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SEDIMENTATION OF THE JOTNIAN SATAKUNTA SANDSTONE, WESTERN FINLAND

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with 20 figures, 2 tables and 1 appendix

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Sedimentology of the Mesoproterozoic ('Jotnian') Satakunta sandstone has been examined by methods of facies and grain size distribution analysis. The unmetamorphosed sandstone covers an NW-SE trending area about 15 × 100 km² in size, as an extension of a wide submarine sandstone area. The thickness of the arkosic sandstone formation is more than 600 meters and has been estimated to reach 1800 m.

Cross-bedding structures indicate NW directed transport of detritus. According both the paleocurrents and the grain size distribution, the proximal part of basin was situated in the SE. At the southwestern contact, supply tranverse to the basin axis is evident, but the northeastern, steep border of the sandstone seems to be controlled by younger faults, not by the primary basin edge.

All primary features observed are typical of fluvial sediments. The only indication of marine contribution is the presence of glauconite in the distal part of the basin. The infilling of the depository was the result of an alluvial plain and, possibly, sandy fan delta. The sedimentation was dominated by poorly cyclic, low sinuosity streams and, in proximal areas, by debris floods. Observations from a drill core (591 m long) indicate that major part of the Satakunta sandstone consists of medium grained arkoses and subarkoses dissimilar to the coarse, pebbly sandstones typical of the present level of erosion. It seems that the alluvial type sediments offlapped more fine grained sandstones as the system prograded towards NW.

The precise age and original extent of the basin are not possible to evaluate, but the development may have begun during the emplacement of rapakivi granites and associated mafic dykes. The final preservation seems to be controlled by the subsidence related to the eruption of 'Postjotnian' dykes and sills, which show a clear spatial connection with the sandstone.

Key words (GeoRef Thesaurus, AGI): paleosedimentology, sandstone, lithofacies, grain size, paleocurrents, deposition, grabens, Proterozoic, Mesoproterozoic, Jotnian, Satakunta, Finland

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INTRODUCTION

The Jotnian Satakunta sandstone, Mesoproterozoic (Riphean) in age, is located in western Finland south of town Pori. The unmetamorphosed, poorly exposed sandstone covers a NW-SE trending, fault-bounded area about 15 × 100 km^2 in size. According to Winterhalter et al. (1981) and L. Bergman (1982) the sandstone extends under the Gulf of Bothnia and links together the red beds of Satakunta graben, Gävle valley and Nordingrå area.

The term 'Jotnian' was introduced by J.J. Sederholm (1897) for unmetamorphic sandstones and associated igneous rocks in the Precambrian of Fennoscandia. The Jotnian-type sediments, arkoses, siltstones, shales and conglomerates, are known to occur in some ten localities (Fig. 1). All these occupy shallow basins, tectonic depressions or grabens bordered by fractures or fault zones most of which are NW-SE oriented.

The Mesoproterozoic is in Satakunta represented by rapakivi granite, sandstone and olivine diabase. The Laitila rapakivi batholith (1570 Ma; Vaasjoki, 1977) is situated immediately to the south of the sandstone and two coeval rapakivi stocks are present close to the northeastern flank of the graben (Vaasjoki et al., 1988). The 'Subjotnian' diabase dykes are held to be slightly older (c. 1650 Ma; Pihlaja, 1987) than the rapakivis. Both the rapakivi and the sediments are cut by the 'Post-Jotnian' diabases (1260 ± 10 Ma; Suominen, 1991), and the sandstone has been estimated 1300—1400 Ma old (Simonen, 1980).

Although detailed works concerning petrology, mineralogy and provenance of the Satakunta sandstone (e.g. Simonen and Kouvo, 1955; Marttila, 1969) are present, the depositional features have not been investigated systematically. The aim of this paper is to study the palaeosedimentology of the Satakunta sandstone by methods of facies analysis. Also palaeocurrent data from 14 localities is presented. The grainsize variation within the sandstone was observed, not only from the outcrops but also from 22 drill cores.

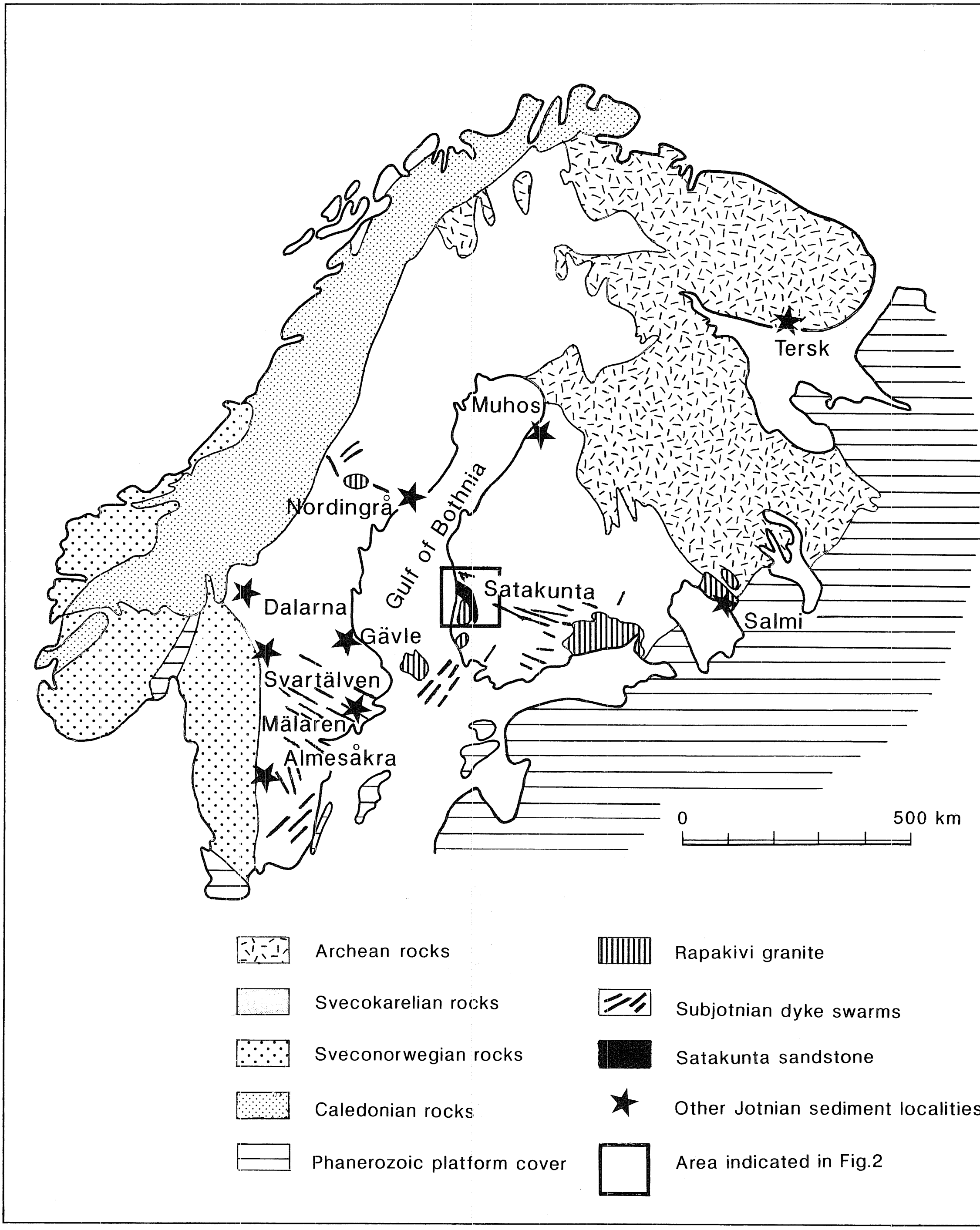

Fig. 1. Location of the Satakunta sandstone and other Jotnian occurences of the Fennoscandian Shield.

GEOLOGICAL SETTING

The bedrock of southwestern Finland is composed mainly of Paleoproterozoic (Svecofennian, 1900—1800 Ma) felsic plutonic and supracrustal rocks; the anorogenic Mesoproterozoic rapakivi granites and diabases are the additional constituents (Fig. 2).

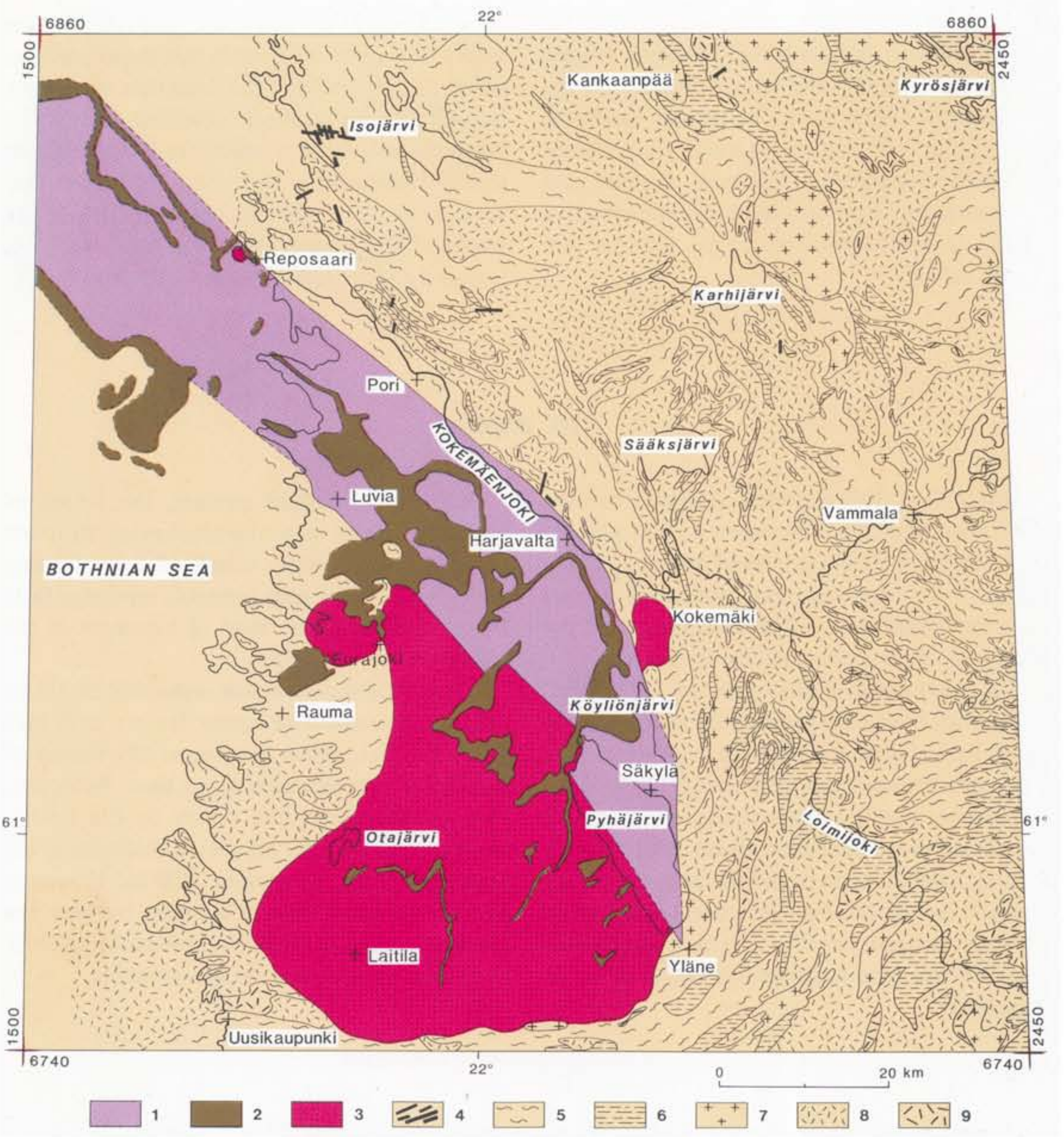

Fig. 2. Geological map of the Satakunta area. 1 = sandstone, 2 = 'Postjotnian' diabase, 3 = rapakivi, 4 = 'Subjotnian' diabase, 5 = migmatitic mica gneiss, 6 = metavolcanite, 7 = granite, 8 = quartz-diorite and tonalite, 9 = diorite, gabbro and ultramafite. Map is simplified from 1 : 100 000 map sheets (partly unpublished) of the Geological Map of Finland.

