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ON THE INFLUENCE OF THE STRUCTURE OF THE EARTH'S CRUST AND THE ICE AGE ON ISOSTATIC EQUILIBRIUM AND LAND UPLIFT IN THE BALTIC SHIELD

BY

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Abstract

A study was made of the compatibility of measured values of land uplift with the differences in mass affecting the isostatic equilibrium calculated from the structural variation observed in the region of the Baltic Shield. The study was further designed to ascertain the extent to which the existence of the continental ice sheet during the Ice Age might have affected the state of this equilibrium.

1. *Land uplift*

The rate of land uplift in Fennoscandia, has received considerable scientific attention. The published data are based both on geodetic research and on studies of lakes and the sea. The entire Baltic Shield is rising. But in the marginal areas the rate of uplift is very slight, while toward the center of the area it increases. In this center, *i.e.*, in the region of the Gulf of Bothnia, the rate of land uplift is as much as 10 mm a year. The available data have been compiled in two publications: *Symposium on recent crustal movements in Finland* [7], edited by T. J. KUKKAMÄKI; and *Proceedings of the second international symposium on recent crustal movements, Aulanko, Finland,* [5], Editorial Board: V. AUER *et al.* In addition, at the most recent ESC meeting, held in Copenhagen L. HIERSEMANN presented: *Rezente vertikale Erdkrustenbewegungen*

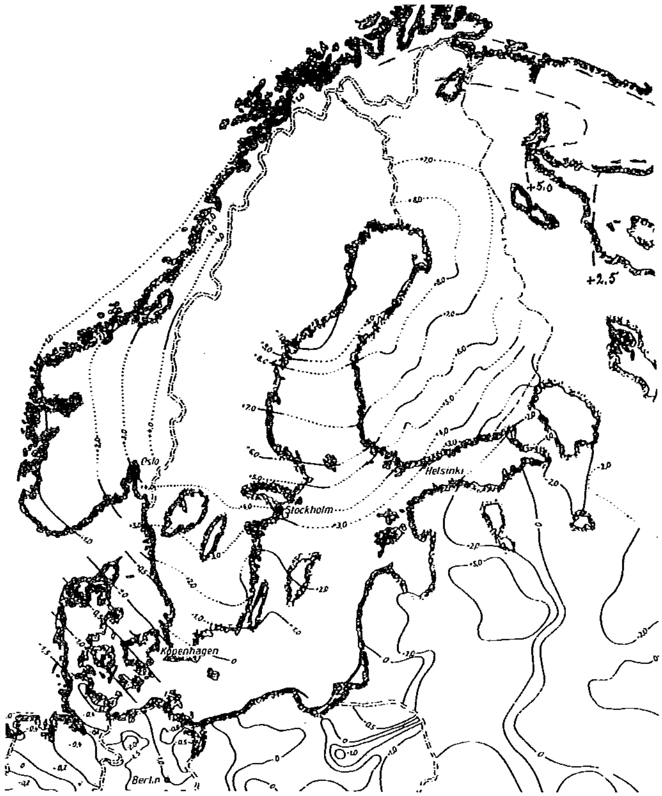

Fig. 1. Land uplift curves in the Baltic Shield (HIERSEMANN [2]).

in Europa (Zusammenfassender Bericht auf der Tagung der Europäisch-Seismologischen Kommission vom 1.—8. August 1966). The results of measurements performed in different areas are given in Fig. 1 (HIERSEMANN, [2]), which shows the annual rate of land uplift in millimeters. The figure has been supplemented by data collected by Russian researchers from the Kola Peninsula. At the most recent CRCM meeting, held in Leningrad May 22—29, 1968, T. J. KUKKAMÄKI presented: *Report on the worck of the Fennoscandian sub-commission, third symposium of the CRCM*, [3]. These results are seen in Fig. 1 a. The Finnish data are presented in Fig. 2. Generally, it is assumed that land uplift in the regions of the Baltic Shield proceeds from the disequilibrium caused by continental ice sheets; but other points of view have also been presented.

