Commentationes Physico-Mathematicae
Vol. 42 1972

Trend surface analysis of a raised shoreline of Lake Saimaa, Finland

Matti Saarnisto
Department of Geology and Palaeontology
University of Helsinki

Frank Huhn
Department of Geology
Royal Ontario Museum, Toronto
Department of Botany
University of Toronto

Abstract: Trend surface analysis was used for mapping a 5000 year old shoreline of Lake Saimaa, southeastern Finland. First through sixth degree best fit surfaces were calculated and corresponding isobase maps produced. It is suggested that the shoreline is a little curved in the direction of the greatest tilt, the gradient decreasing towards the southeast.

Introduction

The Saimaa lake complex, following its isolation from the Baltic Sea, at first discharged to the northwest into the Gulf of Bothnia in the direction of the greatest land uplift. As a result of transgression caused by the tilting of the land the outlet channel shifted southward stage by stage. The water at first rose above the western watershed in Matkuslampi and a little later in Kärenlampi (Fig. 1). Then the water level north of the isobase through Matkuslampi began to sink, but during the western outlets stage transgression continued in southern Lake Saimaa until the waters broke through the outer Salpausselkä at Vuoksenniska ca. 5000 years B.P. and the present Vuoksi outlet to Lake Ladoga originated (Hellaakoski 1922, Saarnisto 1970). The shore indicating the limit of transgression in southern Lake Saimaa became dry. It is distinct morphologically and is situated just above the western outlets. This together with stratigraphical and archaeological data indicates that the shoreline is synchronous between the Vuoksenniska and Matkuslampi isobases. The altitude of the shoreline rises regularly to the nortwest from 79.5 m in Vuoksenniska to 87 m in Matkuslampi. The shore altitude has been levelled at ca. 200 points and by placing the observations on a map. regular isobases have been obtained (Fig. 1).

The purpose of this paper is to find a mathematical form for the 5000 year old shoreline of Lake Saimaa by using trend surface analysis and to compare the results to the earlier model. Trend surface analysis has been used in Scotland for mapping of raised shorelines, but in the study of land uplift it did not provide very useful information, because the synchroneity of the shore observations was not clear (see McCann and Chorley 1967). In this sense the material from Lake Saimaa offers a better possibility.

Methods

For trend surface analysis the location of observation points were taken as rectangular x- and y-coordinates of the Finnish topographical system with an accuracy of 0.1 km. The elevations are mainly from Hellaakoski (1922 and 1934) with some points from Lappalainen (1962) and Saarnisto (1970). The altitude of the shoreline (z-coordinate) is taken with an accuracy of 0.1 metres. The x-coordinate gives the distance from equator in kilometres and y-coordinate the distance from central meridian. The value of the y-coordinate to the west of central meridian is 500 minus the distance from the central meridian and to the east 500 plus the distance from the central meridian. Because the observations are in the area of two central meridian (27°E and 30°E), the data consists of two independent parts. The boundary between the areas, meridian 28°30'E, is marked on the map (Fig. 1). There are 99 observation points in the area of the meridian 27°E, all to the east of the meridian and 80 observation points in the area of the meridian 30°E, all to the west of the meridian.

Our program reads the information of x-, y- and z-values in that order only. The data must be taken from an origin at the lower left portion of the map area with positive vectors directed to the right and up. Therefore the y-values are changed so that in the area of both meridians the y-coordinate is taken as a distance from the easternmost point of the area. This means that the y-value used in calculation is 580 minus the y-coordinate in the topographical map in the area of the meridian 27°E and 500 minus the y-coordinate in the topographical map in the area of the meridian 30°E. The origin is in the southeastern corner of the field for both maps.

The trend surface program described by O'Leary et. al. (1966) was used for analysis. The calculations were made with an IBM 370 computer of the Computer Centre of the University of Toronto. The program calculates the best linear, 2nd degree, etc., up to 6th degree fit for the input data and makes contour maps in the size and contour interval desired. The contour lines are the intersection lines of horizontal (z = constant) equally spaced parallel plane surfaces with a calculated surface, which is the best fit surface for the input data. First through 6th degree contour (isobase) maps were produced for both areas in scale 1 : 600,000.

Results

Table 1 gives the coefficients of correlation for the 1st through 6th degree best fit surfaces in the areas of the western (meridian 27°E) and eastern (meridian 30°E) maps. The best fit first degree surface already has a very high degree of correlation, thus, the surface is almost a regular plane. The coefficient of correlation gets smaller in 4th and higher degree surfaces. The reason for this is that a few anomalous points in an almost regular surface will produce a smaller correlation in higher degree surfaces.