The Svecofennian supracrustals consist mainly of medium-grade metamorphic mica schists and migmatitic mica gneisses. In places, the mica gneisses turn into high-grade metamorphic kinzigites containing garnet, cordierite and, locally, sillimanite. Intermediate to mafic pyroclastics and lavas occur as interlayers within metasediments.

Synorogenic granodiorites, tonalites (sometimes garnetiferous) and quartz diorites are the predominant plutonic rocks of the basement area. Some variants of granodiorite contain microcline megacrysts. Gabbros, diorites and ultramafic rocks are restricted to some intrusive bodies within migmatites. True granites are sparse as well.

The Svecofennian rocks suffered a polyphase deformation. Besides the folding, major shear and fault zones divide the bedrock into blocks showing diverse metamorphic grades and indicating likely different erosional levels. The dominant direction of the Svecofennian ductile shear zones is NW-SE.

The Laitila rapakivi batholith and three minor stocks (Eurajoki, Kokemäki and Reposaari) are situated in proximity of the Satakunta sandstone. In addition, geophysical modelling (Elo, 1976, 1982) suggests that the sandstone is underlain by several kilometers of rapakivis. The olivine diabases occur in form of sills and feeder dykes. The younger ('Postjotnian') set of diabases clearly has a spatial connection with the sandstone (Fig. 2).

THE BASIN

Sederholm (1893) was the first to state that the Satakunta sandstone represents a relict graben. A. Laitakari (1925) established well the factual extent of the poorly exposed sandstone (see review by Hämäläinen, 1985) and recognized the nature of faults bordering the formation.

The gravimetric studies (Laurén, 1970; Elo, 1976, 1982) have since justified the geometry proposed by A. Laitakari (1925); in cross-section the sandstone becomes gradually thicker towards the NE and has finally a subvertical, faulted contact against the Svecofennian basement. Near the NE-contact, stratification of the sandstone, generally nearly horizontal, dips quite steeply (up to 35°) towards the basin (see Fig. 5). This indicates that the fault was here undisputably active after the deposition.

In the southwestern contact, the sandstone seems to form a step-wise shallowing structure (Laurén, 1970). Some inliers of Svecofennian rocks in the fringe area probably represent fault blocks and irregular relief of basement at the margin of the rift valley.

The only direct evidence regarding the thickness of the sandstone comes from a drill hole south of Pori, which penetrated 591 meters of sandstone without reaching the base. According to a gravimetric profile survey by Elo (1976), northwest of Pori the maximum thickness of the sandstone could be around 1800 m. However, due to the small density contrast between the sandstone and the rapakivi granite, the reliability of the method may be questionable.

COMPOSITION AND PROVENANCE OF THE SANDSTONE

The detrital main components of the sandstone are quartz and feldspars; rock fragments, biotite, muscovite and chlorite are the most common accessories. Although the sandy sediments may be collectively labeled as arkoses, also subarkosic and quartz arenitic rock types are present.

Mineralogy of the sandstone has been studied by Simonen and Kouvo (1955) and Marttila (1969). According to these authors, the sandstone contains generally more than 50% (45—60%) quartz and typically 20—40% feldspar. Feldspar is always predominantly microcline. Plagioclase (An_{15}—to An_{38}) is generally less than 5%. Nevertheless, the fine to medium grained arkoses at Leistilä (for location see Fig. 4 and Appendix 1) exceptionally contain nearly equal amounts of K-feldspar and plagioclase.

The matrix in sandstones (4 to 30 %) consists mainly of authigenic quartz and clay minerals (Marttila, 1969). The glauconite, identified from Makholma in NW-part of the area, apparently indicates, at least locally, marine contribution during the diagenesis.

Basal conglomerates have been observed along the SW contact of the sandstone at Luvia. The well rounded pebbles of Luvia conglomerates are almost solely quartz and typically less than 30 mm in size. Conglomerates, slightly different from the Luvia type, are commonly found (especially in the Säkylä-Yläne district in the southeast) as glacial boulders (Fig. 3). The quartz-pebbles are still dominant but also fragments of different basement rocks (gneisses, granites, schists and quartzites) are common. The quartz-cobbles are up to 6 cm in diameter and rock fragments may reach about 10—15 cm in size. Typically the lithic cobbles and quartz pebbles are subangular to rounded, respectively. The sandy

Fig. 3. Conglomerate boulder in Reposaari (about 3 km SW from Tahkoluoto). Note also the sandstone interbeds. The length of the tag is 16 cm.

matrix consists mainly of poorly rounded fragments of quartz and feldspar; in addition some quartz cement and interstitial clay minerals are present.

Chemical analyses of the Satakunta sandstone can be found in Marttila (1969). SiO_2 varies from 76 to 84 % and Al_2O_3 from 6 to 12 %. By comparing the mineral and chemical compositions, a positive correlation between the Na_2O and CaO contents and the amount of plagioclase is obvious. The K_2O content is typically more than 3.5 % (range 2.3—5.8%; 8 analyses).

Both Simonen and Kouvo (1955) and Marttila (1969) concluded that the detritus of the sandstone is from Svecofennian rocks, not from the rapakivi granites. Although the reasoning based on different types of feldspar may be questioned (the feldspar in the Laitila rapakivi is mostly intermediated microcline; A. Vorma, pers. comm.), the detrital heavy mineral assemblage of Satakunta sandstone seems to favour Svecofennian provenance (Marttila, 1969). Also the U-Pb isotopic study of detrital zircons (Vaasjoki & Sakko, 1987) exludes rapakivi as major source and implies that the zircons in Kiperi (Mestilä) locality (see Table 1 for location) are inherited from Svecofennian granitoids.

GRAIN SIZE DISTRIBUTION

The grain size in the Satakunta sandstone formation varies from conglomerate to siltstone and mudstone but various kinds of sandstone clearly predominate. In outcrops, the most typical sandstones are coarse grained and often pebbly. However, the majority of glacial sandstone boulders consists of fine to medium grained arkoses. The only outcrops corresponding the latter type are Leistilä and Tahkoluoto.

The nearly 600 meters long drill core from Pori consist dominantly of medium grained sandstone; the thin mudstone interlayers together with the coarse sandstones in lowermost and uppermost parts being the exceptions. In contrast the drill cores near the SW margin of the sandstone show a vigorous grain size variation. The generally poor sorting is indicated by great difference between average and maximum grain sizes (Fig. 4).

The most coarse grained sediments are clearly clustered in southwestern and southern parts of the area. Observations from drill cores imply that this can not be explained solely by variable erosional levels.

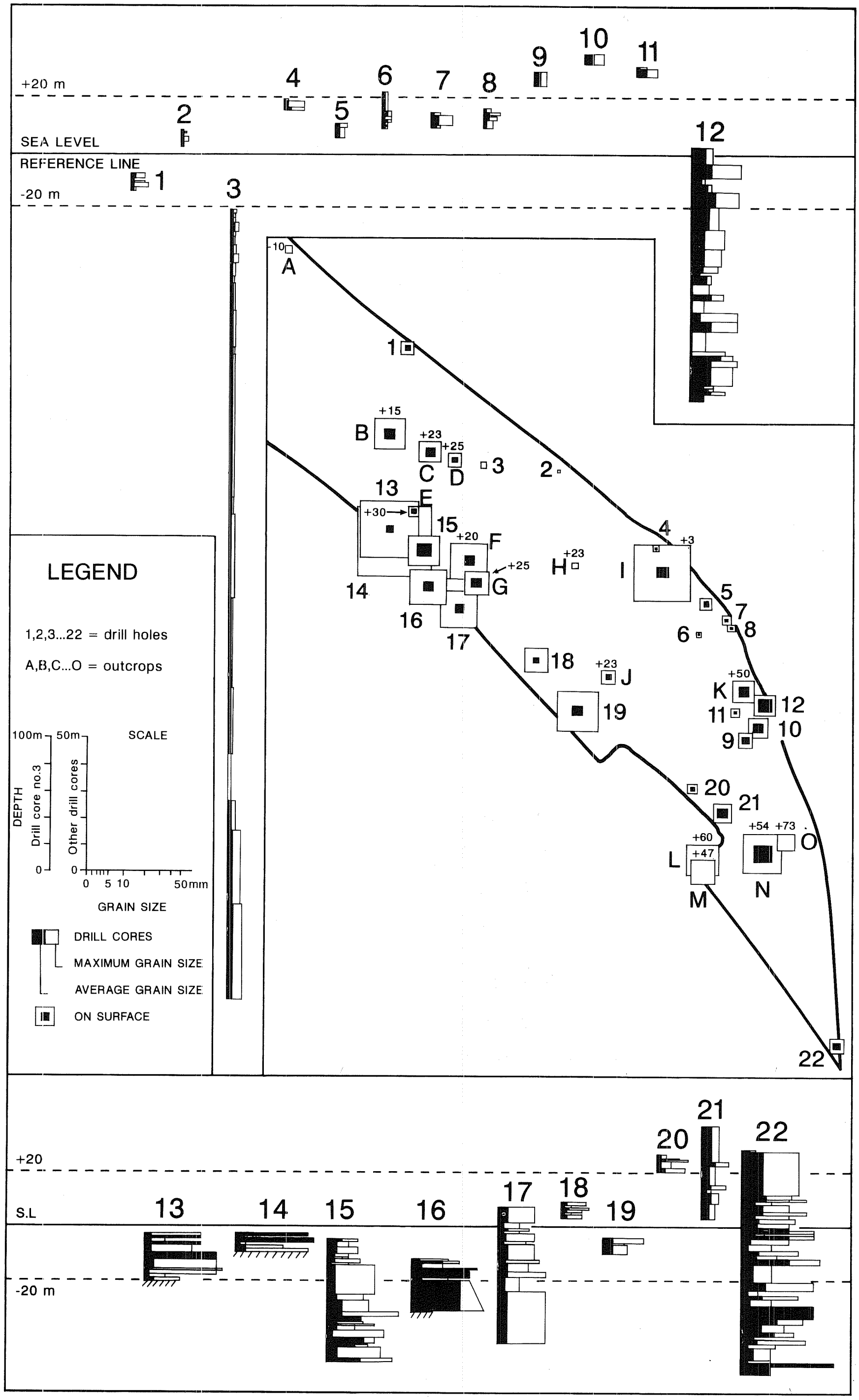

Fig. 4. Grain size variation in outcrops and drill cores. The numbers and letters refer to Appendix 1. The squares refer to maximum (open box) and average (filled box) grain size in outcrops or uppermost part of a drill hole. The elevation is indicated by small numbers (outcrops) or by a reference line (drill holes). Note the condensed vertical scale of the drill core no.3 ('Pori 1').

