floor by waves and currents. Some sandy beaches have been fed from dunes blowing from the land, and in recent decades a few beaches have been nourished artificially with sand brought from inland, alongshore or the sea floor and dumped on the shore (Figure 2). Many beaches contain sediment supplied from more than one source. Some beaches are still receiving sediment, and if the gains exceed the losses they are prograding; others are relict, the sediment source being no longer available, or the processes of delivery no longer active.

The question of where beach material has come from, and whether it is still being delivered, has been examined on various parts of the world's coastline, for example in Australia (BIRD, 1988), North America (SCHWARTZ and ANDERSON, 1986), Europe (DOLOTOV, 1989; ZUNICA, 1987), and elsewhere. This question is now examined with reference to the Estonian islands of Hiiumaa, Saaremaa and Muhu (Figure 3).

Hiiumaa, Saaremaa and Muhu

These Baltic islands, lying west of mainland Estonia, consist of a limestone basement with a southward dip, so that Ordovician rocks crop out in northern Hiiumaa, passing beneath Silurian rocks which dominate Saaremaa (ORVIKU, 1974). The limestones crop out locally in cliffs on the island coastlines, but are extensively overlain by Pleistocene glacial drift deposits, including moraines, eskers and outwash plains left during the final retreat of the ice from the east Baltic region.

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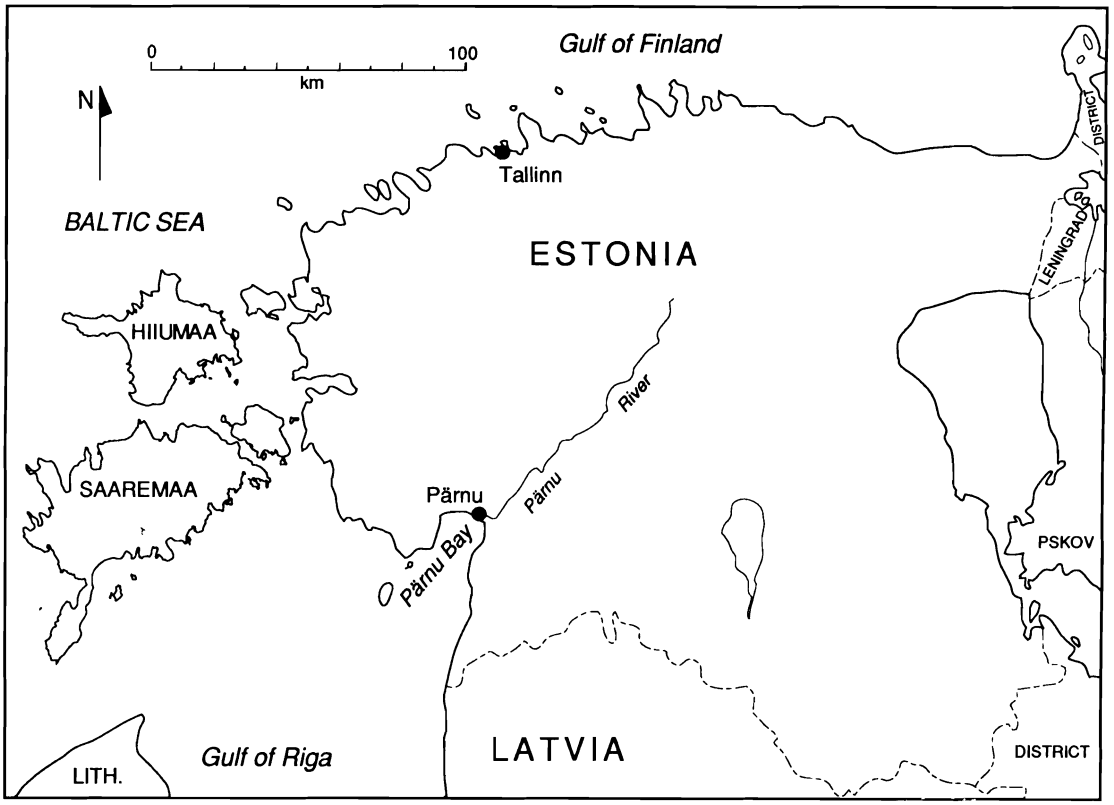

Figure 1. Geographic map of Estonia.

These islands have been emerging as the result of glacio-isostatic uplift during the Holocene, so that there are multiple shoreline features, the highest related to the Ancylus Lake, 9000 yr BP, then those produced during the Litorina marine transgression about 7000 yr BP, then those bordering the shores of the Limnea Sea about 4000 yr BP. The islands thus expanded as the Gulf of Finland shrank (Figures 4 and 5). Beaches associated with the shorelines of the Ancylus Lake, the Litorina Sea, and the Limnea Sea stand at various levels because Holocene uplift (Figure 6) has been greater in northwestern Hiiumaa than in southeastern Saaremaa (ORVIKU, 1974; VALLNER *et al.*, 1988).