Table 1. Coefficient of correlation of 1st through 6th degree surfaces

	1st	2nd	3rd	4th	5th	6th
Meridian 27° E-map	0.9831	*0.9835*	0.9828	0.9797	0.9571	0.9792
Meridian 30° E-map	0.9916	0.9945	*0.9947*	0.9768	0.9473	0.9848

For further analysis only the best fit first, second and third degree surfaces with the highest coefficient of correlation were taken. The difference in the degree of correlation of these surfaces is so small and the coefficients of correlation are so high, that the surfaces can be taken as very reliable. The correlation is a little higher in the area of the eastern map than of the western. The observations on the eastern map also are more regularly spread over the field than on the western map. The isobase maps of the 1st, 2nd and 3rd degree surfaces are presented in Figures 2, 3 and 4. All of them support the earlier views about the present position of the 5000 year old shoreline of Lake Saimaa (Fig. 1). In the comparison of all maps the direction and location of the isobases differ so little, that the difference in the altitude of the shoreline caused by this is at most within 0.5 m, which can be taken as a local fluctuation in shore altitude and thus as a margin of error in shoreline studies on lakes.

The high degree of correlation of the first degree surface (over 98 and 99 per cent) shows, as mentioned above, that the 5000 year old shoreline of Lake Saimaa is almost a tilted plane. The isobases of the western map are at an angle of N 46°E to the 28°30′E meridian and the isobases of the eastern map at a slightly smaller angle, N 44°E. The gradients of the planes differ by 0.1 cm per kilometre (see Table 2).

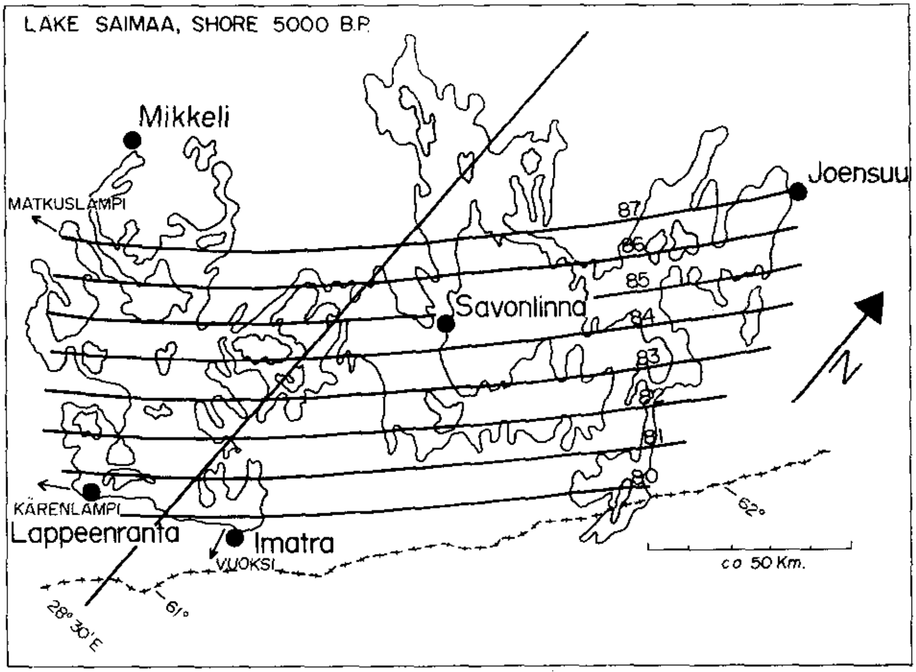

Fig. 1. Isobases for the shoreline of Lake Saimaa 5000 B.P. according to Saarnisto (1970, App. VIII). *Meridian 28°30'E is the boundary between the meridian* 27°E-map area and the meridian 30°E-map area. Altitudes in metres.