LITOFACIES DESCRIPTIONS

Methods and sites of observation

The sandstone area is flat and mostly covered by Quaternary deposits. At present some 30 outcrops of sandstone are known and about 10 of them are large enough for reliable palaeosedimentological observations and measurements. The outcrops studied in detail are listed in Appendix 1 and the locations are indicated also in Figure 4.

During the fieldwork special emphasize was laid on sedimentary structures. The vertical sections were divided into lithofacies by using the lithology (grain size) and depositional features. The facies codes are modified after Miall (1977, 1978). In most sites of observation the flat lying sediments offered vertical sections just a couple of meters long, and the only place suitable for a comprehensive lithofacies study is the well known Lammaistenkoski outcrop at Harjavalta. In addition to the vertical profiles, lateral variation was also observed in road cuttings and other places with good exposure.

The Harjavalta section

The largest outcrop of the sandstone is located below the Lammaistenkoski power plant. The tilted, about 80 m long section is not continuous, but by moving sideways good vertical profiles can be mapped. The two profiles were connected by a laterally continuous horizon at the base of the profile 2 (Figs. 5 and 6).

Gravelly lithofacies (Gm and Gp)

The Gm-facies consists of poorly sorted fine gravel conglomerates and very coarse grained sandstones, which contain scattered pebbles up to 20 mm in diameter. K-feldspar clasts are typically angular, whereas quartz shows better rounding (Fig. 7). No clear lateral variation of grain size was observed. In spite of the overall coarseness, the sediments contain a high quantity of mixed silty material. The color is mostly red, probably because of the oxidation of detrital biotite and other Fe-minerals (cf. Marttila, 1969). The thickness of the massive beds is 30—40 cm varying on average between 15 and 100 cm. The bases of the beds show no evidence of erosion.

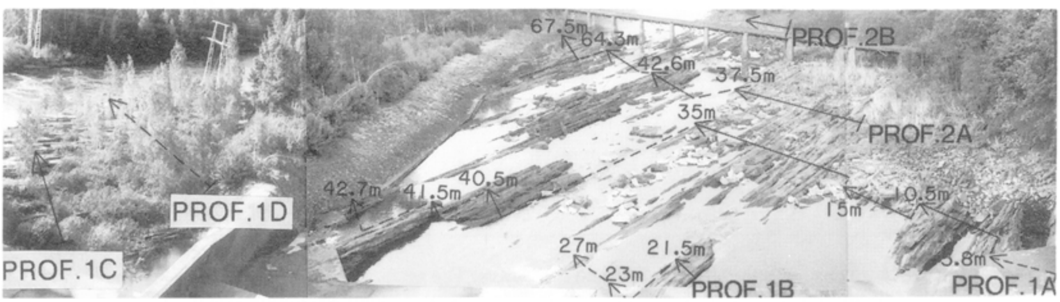

Fig. 5. Collage of three photos illustrating the Lammaistenkoski outcrop at Harjavalta. The location of mapping profiles is also indicated.

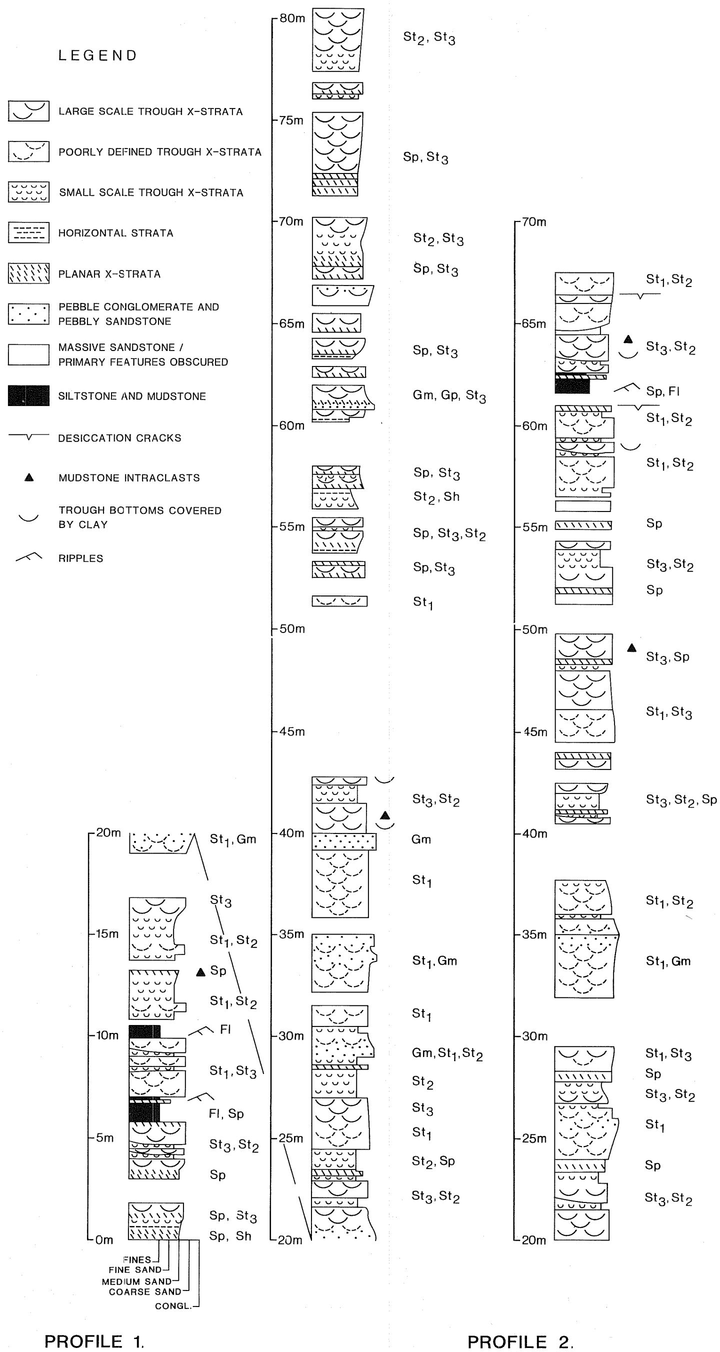

Fig. 6. Columns illustrating lithofacies variation within the Harjavalta profiles.

Fig. 7. Sandy pebble conglomerate of the Gm-facies. Note the angular fragments of feldspar. Harjavalta, profile 1A, 20 m. The length of the tag is 16 cm.

Gm-facies is often followed, without any clear boundary, by grudely cross-bedded sandstones of the St_1-facies. In the upper part of the section, where the gravels are somewhat more sorted and contain less silty material, one set with poorly defined planar cross-bedding (lithofacies Gp) on top of Gm was observed.

Trough cross-bedded facies (St_1, St_2 and St_3)

Three types of trough cross-bedded lithofacies was distinquished. The differences between the facies are often arbitrary, but the characteristic features can be listed. The St_1-facies consists of poorly sorted, often pebbly very coarse sandstone, which typically contains a high quantity of fine material (Fig. 8). The cross-bedding is poorly defined and often the distinction between the Gm-facies is rather obscure. The setbases have a scoop- or wedge-like form. The troughs are 60—100 cm by width (range 40—250 cm) and about 10—20 cm by depth (range 5—30 cm). The individual troughs may often be traced downcurrent for several meters. The basal parts of troughs are often enriched in silty material.

Facies St_2 resembles St_1, but the modal grain size is smaller, the amount of silty material is still larger and pebbles are rare. The small troughs (width 20—90 cm, depth 5—15 cm) are grouped into cosets and the rock is often deeply red colored. The facies most typically appears as laterally discontinuous, lensoid or wedge-like interlayers in the St_1- and St_3-units (Fig. 9), but cosets reaching 150 cm in thickness were also observed.

In the main part of the section St_3-lithofacies consists of coarse to very coarse sandstones, but in the uppermost part also medium grained varieties are present. The sediments show a moderate sorting, and the low proportion of fines is the most striking difference to the St_1- and St_2- facies. This rocktype is relatively resistant against erosion and units of St_3-facies (sometimes together with Sp) form tens of meters long continuous ridges on outcrops (Fig. 5). St_3-facies is composed of well-defined sets of trough cross-beds, with trough width averaging 30—70 cm (range 15 to 100 cm) and depth 3—10 cm (Fig. 10). Pool- or scoop-shaped troughs can have lateral continuity of several meters and probably tens of meters. Cosets vary from 40 cm to 1 m in thickness. A thin (less than 10 mm), purplish red clay layer often covers the base of a trough.

In a two-dimensional section parallel to flow, the cross-strata curve only slightly at the toe, giving an appearance similar to planar cross-bedding. Along with increasing amount of mixed silt, the width/depth-ratio of a trough decreases

Fig. 8. Poorly sorted, coarse grained sandstone of St_1-facies. Harjavalta, profile 1A, 21 m. The length of the tag is 16 cm.

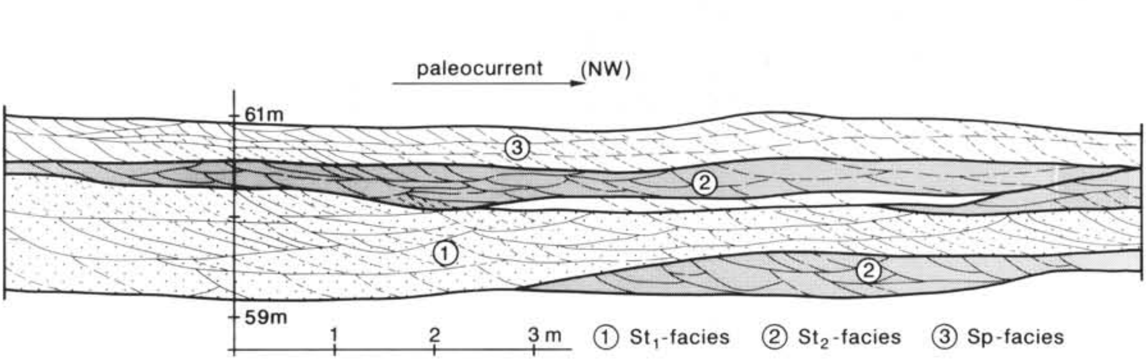

Fig. 9. Lateral variation of different facies at Harjavalta (profile 2A, 59—61 m). Note the lensoid appearance of the silty sandstones of the St_2-facies.

and the difference between the medium grained type of St_3 and the St_2-facies becomes obscure.

Intraclasts of mudstone/siltstone are occasionally present troughout the sandy part of the section, but they are clearly concentrateted in the St_3-facies. In two places a polygonal surface pattern resembling desiccation cracks was observed on top of a St_3-unit.