Beaches of sand, gravel, or both occur on several sectors of the two islands (Figure 7). They are interspersed with indented marshy and bouldery morainic coasts, and stretches of cliff and rocky shore. In some places the beach forms a narrow fringe to the coast, but several sectors show beaches backed by beach ridges which have formed as the result of intermittent progradation, or by dunes of sand blown from the shore. The rivers are clear-flowing runoff from an emerging land, and have delivered very little sand or gravel to the coast. Beach sediments have been derived either from erosion of cliffed and rocky shores, or by inwashing from the sea floor. They have been distributed along the coast by longshore drifting due mainly to the action of waves approaching the shore obliquely, and associated current action (Figure 7). Tides are negligible, and current action is due primarily to wind stress over nearshore waters. There are, however, seasonal variations in level in the eastern Baltic Sea, which is high in August and December, and low in April and October, and the beaches appear slightly emerged when the Baltic is low. The average range is 2 meters.

The major types of beach material on the present coastline, as well as on earlier and higher coastlines, are limestone gravels, produced from

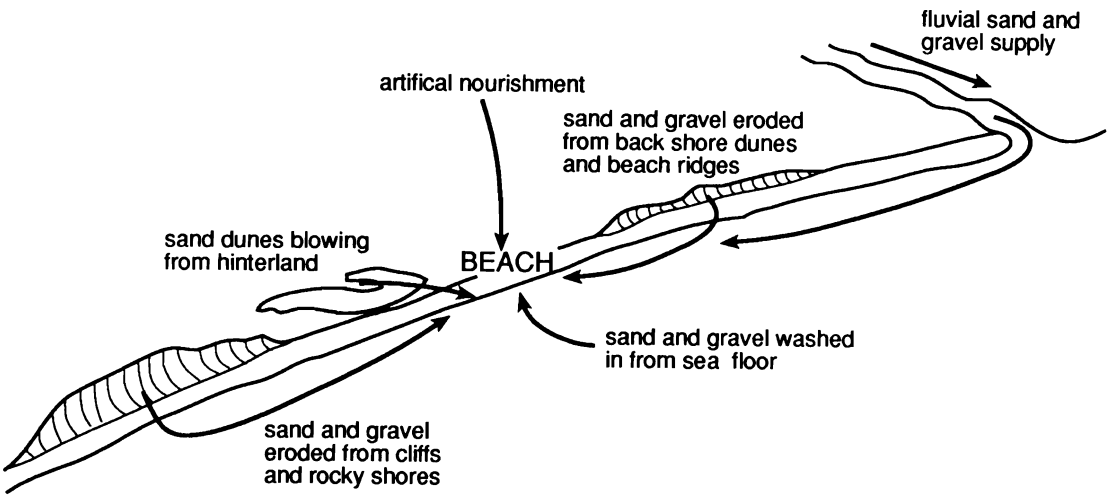

Figure 2. Sources of beach sediment (after BIRD, 1985).

weathered and eroding limestone outcrops, and the sands and gravels derived from glacial drift, especially the glacifluvial deposits which form eskers, segments of which traverse these islands, and outwash plains. These are part of the glacifluvial material, sandy with occasional pebble lenses, associated with the Palivere moraine, which was deposited from the ice front about 11,200 yr BP, and runs south of Tallinn and westward through Hiiumaa and Saaremaa.

LIMESTONE GRAVEL BEACHES

On the southeastern shore of Hiiumaa there is a limestone gravel beach, backed by parallel beach ridges of this material. The older gravels are dark in color as the result of weathering and algal colonialisation, whereas the present beach is dominated by recently deposited pale creamy limestone fragments. Such beaches occur at various levels on Saaremaa and Hiiumaa, reworked by wave action from weathered limestones on the shore and nearshore as the islands emerged from the sea.

At Uügu Pank on Muhu Island, off the northeast coast, there are uplifted beach ridges of subangular limestone gravel with an amplitude of 1.5 meters on an emerged plateau behind a limestone cliff 3 to 4 meters above sea level (Figure 8). The beach ridges formed during a phase of gradual emergence, when gravel was washed up from the upper weathered layers of the Silurian strata. They are no longer forming, for the present shore in front of the limestone cliffs is marshy, and there are varved clays out on the sea floor. There is no longer a source of supply of gravel for beach building.

The southern peninsula of Hiiumaa consists of an esker ridge which ends in a gravel spit, and is bordered by descending beach ridges of limestone gravel. The esker was overwashed by the Litorina Sea, and the beach ridges formed during the ensuing regression as waves reworked the gravelly esker deposits.