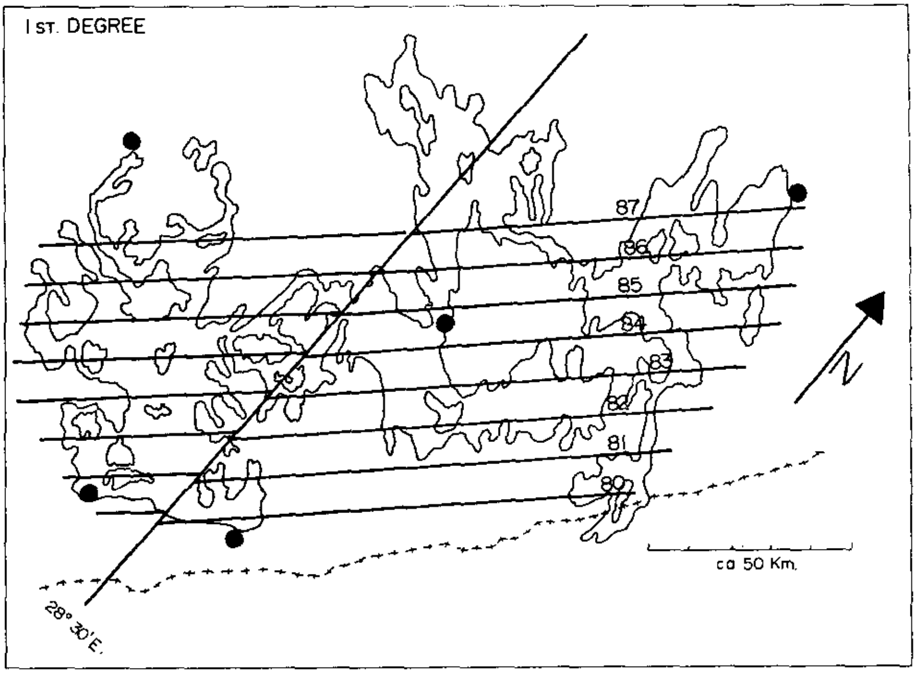

Fig. 2. Best fit first degree surface for the shoreline of Lake Saimaa 5000 B.P.

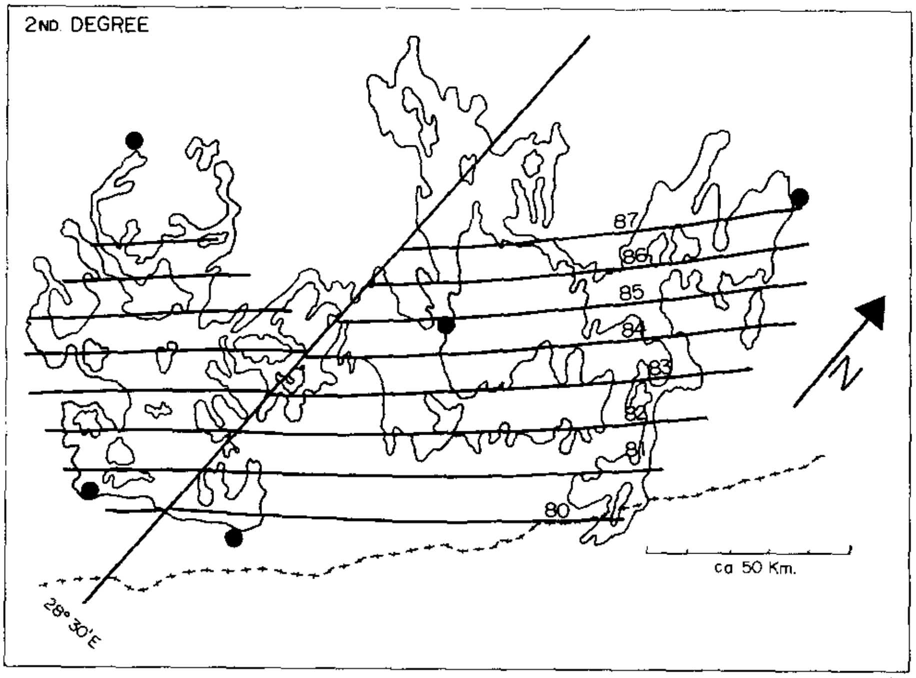

Fig. 3. Best fit second degree surface for the shoreline of Lake Saimaa 5000 B.P.