Planar crossbedded facies (Sp)

The sets comprising the Sp-facies show a well-defined planar tabular cross-bedding. Cosets may consist up to 6 sets, but single sets are most common. Set thickness is generally around 10 cm (range 5—35 cm). In the main part of the section, the rocks are composed of moderately sort-

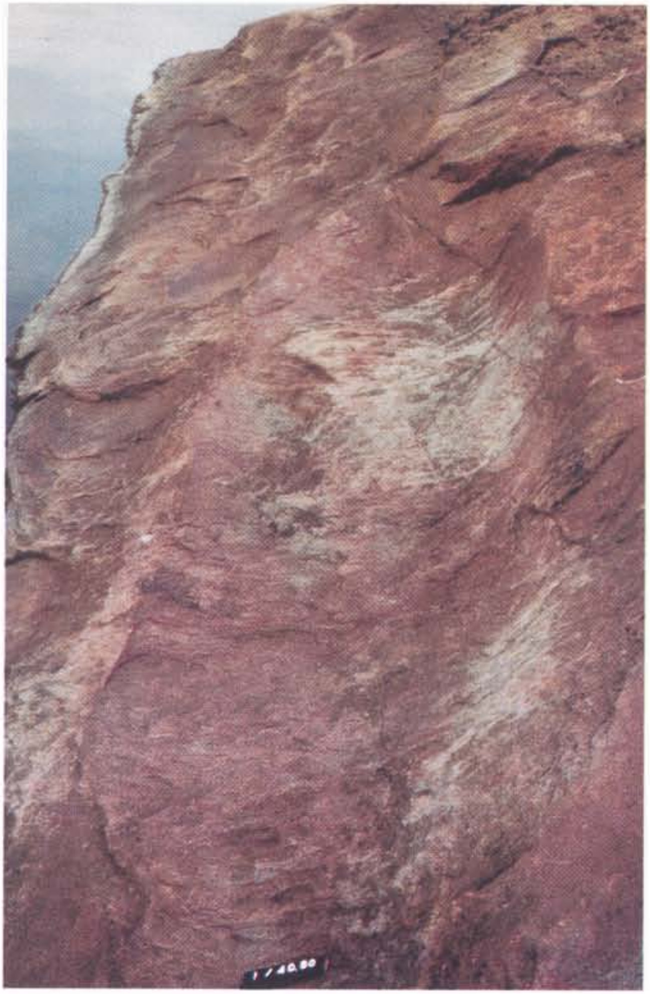

Fig. 10. Well defined, medium scale trough cross-bedding of St_3-facies. Harjavalta, profile 1A, 40.5 m. The length of the tag is 16 cm.

ed coarse to very coarse sand. Planar crossbedded sandstones become more abundant in the upper parts, where the grain size corresponds to that of medium grained sand. The bottom contact of a set is generally angular, but also tangential bases occur. A lateral downcurrent gradation of tangential Sp-facies into facies St_3 was locally observed (Fig. 11).

Horizontally bedded or laminated sandstone facies (Sh)

Horizontally bedded sandstones are rare and occur in two distinctly different associations. The first type is associated with facies St_3 and consists of coarse sands with obscure horizontal stratification. The other type is a medium to fine grained, silty, laminated sandstone existing only in the upper part of the section. This type seems to evolve gradationally from facies St_2 as the proportion of fine sand increases.

Horizontally laminated or rippled sandy mudstone/siltstone facies (Fl)

Fl-facies includes horizontally interlayered laminated muds, silts, sandy silts and rippled sandy silts. All the three occurences of the facies

Fig. 11. Medium grained sandstone of the Sp-facies. Note the downcurrent transition from Sp to St_3 in the topmost set. Harjavalta, profile 1D, 72 m. The tape measure is visible 10 cm.

Fig. 12. Mudstone and sandy siltstone of the Fl-facies overlain by sandstones of St_3- and St_2-facies. Harjavalta, profile 2A, 62 m. The length of the tag is 16 cm.

are about 1 m in thickness and the contacts against the bordering facies appear to be sharp (Fig. 12). The finest laminas are 2—6 mm and those consisting of sandy silt 8—15 mm in thickness. The color of these layers differs, being red and greenish to reddish gray, respectively. However, the red hue does not invariably follow the bedding, but forms irregularly shaped patches of epigenetic oxidation. The sandy silts are partly small scale crosslaminated and may contain scattered clasts up to 3 mm in diameter. The Sp is the only sandstone facies occuring interlayered with the fine sediments.

The Knapernummi section

The vertical section at Knapernummi is only 3,3 meters high (Fig. 13), but the outcrop has lateral contuinity more than 20 meters. The three sandy facies are all composed of coarse to very coarse arkosic sandstone with maximum grain size around 1,5—2 mm (excluding mudstone intraclasts up to 30 mm in size). The lithofacies division is based solely on internal structures.

Trough cross-bedded facies (St)

The St-facies is characterized by poorly defined sets of trough cross-beds.The foresets are seldom visible,but the geometry of set bases can be depicted. The trough depths are 5—10 cm and they form cosets up to 40 cm in thickness.

Planar cross-bedded facies (Sp)

This facies includes planar cross-bedded sets with a tabular planar or wedge planar geometry. The distinction with the facies St is not always clear, because the set bases often show a sligthly concave form and downcurrent gradation into the St-facies was observed. The set thickness vary between 5—20 cm, the thick sets are typically solitary, whereas the thinner ones form cosets up to 4 sets. Mud chips are present in the whole section, but they are clearly enriched near the base of Sp sets or cosets. The lower contanct of a set is generally sharp and angular, but some very low-angle types are also present. The low-angle cross-bedding could, however, simply display variable orientation of foresets in two-dimensional exposure or, alternatively, represent an intermediate type between Sp and Sh.

Horizontally bedded facies (Sh)

This facies is composed of horizontally stratified sandstones. The bedding features are very indistinct and part of these sediments may, in fact, be massive.

Mudstone facies (Fm)

The Fm-facies consists of dark red colored mudstone. It occurs as discontinuous thin layers (max. thickness 40 mm, commonly 2—6 mm) between the sandy sets. The rock type, as well as the mode of occurrence, is very similar to the fine sediments associated with St_3-facies in the Harjavalta section. The narrow mudstone layers form in vertical section an anastomosing pattern between the lensoid, wedge-shaped or tabular bedforms of sandstone (Fig. 13). On a surface parallel to the bedding plane the gentle pools and ridges are visible. The pool bases are covered by mudstone which thins laterally out in a short distance. One rippled surface with small scale, large index ripples was observed.

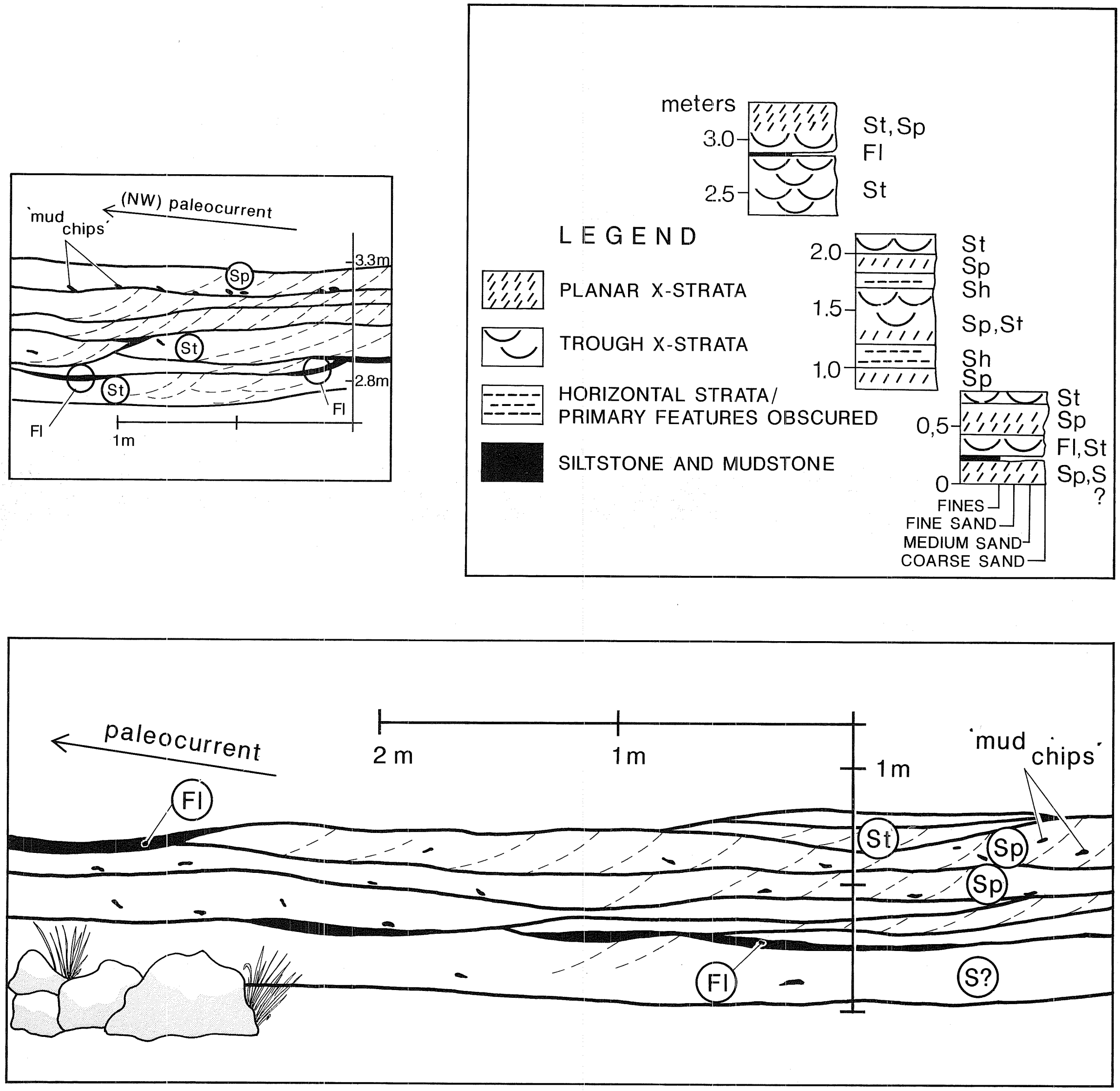

Fig. 13. Vertical profile and lateral relationships of the different facies at Knapernummi. The pictures (top left and bottom) are viewed towards the north; numbers of the vertical bars refer to the vertical profile (top right).

Sedimentary structures in other observation sites

At *Naskalinkallio* a section 10,5 m by total length (about 7 metres exposed) is present. The lower part consists of very coarse grained, partly pebbly, arkose with lensoid more gravelly beds. One thin (2 cm) interbed of siltstone was observed. Internal structures are seldom visible. This may be caused partly by the coarse grain-size (massive beds), but also abundant lichen on the outcrops hinder the observation. The only clear bedding features are some about 20 cm thick planar crossbedded sets. The upper part of section is characterized by coarse to very coarse grained sandstone with poorly defined trough crossbedding resembling the St-facies at Knapernummi.

In *Kiperi* road cutting (section 6,5 m) and at *Murronmäki* (section 1,2 m) the sedimentary structures are obscure. Both outcrops consist of moderately sorted, coarse sandstone interlayered occasionally with thin (less than 2 cm) remnants of greenish siltstone. In places trough crossbedded units with set thicknesses around 15 to 25 cm are visible.