Sectors of gravelly beach occur wherever there is a nearby source of weathered limestone. On the west coast of Hiiumaa the Kopu Peninsula is bordered by sandy beaches, but on the south coast of this peninsula at Kalana, coastal and nearshore outcrops of limestone have provided material for the construction of beach ridges of limestone gravel, which extend eastwards as a longshore spit.

On the north coast of Saaremaa the bold limestone cliff at Panga Pank is a prominent feature, standing behind a wide shallow platform cut in limestone, and strewn with glacial erratic boulders, mainly of crystalline rocks from Finland (Figure 9). Waves break at the outer edge of this platform. To the west the cliff gives way to a beach of angular to subangular limestone gravel derived from weathering and erosion of the cliff and platform outcrops. The beach continues southwards until it becomes a recurved spit, which has grown in front of, and partly overrunning, earlier lunate gravel barrier islands. The spit has lengthened as

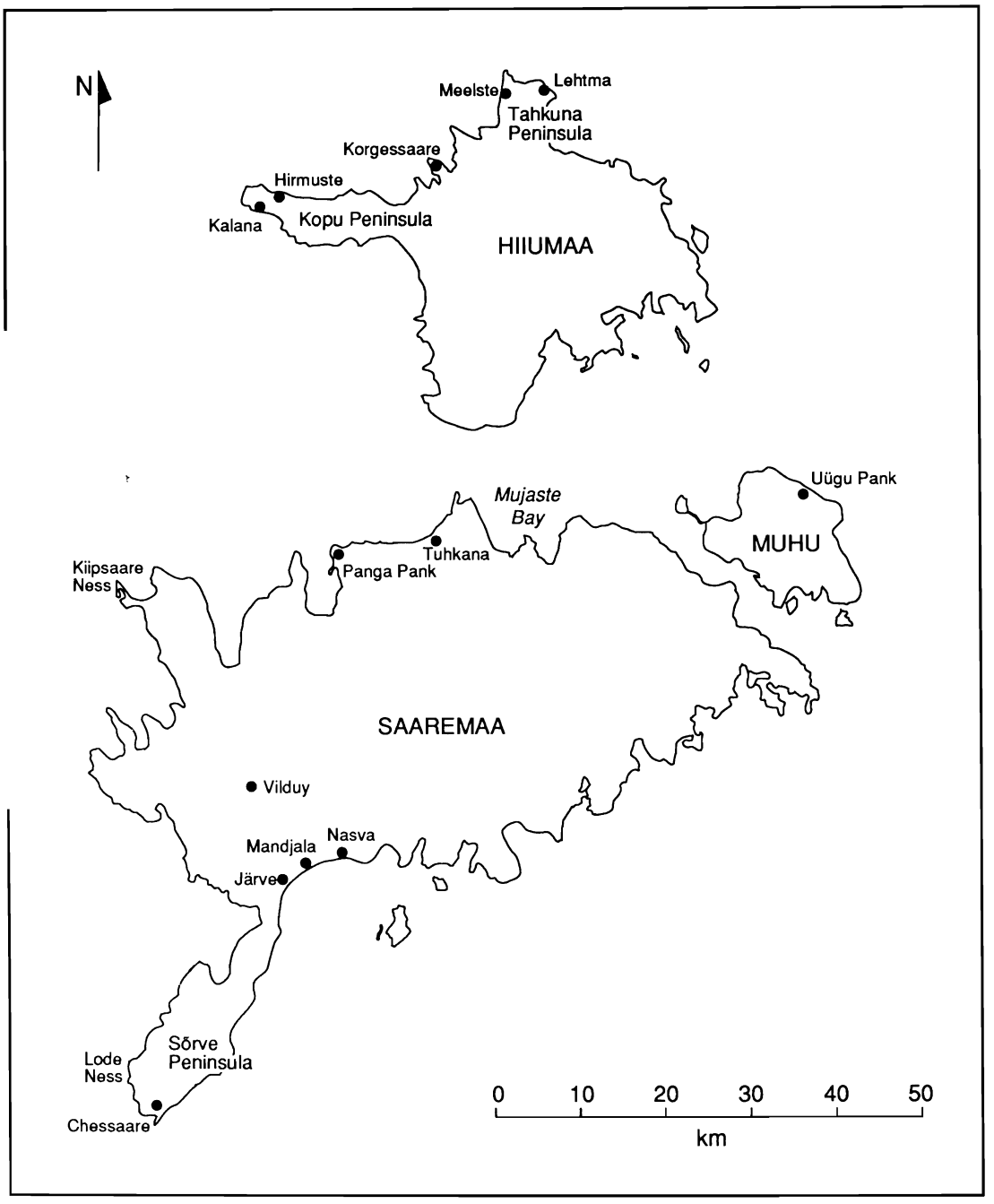

Figure 3. Site locations on Hiiumaa, Saaremaa and Muhu.

the result of the successive storm surges, and is now growing back over grassy marshland.