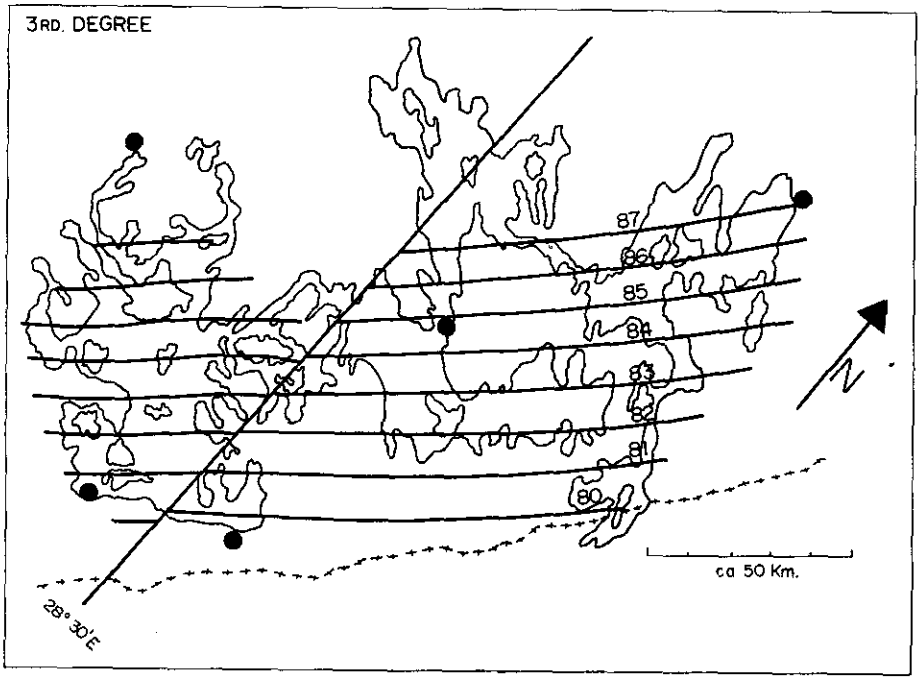

Fig. 4. Best fit third degree surface for the shoreline of Lake Saimaa 5000 B.P.

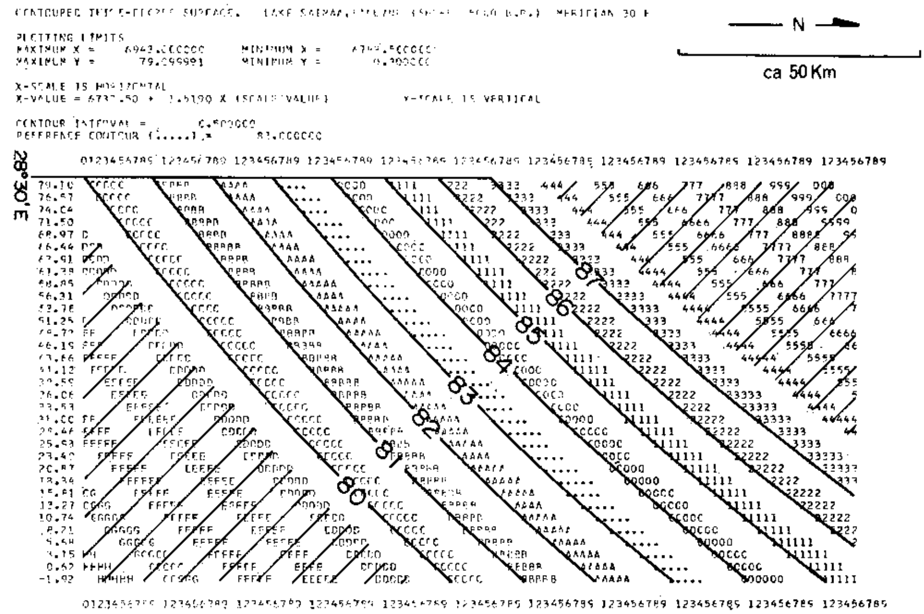

Fig. 5. Best fit third degree surface for the shoreline of Lake Saimaa 5000 B.P. in the area of the meridian 30°E-map. The map given as an example of the computer output has the highest coefficient of correlation (0.9947) of the 12 maps produced.

The best fit 1st degree surface of the meridian 27° E-map has the equation
$Z = -437.18258 + 0.07625\ X + 0.07291\ Y'$
when Z = the shore altitude in metres a.s.l., X = distance from equator in kilometres (= x-coordinate in topographical map), and Y' = 580 minus the y-coordinate in topographical map (in kilometres).

The best fit 1st degree surface of the meridian 30° E-map has the equation
$Z = -422.00497 + 0.07319\ X + 0.07361\ Y'$
when Z and X are as above and Y' = 500 minus the y-coordinate in topographical map (in kilometres).