At *Kallionpää,* a badly vegetated sandstone step 0,8 m high was found. Two tabular planar cross-stratified sets (thickness 15—20 cm) are followed by a trough crossbedded unit. The outcrop is much like the Knapernummi station both by the rock-type and the depositional style.

Metsäkulma and *Makholma* are flat outcrops parallel to bedding plane. They are very similar to each other with gently undulating surface of a coarse grained arkosic sandstone with thin remnants of mudstone covering the pools. At Makholma 'mud chips' are very common (Fig. 14). At Metsäkulma a lot of small scale troughs are visible on plan view. In addition, a surface texture resembling raindrops imprints was observed.

In the blasted walls of the *Leistilä* water channel about 5 meters long section of sandstone is visible near a contact of a diabase dyke. The arkosic sandstone is heavily jointed and the primary features have been largely destroyed. The arkose is more fine grained and quite well sorted in comparison to most other places studied. The bedding structures typical for this type of the well sorted, medium grained sandstone are best seen in glacial boulders and in the walls of the Ulvila church.

At *Tahkoluoto,* long walls perpendicular to each other were exposed during the construction of the new harbour. Large scale channels and trough cross-bedding structures are typical for this location (Fig. 15). The rock type is mainly

Fig. 14. Mudstone intraclasts in a coarse grained sandstone at Makholma. Note the epigenetic red coloring of clast margins. The lens cap is 5.5 cm in diameter.

Fig. 15. The blasted southern (at right) and eastern (at left) walls of the Tahkoluoto harbour basin. Note the basal bounding surface of a SSE-NNW directed channel in the southern wall near the corner and corresponding large-scale cross-beds in the eastern wall.

medium grained arkose or subarkose quite similar to Leistilä. Unfortunately, the pool was accidentally invaded by sea before more detailed observations were executed.

The all other outcrops presented in Figure 4 (*Saarenmaa, Myllyoja, Sahankoski* and *Markkula*) consist of coarse grained arkose and allow very restricted possibilities for investigation.

The drill core 'Pori 1'

All known drill cores from the Satakunta sandstone area were re-examined. Unfortunately, the primary structures are hard to identify from a core and a meaningful lithofacies division was not possible to establish. Most drill cores are some tens of meters long, and their features resemble those observed in outcrops. The long drill hole (Pori 1), however, reaches more than 600 meters in depth and is of a special interest.

The first 130 m (excluding 28 m of overburden) is characterized by medium to coarse grained sandstones, which show patchy or overall purplish red coloring. Rocks are typically cross-bedded (dominantly small scale trough cross-bedding ?). Between 130 and 360 meters the sandstone is medium grained, well-sorted and seemingly massive. From 360 meters downwards cross-bedding is obvious again and from 470 meters the average grain size corresponds coarse sand and becomes gradually still coarser in the lowermost part of the drillhole. The purple or red hue appears again in depth of 400 meters and is still locally present between 480—580 meters. The lowermost part is not epigenetically colored and light grey.

When looking at the core as a whole, most

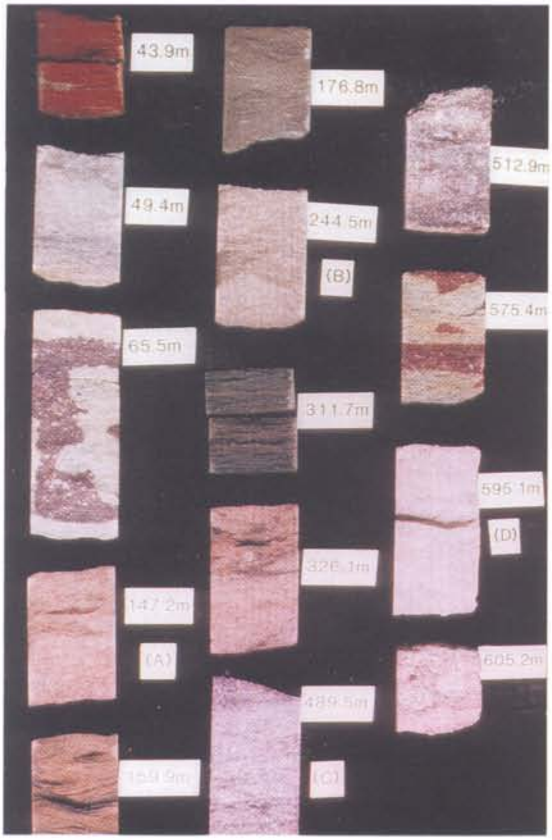

Fig. 16. Different rocktypes of the drill hole 'Pori 1'. Typical samples are marked by letters: (A) Pink, seemingly massive, medium grained arkose; (B) Light brown, seemingly massive, medium grained arkose; (C) Light purplish, cross-bedded coarse sandstone; (D) Light greyish, cross-bedded quartz rich sandstone. The diameter of the core is 32 mm. Photo by J. Väätäinen.

typical are pinkish arkoses ('A' in Fig. 16) and subarkoses, but also nearly quartz-arenitic types ('D' in Fig. 16) are locally present. Mudstone rip-ups of different size are common in sandstones.

The mudstone interbeds are present in the whole section, excluding the lowermost portion (rare below 470 m). They are red, green or dark grey in color (see Fig. 16). The individual interbeds are typically 5 to 30 cm (range 0.5—50 cm) in thickness, and the fine sediments form together less than 5 % of the core.

FACIES SEQUENCES

The main part of the **Harjavalta section** (0—55 m) is characterized by alternation of the three St-lithofacies interrupted sharply by Fl-facies. The most striking feature is the overall poor sorting; coarse pebbly arkoses include considerable portion of silty material. Erosional features are rare, sorted orthoconglomerates and reactivation surfaces being virtually absent. This system was named as 'facies association 1' (later on FA 1, for short).

In the upper part of the Harjavalta profile 1 sorting is better and the modal grainsize smaller when compared to the FA 1. Most characteristic for this 'facies association 2' (FA 2) are the medium to coarse grained arkosic sandstones with well defined planar and trough crossbedding. Sp-facies is common and it often has gradation upwards to lithofacies St_3.

The lower and upper parts of the section differ in average grainsize, sorting and sedimentary structures, but parts of the FA 2 are clearly analogous with the FA 1. Thus, the boundary between associations is not abrupt, but the change in sedimentary style may roughly be located between 50 and 60 meters in the profile 1.

The facies sequence was studied statistically by the 'Markov chain analysis'. The raw facies relationship sequence was first arranged in form of a matrix and then a difference matrix was calculated (for details of the method; see Miall, 1973). Positive values in the difference matrix indicate lithofacies transitions more probable than random. The target is to figure out real relations between the lithofacies and study the cyclicity of the sequence.

The major drawback of the method is that it ignores the thickness of the units and the character of the contacts (sharp, gradational, erosional). An additional source of statistical error are the unexposed parts of the section, because they may not be situated randomly and lithofacies with low resistance against erosion can be underrepresented in the sequence. This effect may somewhat distort the cyclic models.

In Figure 17 all observed lithofacies relations in Harjavalta section are presented. The important transitions, with positive values and significant total number of cases, are printed by thick in Table 1.

The lower association does not show any clear cyclicity, althought the transitions St_1 to St_2 and St_3 to St_2 are clearly significant. In the upper association we can outline a repetative feature Sp to St_3 to St_2. The most important difference with the former association is the high probability of the transition Sp to St_3.

The short section at **Knapernummi** is characterized by alternation of lithofacies Sp and St (see Fig. 13). The bases of Sp units are sharp and these planar crossbedded sets tend to be followed gradually by facies St. The thin Fm-units are associated with facies St. The Sh lithofacies is quite obscure, but its position allows a tentative cycle Sh via Sp to St (with Fm) to be figured out.

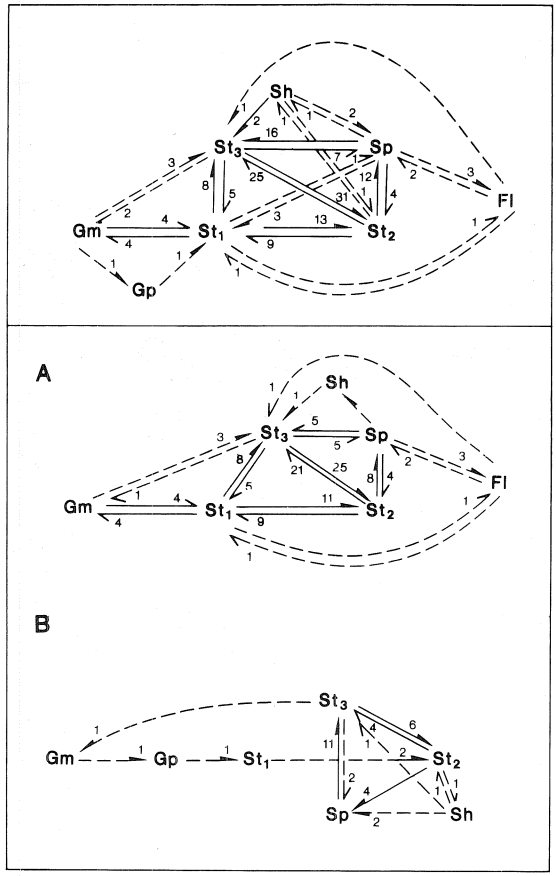

Fig. 17. The observed lithofacies relationships within the whole Harjavalta section (above) and for the facies associations (below): (A) FA 1; (B) FA 2. The number of facies transitions is indicated.

Table 1. Difference matrices, Harjavalta section.

	Fl	Sh	Sp	St$_1$	St$_2$	St$_1$	Gm	Gp	
Fl		—0.01	0.35	—0.01	—0.31	0.11	—0.04	0.01	
Sh	—0.03		0.25	0.05	—0.11	—0.14	—0.04	0.01	
Sp	0.08	0.02		**0.19**	—0.21	—0.06	—0.04	0.01	
St$_3$	—0.03	—0.02	—0.05		**0.43**	—0.08	0.01	0.01	
St$_2$	—0.03	0.00	0.05	0.06		—0.01	—0.05	0.01	d_{ij}
St$_1$	0.01	—0.01	—0.14	—0.11	**0.12**		0.10	0.01	
Gm	—0.03	—0.01	—0.15	0.02	—0.31	**0.35**		0.02	
Gp	—0.02	—0.01	—0.01	—0.34	—0.30	0.86	—0.04		
Fl		—0.01	0.37	—0.07	—0.33	0.07	—0.04		
Sh	—0.03		—0.12	0.69	—0.31	—0.17	—0.04		
Sp	0.15	0.05		—0.03	—0.11	—0.01	—0.04		
St$_3$	—0.04	—0.01	—0.04		**0.25**	—0.10	—0.03		d_{ij}
St$_2$	—0.04	—0.01	0.03	**0.11**		—0.01	—0.06		
St$_1$	0.00	—0.01	—0.11	—0.06	**0.05**		0.11		
Gm	—0.03	—0.01	—0.13	0.10	—0.33	0.39			
Sh			0.25	—0.23	—0.02	—0.03	—0.03	—0.03	
Sp		—0.04		**0.38**	—0.34	—0.03	—0.03	—0.03	
St$_3$		—0.04	—0.06		**0.34**	—0.04	0.08	—0.04	
St$_2$		0.08	0.16	—0.13		—0.04	—0.04	—0.04	d_{ij}
St$_1$		—0.03	—0.23	—0.45	0.74		—0.02	—0.02	
Gm		—0.03	—0.22	—0.44	—0.25	—0.03		0.97	
Gp		—0.03	—0.22	—0.44	—0.25	0.97	—0.03		

PALEOCURRENTS

In Harjavalta, Knapernummi and Naskalinkallio the paleocurrent data represents the whole section, and no more than two readings from an individual coset was taken. In all other localities paleocurrent indicators were few and exposure allowed no systematic data collection. A total of 211 measurements were made in 14 localities.