On the west coast of the Sorve peninsula there are low cliffed headlands in bedded limestone, separated by bays and occasional cuspate promontories (such as Lode Ness). There are beaches and beach ridges of locally-derived limestone gravel. At Chessaare the 4 meter bluffs of fossil-

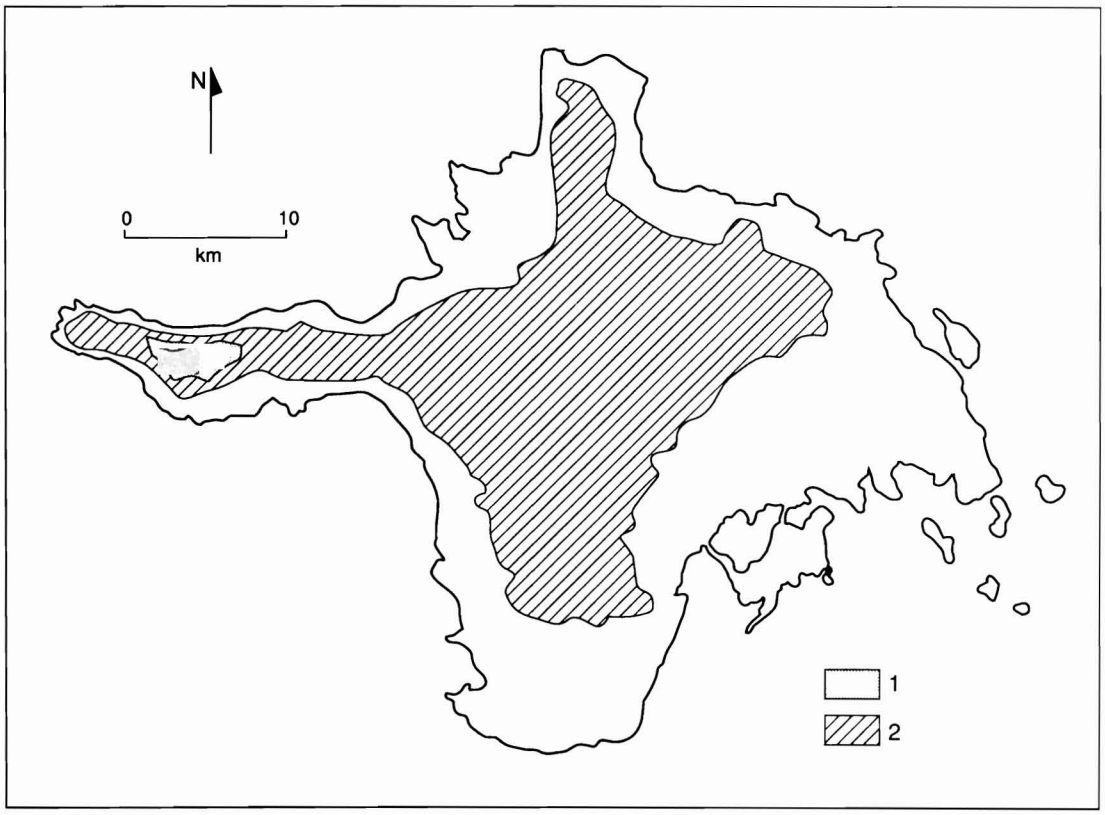

Figure 4. Evolution of Hiiumaa Island in post-glacial time (after KESSEL and RAUKAS, 1967). (1) small island during Ancylus transgression; (2) Hiiumaa at end of Litorina Sea phase.

iferous Silurian limestone are fronted by a shallow sea with large ice-rafted erratic boulders of pink granite, and capped by festoons of beach ridges of limestone gravel, derived from the upper frost-shattered horizons of the limestones.

BEACHES DERIVED FROM GLACIAL DRIFT DEPOSITS

The kinds of sediment available from glacial drift deposits are exposed in a number of quarries on Saaremaa and Hiiumaa. Southeast of Korgessaare on Hiiumaa the quarry at Partsi exposes a long section of inclined bedded sandy gravels, well rounded but poorly sorted, containing marine mollusks, and formed as a spit in the lee of an esker island by the waves of the Litorina Sea.

A high sandy and gravelly esker runs southward across the western part of Saaremaa. It has been truncated in places by wave action when sea level was higher, producing beaches and dunes of Litorina age now stranded some way inland. At Vilduy it forms a steep-sided ridge which was trimmed by the sea in the Litorina stage, when it stood 20 meters above present sea level. Farther south, at Viieristi on the Sorve peninsula, a quarry in this esker (Figure 10) shows inclined layers of poorly sorted, well rounded, sand and gravel, containing freshwater mollusks, and formed as a beach of reworked sand and gravel by the waves of the Ancylus Lake, some 8200 to 8600 yr BP. The northern part of the Viieristi quarry is sandy, cut into dunes that formed on the shore of the Ancylus Lake, and to the east of the quarry is a steep bluff, cliffed by the Litorina Sea, which deposited a series of descending beach ridges on the coastal plain during the ensuing emergence. As this emergence proceeded, sand derived from the Sorve esker was removed to lower levels to form the Limnea marine deposits at Järve. Sandy beaches, derived from these reworked esker deposits, are