The isobase maps for the best fit 2nd and 3rd degree surfaces differ only a little and they will be analysed together. In the area of the western map the 2nd degree surface has the highest degree of correlation and in the area of the eastern map the 3rd degree surface has the highest degree of correlation (Fig. 5). There are small irregularities in the isobases of the western maps. This may be caused by a few anomalous points, so they will not be discussed here. In the area of the eastern map, where the coefficients of correlation are also higher, the isobases are regular.

A common feature of 2nd and 3rd degree surfaces is that the distance between isobases gets smaller towards the northwest, that is to say, the

Table 2. Gradients for the shoreline of Lake Saimaa 5000 B.P.

Lake Saimaa shoreline 5000 B.P. (Saarnisto 1970; see Donner 1970)		
Isobases	Gradient	
80—87 m	10.5 cm/km	
Meridian 27° E-map		Meridian 30° E-map
1st degree surface		1st degree surface
80—87 m	10.5 cm/km	10.4 cm/km
2nd degree surface		3rd degree surface
80—81 m	9.8 cm/km	9.5 cm/km
81—82	10.4	9.8
82—83	10.4	10.1
83—84	10.8	10.4
84—85	10.8	11.1
85—86	11.5	11.9
86—87	11.5	11.9

gradient becomes greater. The trend is weak but regular. The steepest change seems to be in the area between the 84 and 86 m isobases. In addition to the maps this can be seen in Table 2, which includes the gradients of the 2nd and 3rd degree surfaces which have the highest coefficients of correlation. The gradients have been measured in the direction of the greatest tilt. The gradients decrease in both map areas at the rate of ca 2 cm/km over a distance of 60—70 km. The change is small, as can be seen also in Fig. 6. The difference in altitude between the earlier determined straight shoreline and the curved line is at most 0.3 m, clearly less than the local variations in the altitude of the shoreline, and it was not taken into account in constructing the earlier diagram. The change in gradients, however, is so regular that it has to be discussed.

There seems to be in southern Lake Saimaa a broad zone in the direction of the isobases, where the shoreline discussed here is a little curved. There is no reason to assume that the land uplift outside this area would follow the mathematical equation which explains the form of the shoreline in southern Lake Saimaa. If, however, we continue to the southeast, to the Lake Ladoga area, by using equal changes in gradient, we get a gradient which corresponds to the maximum gradient (6 cm/km) of the 5000 year old shoreline in the Lake Ladoga area as determined by Saarnisto and Siiriäinen (1970).

In the more central area of uplift northwest of southern Lake Saimaa, no curving in shorelines can be seen although they are longer in the direction of the greatest tilt. As examples can be mention shoreline diagrams from the middle and northern parts of Lake Saimaa, and from the Lake Päijänne area (Saarnisto 1970, App. VII, 1971, Fig. 10), and from south-