The cross-bed measurements were first corrected for tilt by stereographic projection, and obtained values were divided into 30° classes. Data include planar foreset, trough foreset and trough axis azimuth measurements. The trough axis azimuths may be held as most reliable paleocurrent indicators (Meckel, 1967; Michelson and Dott, 1973) and within these the variability is very small. In statistical calculations (Table 2) all readings of a station were put together in spite of varying »internal» variability of different types of measurements (eg. trough axis azimuths and trough foresets). Because the total variance is small in all localities, this procedure may not distort the results.

In all localities paleocurrents show unimodal pattern with main transport direction towards NW or N. The stations near the SW contact of the sandstone area show slightly more northern trend compared to other localities (Fig. 18).

The genetic relationships between the current and inclined bedding may be complicated in detail, and variable methods and scales of reference studies hinder straigthforward comparisons (cf. Allen, 1966; 1967; Miall, 1974). However, the

Table 2. Paleocurrent statistics.

Station	Number of Readings	Vectoral Mean (degrees)	Consistency Ratio (%)	Arithmetic Standard Deviation (degrees)	Arithmetic Variance
Harjavalta	135	**320**	88.5	28.8	829
Knapernummi	21	**019**	88.7	28.5	811
Naskalinkallio	10	**042**	83.8	35.6	1264
Leistilä	5	**322**	88.6	31.2	973
Metsäkulma	8	**282**	94.9	19.6	384
Kallionpää	7	**324**	91.3	26.1	682
Makholma	5	**341**	88.4	31.4	989
Tahkoluoto	4	**328**	99.9	2.4	6
Kiperi	4	**338**	94.2	22.7	516
Murronmäki	5	**016**	97.8	13.4	181
Myllyoja	3	**277**	97.6	15.3	233
Markkula	2	**357**	98.8	12.7	162
Saarenmaa	1	**012**	—	—	—
Sahankoski	1	**335**	—	—	—
Total	211				

paleocurrent pattern apparently has some environmental significance. Unimodal, low variance patterns has been reported to occur in deltaic, turbiditic and even eolian environments, but it is most characteristic to rivers with a high gradient and low sinuosity (e.g. Potter and Pettijohn, 1977).

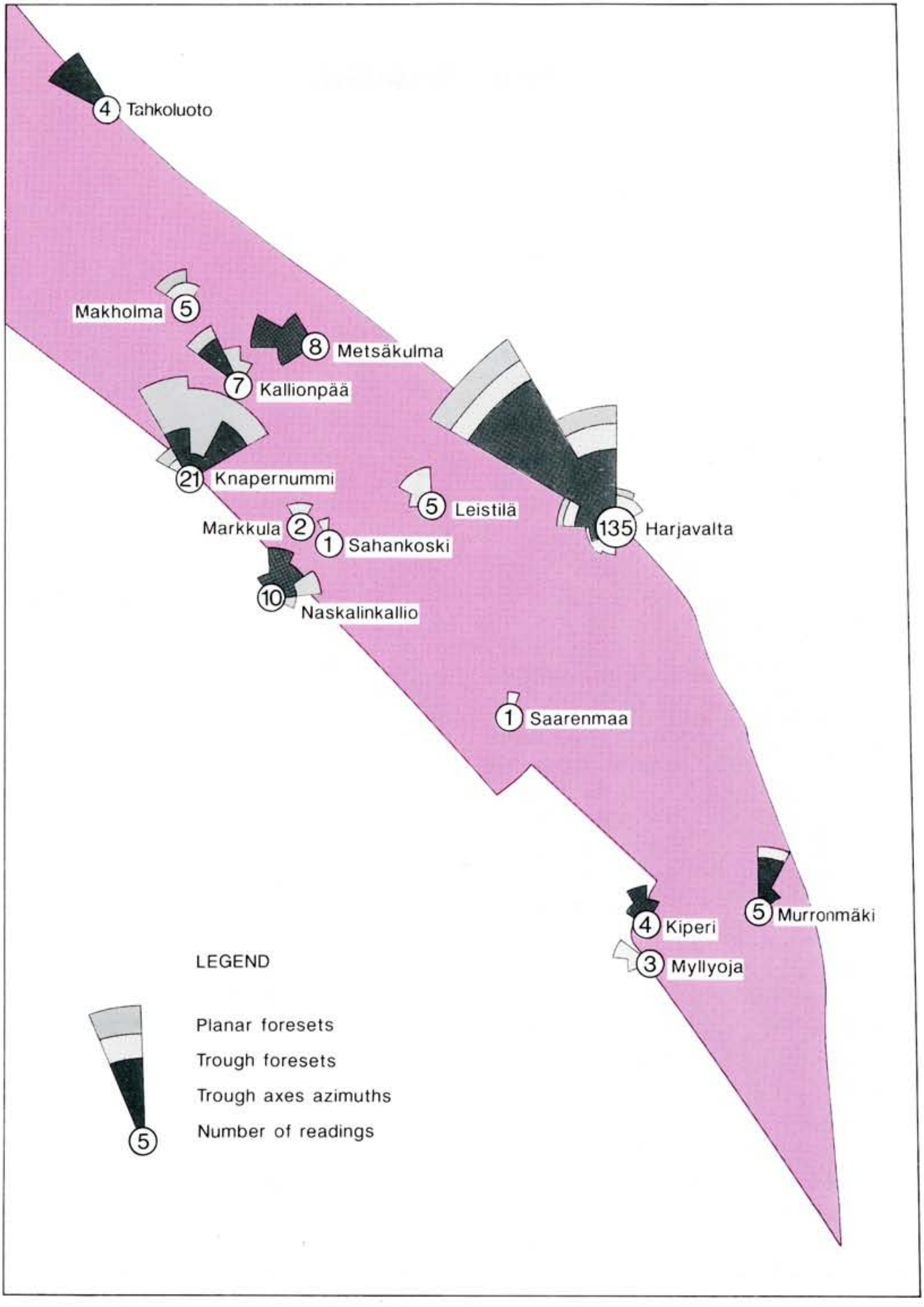

Fig. 18. The distribution of paleocurrent observations.

DEPOSITIONAL MODELS

Individual primary features or lithofacies are seldom diagnostic, and the interpretation depends on the framework. Thus, the procedure generally progresses from large to small. The facies sequence and facies relationships act as a norm, and the first step is to outline the most probable depositional environment by comparing the observed facies association to the existing models. In this phase also the overall nature and geological setting of the studied sequence are taken on account. The second phase is to discuss the depositional processes behind a particular lithofacies within the created framework. Consequently, the validity of the latter interpretations is solely dependent of the model used.

The important general features of the Harjavalta section may be listed as follows: (1) the overall coarseness of the sediments; (2) the arkosic, poorly sorted and rounded nature of the material (low maturity); (3) the minor amount of fine sediments (less than 3% of the total section measured); (4) abundance of trough- and planar cross-bedding; (5) lack of major reactivation surfaces and (6) unimodal paleocurrent pattern.

The short Knapernummi section resembles the St_3 dominated parts of the Harjavalta profile and also all the general features listed above are valid. In all other sites of observation the section is so short, or the primary features are so obscured, that their usefulness in the paleosedimentological reconstruction is vague. However, most places show features quite similar to the Knapernummi section. The important exceptions are the more fine grained Leistilä and Tahkoluoto, which might represent a depositional environment different from all the other stations.

The general features listed directly rule out many environments and clearly favour rapid deposition in a fluvial setting. Accordingly, the only comparable lithofacies models are those presented for braided alluvial environment (e.g. Miall, 1977; Walker, 1979; Reading, 1986) which can further be divided into braided rivers, alluvial fans and alluvial plains (Rust, 1978).

In spite of the recent invasion of fluvial facies models, the Satakunta litofacies associations are compared to the 'standard models' of Miall (1977, 1978). For the purpose of this study they represent the major braided river types with sufficient accuracy to be used as a basis for interpretation. The models have been derived from (and named after) recent examples, and their major differences are in the facies assemblages and in the features reflecting cyclicity.

The lower part of the Harjavalta section (FA 1) resembles the Donjek-model or an intermediate between it and the more distal-type South Saskatchewan-model. The models represent gravelly and sandy braided rivers, respectively. An important difference to these is, however, the observed poor cyclicity of FA 1.

The development of autocyclic features is controlled mainly by the degree of channelling in the river system (Miall, 1977). The unsorted nature of sheet-like coarse units and scarce erosional structures are also features indicating poor channel development at Harjavalta. The braided vertical profile models of Miall (1978) lack an example for a non-cyclic sandy-gravelly stream. However, the concept of the non-cyclic (sandy) Platte-type sequence and the general factors controlling fluvial depositional styles (cf. Miall, 1985) points the interpretation of the FA 1 to an environment with broad, shallow rivers or braidplains characterized by low sinuosity and poor channeling.

The gravelly Gm-lithofacies allows two alternative interpretations. Poorly washed, massive sediments are typical products of 'gravity-driven' debris flows, common in some proximal (steep slope) alluvial environments. However, in the studied section also texturally similar sands with current bedding features (lithofacies St_1) are present. This might indicate simultanous depo-

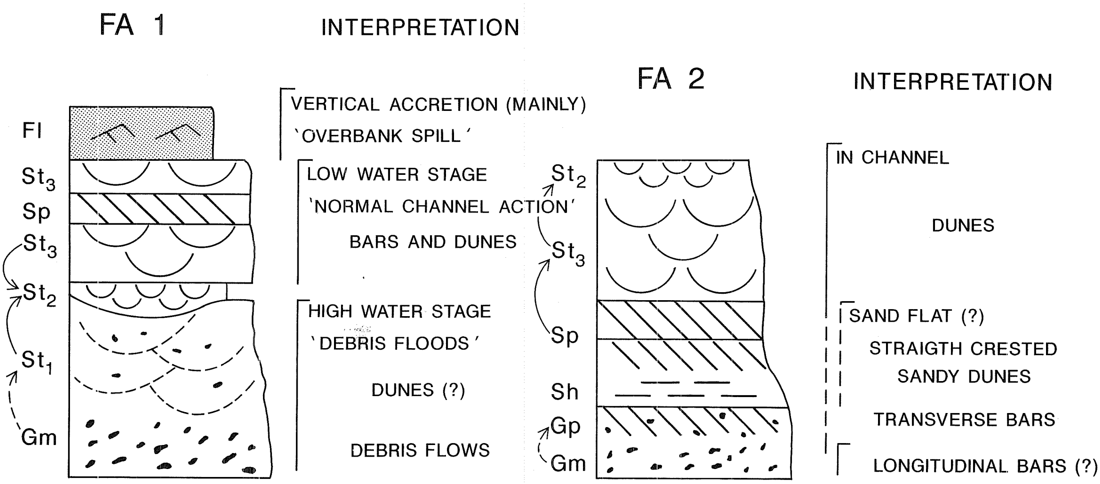

Fig. 19. Simplified depositional models for the lower (FA 1) and upper (FA 2) lithofacies associations of the Harjavalta section.

sition of all grain sizes from a heavily loaded river ('fluid-driven' debris flow) in conditions where the velocity of the stream suddenly decreases. Together these facies (Gm and St_1) might represent the high water stage of the river system and associated debris floods.