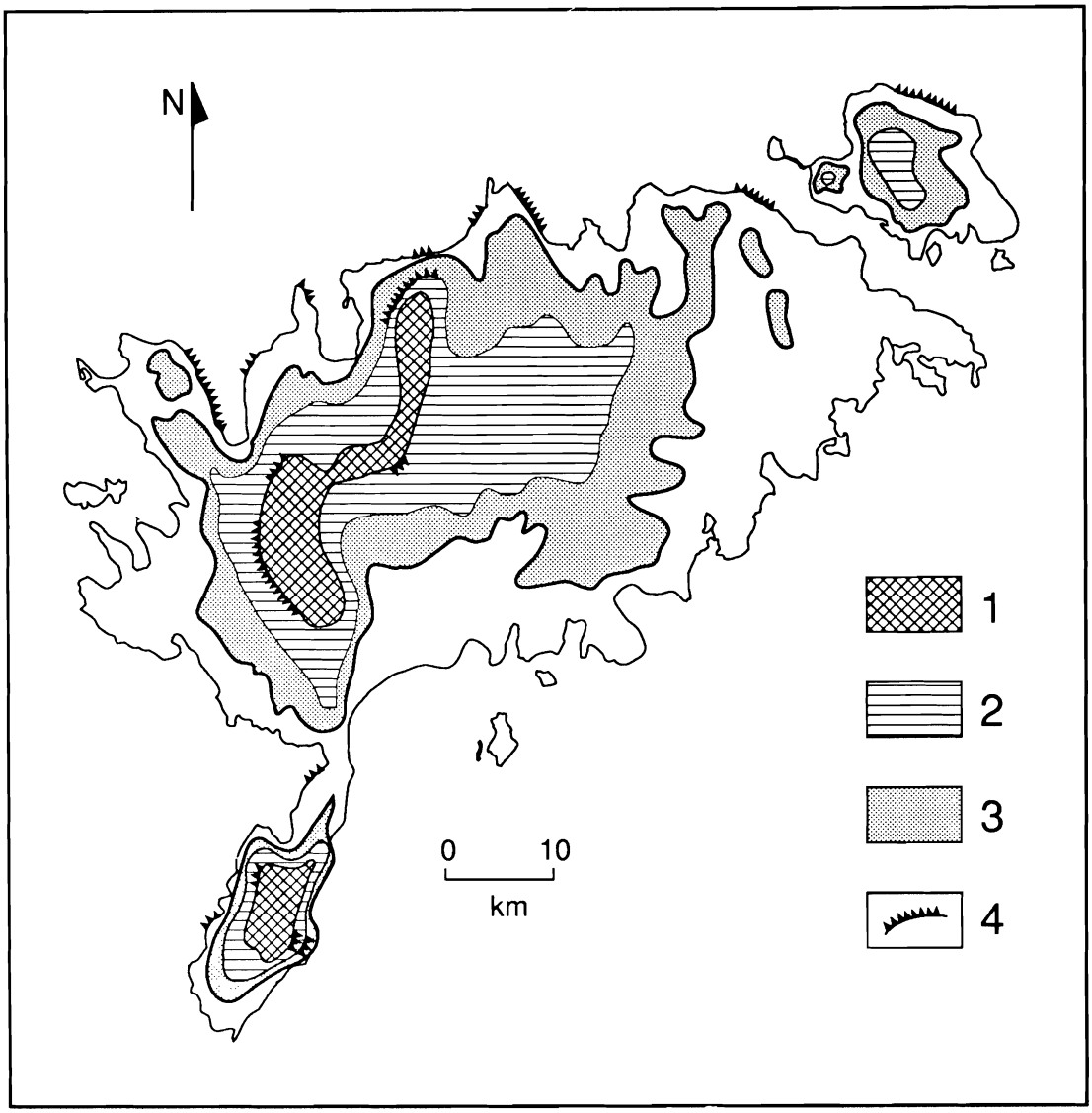

Figure 5. Evolution of Saaremaa and Muhu islands in postglacial time (after KESSEL and RAUKAS, 1967). (1) area above the Ancylus transgression; (2) area above the Litorina transgression; (3) area above sea level at the beginning of the Limnea Sea phase; (4) cliffs and scarps.

on the east coast rather than the west coast of the peninsula, and it is possible that westerly winds helped distribute the sand to the lee shore.