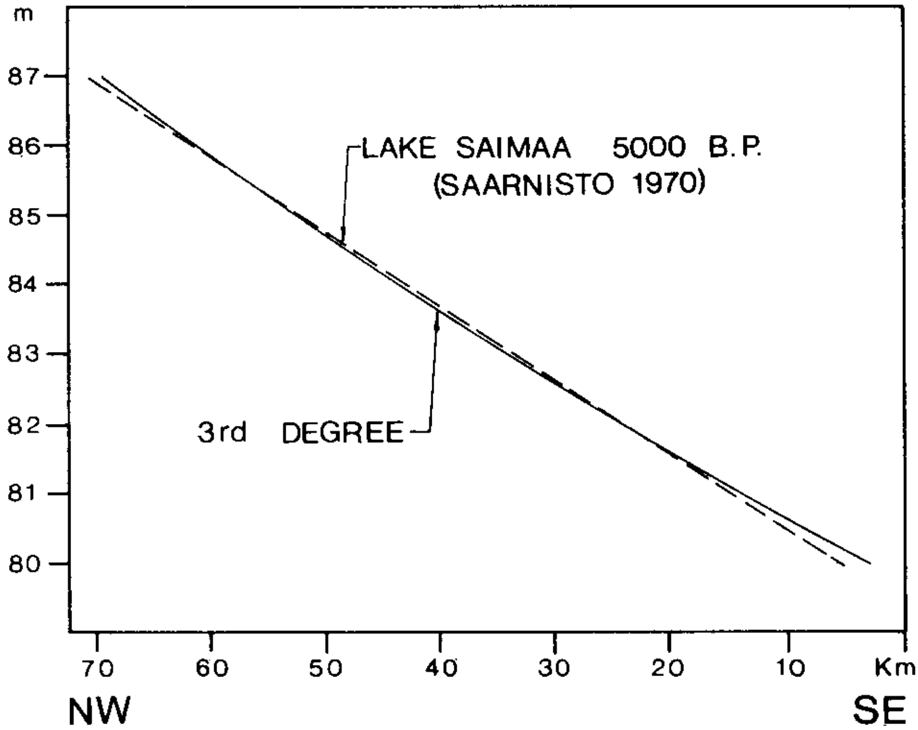

Fig. 6. Distance diagram for the shoreline of Lake Saimaa 5000 B.P. according to Saarnisto 1970 (broken line) and for the best fit 3rd degree surface in the area of meridian 30°E-map. (continuous line).

western Finland (Donner 1969, Fig. 4). The shorelines older than 5000 years in southern Lake Saimaa have been determined within so great a limit of error that no possible curving can be seen.

In a recent study Donner (1969, 1970) discussed the deformation of shorelines in the southeastern part of the Fennoscandian land uplift area. Donner concluded that the shorelines in Estonia and in the area of Lake Ladoga are less tilted than the corresponding shorelines in southern Finland. Between these areas there is possibly a hinge-line or hinge zone, at least 400 km long in the direction of the isobases for the recent uplift from Gulf of Finland to the area southeast of Lake Saimaa. The shorelines drawn as straight lines north and south of this zone can be connected only with curved lines in diagrams. It is possible that the shorelines in the coastal area of southwestern Finland are slightly curved already, but the curving is so weak that it was not detected (Donner 1969, p. 19).

The results in southern Lake Saimaa, thus, show that there is a broad zone rather than a hinge-line in that part of land uplift area, where the

5000 year old shoreline of Lake Saimaa is a little curved. The well developed shoreline indicating the upper limit of the Lake Ladoga transgression is straight (Saarnisto and Siiriäinen 1970). So the zone where the curving of the shorelines is noticeable is situated, in addition to southern Lake Saimaa, in the area north of Lake Ladoga.

Acknowledgements: The authors wish to thank Dr. J. McAndrews, Department of Geology, Royal Ontario Museum, Toronto, and Prof. J. Terasmae, Department of Geological Sciences, Brock University, St Catharines, Ontario, for help and for permission to use the facilities of their departments, and Prof. J. Donner and Dr. H. Hyvärinen for valuable comments on the manuscript. Financial support through a grant to M.S. from the National Research Council for Sciences, Finland, is gratefully acknowledged.

References

DONNER, J., 1969. A profile across Fennoscandia of Late Weichselian and Flandrian shorelines. — Comment. Phys.-Math. 36, 1. 23 pp.

—»— 1970. Deformed Late Weichselian and Flandrian shore-lines in south-eastern Fennoscandia. — Comment. Phys.-Math. 40, p. 191–198.

HELLAAKOSKI, A., 1922. Suursaimaa. Referat: Gross-Saimaa. — Fennia 43, 4. 122 pp.

—»— 1934. Die Eisstauseen des Saimaa-Gebietes. — Fennia 59, 4. 102 pp.

LAPPALAINEN, V., 1962. The shore-line displacement on southern Lake Saimaa. — Acta Bot. Fennica 64, 125 pp.

MCCANN, S. and CHORLEY, R. 1967. Trend surface mapping of raised shorelines. — Nature. Vol. 215, p. 611–612.

O'LEARY, M., LIPPERT, R. and SPITZ, T., 1966. Fortran IV and map program for computation and plotting of trend surfaces for degrees 1 through 6. — Computer contrib. 3, State Geol. Surv., Univ. Kansas.

SAARNISTO, M., 1970. The Late Weichselian and Flandrian History of the Saimaa Lake Complex. — Comment. Phys.-Math. 37, 107 pp.

—»— 1971. The upper limit of the Flandrian transgression of Lake Päijänne. — Comment. Phys.-Math. 41, p. 149–170.

—»— and SIIRIÄINEN, A. (1970) Laatokan transgressioraja. Referat: Die Transgressionsgrenze des Ladogasees. — Suomen Museo 1970, p. 10–22.

Societas Scientiarum Fennica
Communicated 16 October 1972 by J. Donner
Printed December 1972

Keskuskirjapaino—Centraltryckeriet
Helsinki—Helsingfors