From this starting point, the better sorted St_3- and Sp-sands represent sorting of previous sediments and final deposition from sinuous crested dunes and linguoid or transverse bars, respectively ('normal channel action' in Fig. 19), during the low water stage. In this model, the St_2-facies represents infill of minor channels or deposition in the lee of larger bars and dunes.

The most fine-grained portion of the lithofacies Fl is best explained by vertical accretion in the abandoned parts of the channel system (or floodplain) with occasional seasonal reoccupation (rippled parts and Sp-interlayers). In general, the rarity of this facies suggests deposition in an environment with poorly defined channels and interchannel floodplain areas and/or poor preservation of mudstones in a cannibalistic braided river system characterized by frequently changing pattern of shallow channels.

The lithofacies association 2 of the Harjavalta section is well comparable to the facies model of sandy, braided South Saskatchewan river (Cant, 1978; Miall, 1978). The FA 2 is characterized by smaller overall grainsize, better sorting and abundance of Sp units when compared to the FA 1. The two former features can be explained by a more distal location in the fluvial system and the latter by common appearance of sand flat complexes in sandy braided systems. The observed Sp to St_3 gradation may reflect change in bedform morphology from sand flats to sinuous crested dunes downcurrent and/or towards the main channel.

Both the grain size characteristics and structures of the Knapernummi section are quite similar to those of the St_3/Sp dominated parts of the FA 1 in Harjavalta. The coarse sands with poorly defined horizontal stratification might have been originated through bottom traction in channel; the development of sandy foreset bars and dunes with increasing discharge probably produced the facies Sp and St. During the low water season, the abandoned pools between bars dried out and the thin clay deposits on sandy units formed. The subsequent high water cycle then partly eroded previous bar tops and deposited the mud chips in the lower parts of the cross-bedded units.

It is to be pointed out, however, that the depositional models and processes suggested are only simplified attempts based on the modern analoques. The spectrum of fluvial systems is wide and facies models must be seen only as fixed points in the continuum of variability. Even within fluvial environment different processes may create analogous facies relations. A detailed interpretation of depositional processes demands techniques more sophisticated than vertical profiles, but in lithified record lacking three-dimensional exposure such methods (e.g. 'structural element analysis'; Miall, 1985) are seldom applicable.

SUMMARY AND DISCUSSION

The typical sedimentary structures of the Satakunta sandstone are planar and trough cross-beddings, symmetric, asymmetric and linguoid ripple marks, mud cracks, clay galls and raindrop imprints, and all of them are in accord with continental conditions of deposition. The red color of the sediments has been interpreted (Simonen and Kouvo, 1955) to indicate a terrestial, oxidizing environment. However, the purplish red coloring seems to be partly, at least, epigenetic in origin.

Although the primary features and facies associations observed on outcrops fit well to the fluvial models, it seems — in the light of the glacial boulders and the drill hole 'Pori 1' — that coarse grained sandstones are clearly over-represented on outcrops. The depositional interpretation presented is based mainly on the Harjavalta section and must be kept in the appropriate context; it is related only to the presently exposed level of the entire sandstone body. Major part of the sandstone has not been studied. Unfortunately, the only outcrops, Leistilä and Tahkoluoto, consisting of medium grained sandstone, are heavily jointed and presently under the sea, respectively. Although fluvial model seems to be sound, at least for the Tahkoluoto, one has to remember that a major part of the Jotnian Dala sandstone in Sweden has been interpreted as eolian in origin (Pulvertaft, 1985).

Both the paleocurrent pattern and the grain size distribution strongly support that the distal part of the basin was situated in the NW. No evidence of delta sedimentation was found, but topset deposits of a Gilbert-type fan delta are often difficult to distinguish from fluvial sediments. In any case, the glauconite in the NW presumably means marine contribution in the distal parts of the basin. According to Axberg (1980) the Jotnian sandstone at the bottom of the Bothian Sea is »more or less quartzitic», but, unfortunately no exact data is available. This lithological transition, together with the southern and eastern paleocurrents from Nordingrå (Bergman, G., 1980) could indicate existence of a shallow marine paleobasin between these areas (see Fig. 1).

No evidence of rapakivi provenance has been reported, but if rapakivis were exposed to erosion at late stages of the basin filling and given that the depositional model (Fig. 20) is valid, the conglomerates in SE part of the area are relatively young and most potential to include debris derived from the rapakivis. In contrast, the quartz-pebble conglomerates at Luvia may represent real 'basal conglomerates'. Their mature composition could reflect a weathered source and stable conditions prior to the faulting that resulted in deposition of the unmature arkosic sediments.

The northern trend of paleocurrents at the SW contact reflects supply tranverse to the basin axis. The Harjavalta section is located near the NE margin of the sandstone, but here all the paleocurrent are parallel to the longest dimension of basin. This observation probably means that

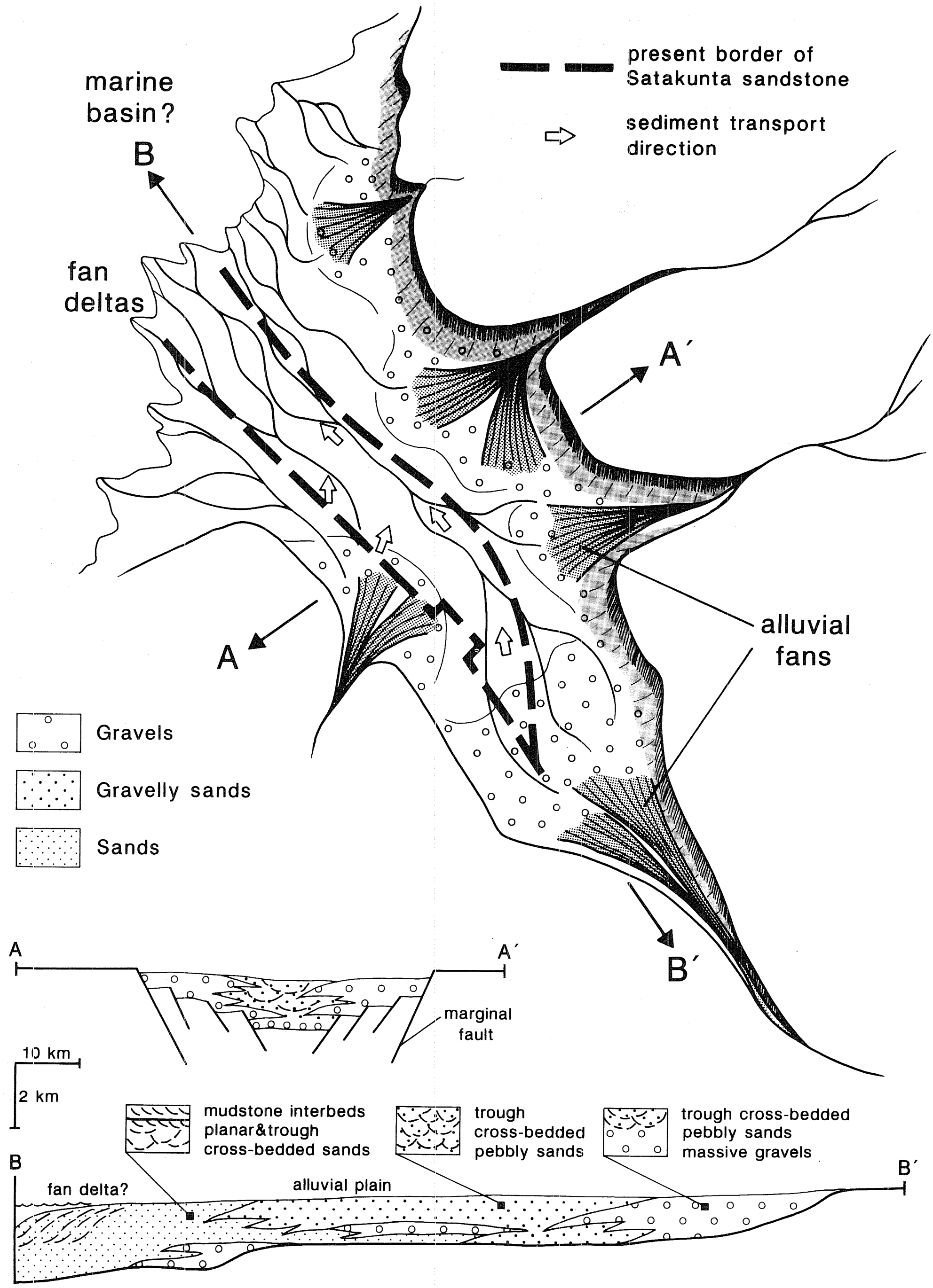

Fig. 20. Schematic paleogeographic reconstruction of the Satakunta basin about 1400 Ma ago.

the NE contact is not the edge of the primary basin, but controlled by later events. This is supported by tilting of strata at Harjavalta.

The filling of the Satakunta basin may have a long and compound history. The major trend of both 'Subjotnian' and 'Postjotnian' dykes in Finland is parallel to the axis of the Satakunta basin (see Figs. 1 and 2). No conclusive evidence on the age relationship between the 'Subjotnian' rapakivi-diabase association and the Satakunta sandstone is present; neither clastic material from rapakivis (or from 'Subjotnian' diabases) nor sedimentary contact against rapakivi has been reported, and — on the other hand — observations of cross-cutting rapakivi granites are lacking as well. In Sweden the Jotnian sandstone of Nordingrå has a depositional contact against granite of age 1578 Ma (Lundqvist, 1990), and both the Gävle and Nordingrå sandstones contain fragments derived from the 'Subjotnian' complex (Gorbatchev, 1967; Bergman, G., 1980).

Although the reliability of the old K-Ar age determination of the shale interbed (1300 Ma; Simonen, 1960) may be questioned, the paleomagnetic results (Neuvonen, 1973; Pesonen et al., 1989) indicate that the Satakunta sandstone cannot be considerably older than the 'Postjotnian' dykes. However, the present sampling horizon seems to be underlain by nearly a kilometer thick pile of sandstone, and the maximum age of these deposits may in principle, at least, be extended even up to 1800 Ma. In summary, the upper part of the sandstone probably deposited about 1400—1300 Ma ago, but, as long as the field relations between the 'Subjotnian' intrusives and the sandstone are not observed, the possibility of the basin initiation during the 'Subjotnian' rifting (c. 1650 Ma ago) should not be ruled out.

The original extent of the basin system is not possible to estimate, but a comparison with the Riphean basins of the Russian platform (cf. Salop, 1983) makes clear that it may have been much wider than presently. As suggested by I. Laitakari (1983), the final preservation — and the present margins — of the sandstone are probably controlled by the subsidence related to eruption of 'Postjotnian' basic magmas. This late event has not necessarily much to do with the deposition of the sandstones studied.