At Järve the sandy beach is being fed by material eroded from a cliff cut into bedded Limnea sand, shells and gravel, which here stand up to 3 meters above sea level (Figure 11). Sandy material has drifted northward from here to form a beach extending past Mandjala, where it is backed by beach ridges indicating progradation. Beyond Mandjala the shore becomes reedy, perhaps because the low sandy beach has been invaded by reed vegetation (BIRD *et al.*, 1990). However, sand is drifting on along nearshore bars which have built up alongside the Nasva harbor jetties, completed in 1965. This accumulation of nearshore

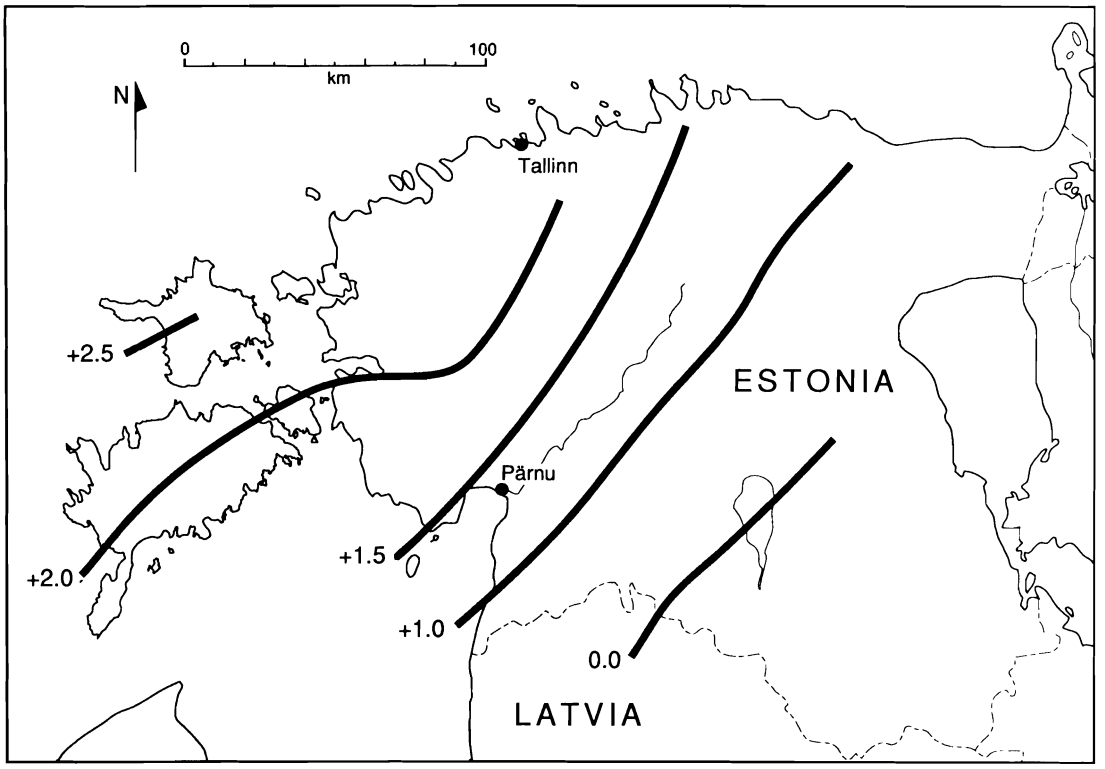

Figure 6. Average annual velocities (in mm) of displacement over a levelling network in Estonia during the last 50 years (after VALLNER *et al.*, 1988). In contrast to this, RAUKAS and GAIGALAS (1993) have calculated that the average annual rate of uplift in the region around 10,000 yr BP was 26 mm.

sand has required dredging to maintain navigability into the harbor, and the dredged sand is pumped over on to the lee side.

The north coast of Saaremaa has reedy and bouldery morainic shores west to Mujaste Bay, where an irregular beach of sand and gravel is fronted by a shallow sea with scattered boulders, emplaced by winter ice. In September, when the eastern Baltic is low, part of this foreshore is exposed, and it is clear that little sand is now coming in from the sea floor. This seems to be an example of a beach system that was nourished by shoreward drifting of material derived from submerged glacifluvial deposits on the sea floor, but land uplift has cut off this supply and the existing beach is a relict landform. Farther west, at Tuhkana, there is a sandy beach backed by hummocky dunes under forest. The sandy shore has prograded, with development of several beach ridges capped by dunes. Again the foreshore is boulder-strewn, the boulders being embedded in glacial clay, exposed in a boat channel excavation. The beach sand could not have come from the boulder clay, which must previously have been capped by sandy deposits. As in Mujaste Bay, land emergence has raised this beach and the derived dunes above the level at which shoreward sand drifting occurred.

On the western tip of Saaremaa at Kiipsaare Ness glacial drift deposits, sand and gravel, have been reworked by wave action and built into a complex foreland, with extensive beach ridges, the pattern of which shows stages in its evolution. The lighthouse stands on a cuspate spit which has migrated northwards, so that beach ridges, capped by foredunes, have been truncated on the southern shore where, east of the lighthouse, a lobate foreland curves out behind a line of morainic boulders, mainly erratic crystalline rocks from Finland, in a shallow nearshore sea.

The north coast of Hiiumaa, east and west of Korgessaare, is an indented coast of Silurian limestone, overlain by the sandy deposits of a large

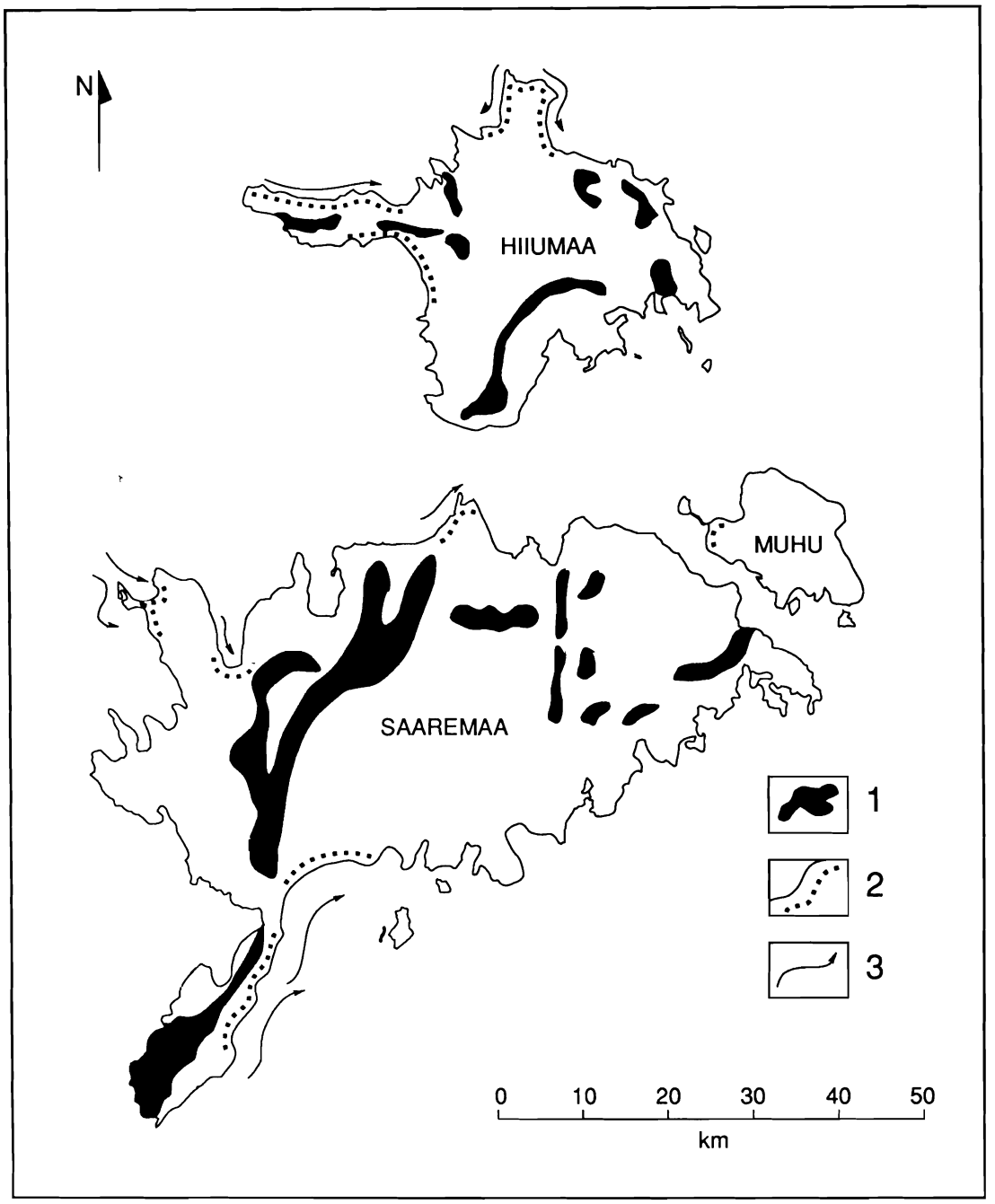

Figure 7. Schematic drawing showing glacial deposits and shore features on Hiiumaa, Saaremaa and Muhu (compiled by Eric Bird). (1) end moraines and radial eskers; (2) sandy beaches; (3) major direction of sand drift.

Figure 8. Limestone cliff behind marshy shore at Uüga Pank on Muhu (photo: M. Schwartz).