CONCLUSIONS

1. The deposition of the Satakunta sandstone represented at present exposure level occurred by poorly channeled braided streams in an alluvial environment.

2. The paleocurrent pattern observed is of unimodal, low variance type. The main direction of transport was towards the NW, but north directed paleocurrents are evident in the SW-part of area. According to the paleocurrents and the grain size distribution, the proximal part of the basin was situated in the SE.

3. The elongated, thick, fault bounded sandstone body is interpred as a graben fill sequence. The present areal extent of the Satakunta sandstone is controlled mainly by movements related to eruption of 'Postjotnian' basic magmas.

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REFERENCES

Allen, J.R.L., 1966. On bedforms and paleocurrents. Sedimentology 2, 93—114.

Allen, J.R.L., 1967. Notes on some fundamentals of paleocurrent analysis, with reference to preservation potential and sources of variance. Sedimentology 9, 153—190.

Axberg, S., 1980. Seismic stratigraphy and bedrock geology of the Bothnian Sea, Northern Baltic. Stockholm Contrib. Geol. XXXVI:3, 153—213.

Bergman, G., 1980. Quicksand structures in the Jotnian sandstone of central Sweden. Geol. För. Stockholm, Förh. 102, 111—116.

Bergman, L., 1982. Clastic dykes in the Åland Islands, SW Finland and their origin. Geol. Surv. Finland, Bull. 317, 7—33.

Cant, D.J., 1978. Development of a facies model for sandy braided river sedimentation: comparison of the South Saskatchewan river and the Battery Point formation. In: Miall, A. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 627—639.

Elo, S., 1976. An interpretation of a recently measured gravity profile across the Jotnian sandstone formation in southwestern Finland. Unpubl. Report Q 20/21/1976/1. Espoo, Geol. Surv. Finland, 11 p.

Elo, S., 1982. Satakunnan kallioperää koskevista gravimetrisistä tutkimuksista. Unpubl. Report. Espoo, Geol. Surv. Finland, 17 p.

Gorbatchev, R., 1967. Petrology of Jotnian rocks in the Gävle area. Sveriges Geologiska Undersökning C 621, 50 p.

Hämäläinen, A., 1985. Satakunnan jotunialueen geologisen karttakuvan historiallinen kehitys sekä uuteen tutkimusaineistoon perustuva kallioperäkarttaluonnos. Unpubl. thesis, University of Helsinki, Department of Geology, 104 p.

Laitakari, A., 1925. Über das Jotnische Gebiet von Satakunta. Bull. Comm. Géol. Finlande 73, 43 p.

Laitakari, I., 1983. The Jotnian (Upper Proterozoic) Sandstone of Satakunta. In: Laajoki, K. and Paakkola, J. (eds.) Exogenic processes and related metallogeny in the Svecokarelian geosynclinal complex. Geologinen tutkimuslaitos — Opas, Geological Survey of Finland — Guide 11, 135—139.

Laurén, L., 1970. An interpretation of the negative gravity anomalies associated with the rapakivi granites and the Jotnian sandstone in southern Finland. Geol. För. Stockholm, Förh. 92, 21—34.

Lundqvist, T., 1990. Beskrivning till bergrundskartan över Västernorrlands län. Sveriges Geologiska Undersökning, Ser. Ba, 31. 429 p.

Marttila, E., 1969. Satakunnan hiekkakiven sedimentaatioolosuhteista. Unpubl. thesis, Dept. Geology, Univ. Turku, 157 p.

Meckel, L.D. 1967 Tabular and trough cross-bedding: comparison of dip azimuth variability. Jour. Sed. Petrol. 37, 80—86.

Miall, A.D., 1973. Markov chain analysis applied to an ancient alluvial plain succession. Sedimentogy 20, 347—364.

Miall, A.D., 1974. Paleocurrent analysis of alluvial sediments: a discussion of directional variance and vector magnitude. Jour. Sed. Petrol. 44, 1174—1185.

Miall, A.D., 1977. A Review of the braided river depositional environment. Earth Sci. Rev. 13, 1—62.

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, A. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 597—604.

Miall, A.D., 1985. Architectural Element Analysis: A New Method of Facies Analysis Applied to Fluvial Deposits. Earth Sci. Rew. 22, 261—308.

Michelson, P.C. & T Dott, R.H., 1973. Orientation analysis of trough cross-stratification in Upper Cambrian sandstones of Western Wisconsin. Jour. Sed. Petrol. 43, 784—794.

Neuvonen, K.J., 1973. Remanent magnetization of the Jotnian sandstone in Satakunta, SW-Finland. Bull. Geol. Soc. Finland 45, 23—27.

Pesonen, L.J., Torsvik, T.H., Elming, S.-Å. & Bylund, G., 1989. Crustal evolution of Fennoscandia — paleomagnetic constraints. Tectonophysics 162, 27—49.

Pihlaja, P., 1987. Porin seudun Subjotuniset diabaasit — The Subjotnian diabases of the Pori region, southwestern Finland. In: Aro, K. and Laitakari, I. (eds.) Suomen diabaasit ja muut mafiset juonikivilajit — Diabases and other mafic dyke rocks in Finland. Geologian tutkimuskeskus — Tutkimusraportti, Geological Survey of Finland — Report of Investigation 76, 133—150.

Potter, P.E. & Pettijohn, F.J., 1977. Paleocurrents and basin analysis, 2nd ed. Berlin, Springer-Verlag. 425 p.

Pullvertaft, T.C.R., 1985. Paleocurrent directions in the lower Dala sandstone, west central Sweden. Geol. För. Stockholm Förh. 107, 59—62.

Reading, H.G. (ed.), 1986. Sedimentary Environments and Facies, 2nd ed. Oxford: Blackwell Scientific Publications. 615 p.

Rust, B.R., 1978. Depositional models for braided alluvium. In: Miall, A.D. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 605—625.

Salop, L.J., 1983. Geological evolution of the earth during the Precambrian. Berlin, Springer-Verlag. 459 p.

Sederholm, J.J., 1893. Om berggrunden i södra Finland. Fennia 8, No. 3. 165 p.

Sederholm, J.J., 1897. Om indelningen af de prekambriska formationerna i Sverige och Finland och om nomenklaturen för dessa äldsta bildningar. Geol. För. Stockholm, Förh. 19, 20—53.

Simonen, A., 1960. Pre-Quaternary rocks in Finland. Bull. Comm. géol. Finlande 191, 49 p.

Simonen, A., 1980. The Precambrian in Finland. Geol. Surv. Finland, Bull. 304, 58 p.

Simonen, A. & Kouvo, O., 1955. Sandstones in Finland. Bull. Comm. géol. Finlande 168, 57—87.

Suominen, V., 1991. The chronostratigraphy of southwestern Finland, with special reference to Postjotnian and Subjotnian diabases. Geol. Surv. Finland, Bull. 356. 100 p.

Vaasjoki, M., 1977. Rapakivi granites and other postorogenic rocks in Finland: their age and the lead isotopic composition of certain associated galena mineralizations. Geol. Surv. Finland, Bull. 294, 64 p.

Vaasjoki, M. & Sakko, M., 1987. Zirkoni-indikaatio Satakunnan hiekkakiven alkuperästä. Summary: A zircon indication on the provenance of the middle Proterozoic Satakunta sandstone, Finland. Geologi 39, 184—187.

Vaasjoki, M., Pihlaja, P. & Sakko, M., 1988. The radiometric age of the Reposaari granite and its bearing on the extent of the Laitila rapakivi batholith in western Finland. Bull. Geol. Soc. Finland 60, Part 2, 129—134.

Walker, R.G. (ed.), 1979. Facies Models. Geoscience Canada Reprint Series 1. Toronto, Geol. Ass. Canada. 211 p.

Winterhalter, B., Flodén, T., Ignatius, H., Axberg, S. & Niemistö, L., 1981. Geology of the Baltic Sea. In: Voipio, A. (ed.), The Baltic Sea. Elsevier Oceanogr. Ser. 30, 1—121.

Appendix 1. Names and locations of outcrops and drilling sites in Figure 4.

Outcrops

A	Tahkoluoto, Pori	x = 6836.50	y = 1520.50
B	Makholma, Pori	x = 6818.56	y = 1531.50
C	Kallionpää, Pori	x = 6816.29	y = 1537.53
D	Metsäkulma, Pori	x = 6815.60	y = 1537.16
E	Knapernummi, Luvia	x = 6810.48	y = 1532.60
F	Markkula (Määrvuori), Luvia	x = 6804.76	y = 1538.13
G	Sahankoski, Luvia	x = 6803.04	y = 1539.50
H	Leistilä, Nakkila	x = 6805.10	y = 1550.95
I	Lammainen, Harjavalta	x = 6803.90	y = 1559.78
J	Saarenmaa (Panelia), Kiukainen	x = 6793.50	y = 1553.05
K	Koomankangas, Kokemäki	x = 6791.60	y = 1566.54
L	Kiperi (Mestilä), Eura	x = 6774.64	y = 1562.25
M	Myllyoja (Kiperjärvenoja), Eura	x = 6774.18	y = 1562.00
N	Lännen tehtaat, Säkylä	x = 6775.29	y = 1567.96
O	Murronmäki, Köyliö	x = 6776.97	y = 1569.67

Drilling localities and depths (m)

1	Enäjärvi, Pori (17.97)	x = 6827.47	y = 1532.82
2	Vanhakylä, Ulvila (14.12)	x = 6814.62	y = 1549.11
3	Lattomerenoja (Pori 1), Pori (618.55)	x = 6815.50	y = 1540.16
4	Pirilä, Harjavalta (12.70)	x = 6806.20	y = 1558.84
5	Vareksela, Harjavalta (24.47)	x = 6800.97	y = 1562.69
6	Näyhälänkangas, Harjavalta (35.75)	x = 6798.01	y = 1563.70
7	Kankaala, Harjavalta (32.70)	x = 6798.56	y = 1564.74
8	Kankaala, Harjavalta (27.00)	x = 6798.39	y = 1565.13
9	Kalmeenkulma, Köyliö (24.42)	x = 6788.00	y = 1566.79
10	Kalmeenkulma, Köyliö (15.46)	x = 6788.23	y = 1567.12
11	Pitkäjärvi, Kokemäki (25.86)	x = 6789.95	y = 1568.11
12	Pitkäjärvi, Kokemäki (145.37)	x = 6790.13	y = 1568.27
13	Sassila, Luvia (31.50)	x = 6808.42	y = 1530.47
14	Sassila, Luvia (23.00)	x = 6807.79	y = 1530.85
15	Hutsaari, Luvia (50.50)	x = 6804.90	y = 1533.89
16	Hallaperä, Luvia (40.70)	x = 6803.59	y = 1533.95
17	Naskalinkallio, Luvia (50.00)	x = 6801.16	y = 1536.74
18	Huhta, Eurajoki (16.90)	x = 6795.23	y = 1544.87
19	Kyydämäki, Kiukainen (29.00)	x = 6790.46	y = 1549.01
20	Kaanaanmaa, Eura (17.07)	x = 6782.15	y = 1561.90
21	Kauttua, Eura (49.68)	x = 6779.61	y = 1563.13
22	Pehkuranta, Yläne (101.10)	x = 6755.56	y = 1575.32

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