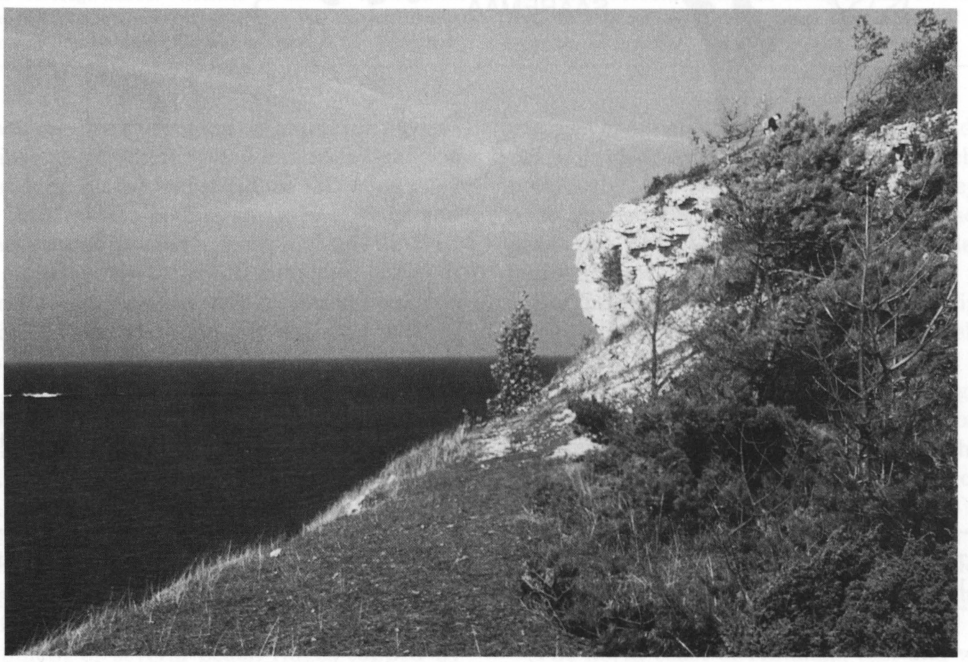

Figure 9. Limestone cliff at Panga Pank on Saaremaa (photo: M. Schwartz).

Figure 10. View of esker looking across quarry at Viieristi (photo: M. Schwartz).

Figure 11. Sandy beach at Järve, sediment being eroded from 3-m-high cliff in background (photo: M. Schwartz).

glacifluvial delta. The sandy beach at Luidja, to the west, has broad emergent bars in front of a grassy backshore sand terrace, and sandy beach ridges covered by alder woodland. Sand is still being delivered to this shore, washed in from sandy glacifluvial delta deposits on the adjacent sea floor. To the east at Meelste, a fine sandy beach is backed by beach ridges under forest, but fronted by scattered boulders. Sand is no longer being washed in to this sector, but the beach deposits have drifted about a kilometer south, where the marshy morainic coast of Korgessaare begins.

The western peninsula of Hiiumaa has a central ridge of high dunes, rising to 63 meters above present sea level. A sandy esker emerged from the Ancylus Lake, and was cliffed by the Litorina Sea. It is now bordered by sandy beach ridges to the north, formed during the subsequent regression. These continue westward to the far point at Hirmuste, a cuspate spit of sand and gravel, with a tombolo linking an outlying rocky gravelly island.

On the northeast coast of Hiiumaa the harbor of Lehtma was developed by the building of a breakwater on a sandy shore. Longshore drifting of sand derived from the glacifluvial delta deposits of the Tahkuna Peninsula has supplied sand to the beaches. It has accumulated to form a prograded foreland, with low dunes, on the western side of this breakwater, where about 10,000 cubic meters of sand has been trapped. The harbor entrance has to be dredged annually. To the east the sandy shore is backed by parallel beach ridges formed during earlier progradation, but the coast is now eroding because the sand supply has been cut off by the Lehtma breakwater. The sandy shore is cliffed, and there are undercut and fallen alder trees; beach erosion was severe during the February 1990 storm surge, which formed sandy washovers into the backing beach ridges. Farther east, the eroded sector gives place to a prograded area, where longshore sand drifting has built a complex recurved longshore spit.

CONCLUSIONS

The nature and distribution of beaches on these emerging islands in the eastern Baltic can be explained in terms of the pattern of source materials, with sand and gravel beaches occurring at and down-drift of sectors where glacial and glacifluvial drift deposits intersect the coastline or were formerly present offshore, and some limestone gravels coming from weathered outcrops of the Ordovician and Silurian rocks exposed in cliffs or reworked from nearshore deposits. Intervening sectors, where these materials have not been available, are either rocky or marshy. Similar relationships can be traced along the emerged coastlines of the early Holocene Ancylus Lake and the Litorina and Limnea Sea stages, which now stand at various higher levels around the tilting islands. As continuing emergence encounters new sea floor sources of sand and gravel, these in turn will be reworked and shaped into beach deposits. On the other hand, a rising sea level will in due course revive the early Holocene beaches that now stand at higher levels.

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