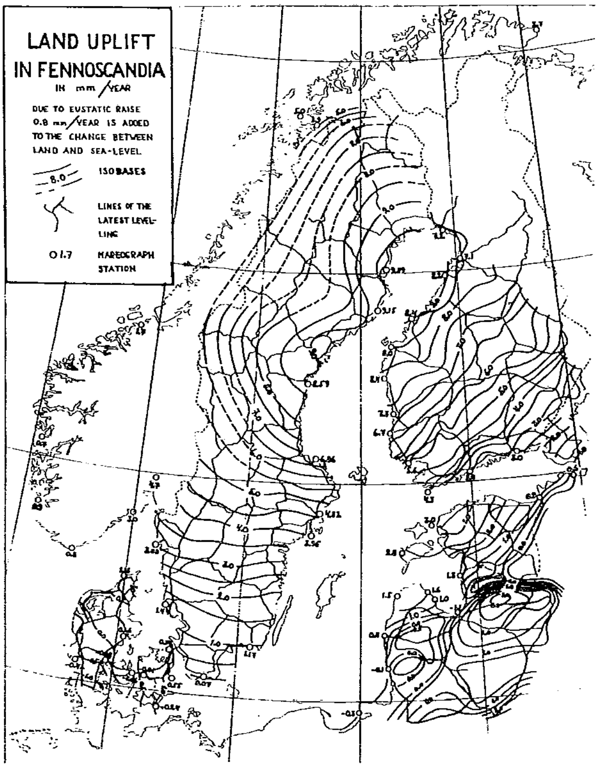

Fig. 1 a. Isobases in Fennoscandia (Kukkamäki [3]).

2. *Crustal structure*

Reports summarizing information on the structure of the earth's crust and on wave velocities in the region of the Baltic Shield have been published by Sellevoll [6] and Penttilä [4]. The latter includes previously unpublished results obtained in recent studies carried out in Finland. These studies indicate that the crust is thickest in the region of the Gulf of Bothnia. The basalt layer appears to be at its thickest along the Skagerak — Gulf of Bothnia — White Sea sequence, whereas the granite layer would seem to thin down from eastern Finland toward the west, *i.e.*, toward the Norwegian coast. More detailed data concerning the thickness of layers 1 and 2 of the crust in the different regions are given in Table 1, which incorporates the values published by Penttilä (*op.cit.*).

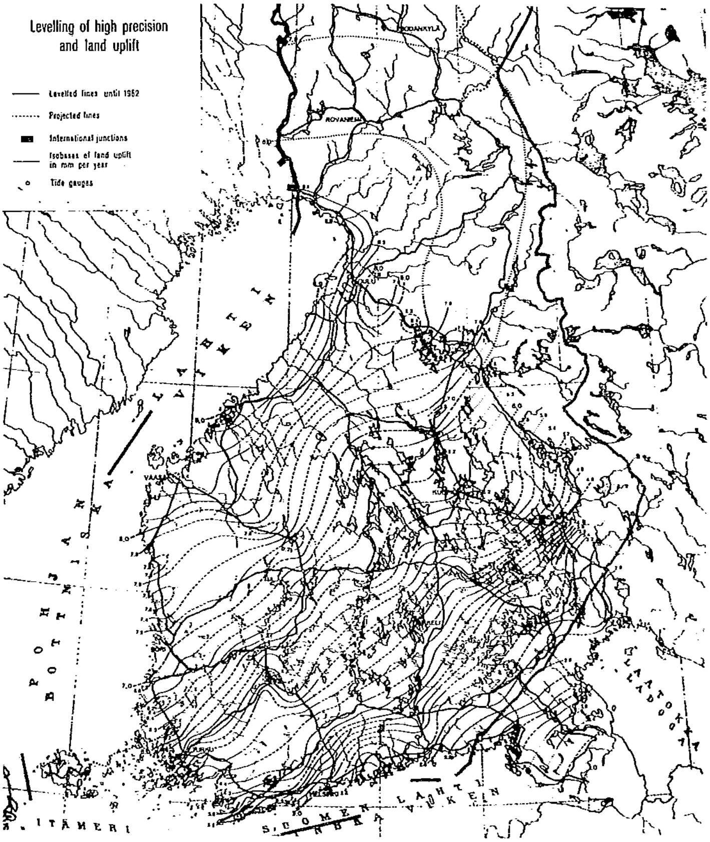

Fig. 2. Land uplift curves in Finland (KÄÄRIÄINEN [5]).

3. *Isostatic equilibrium*

For the study of the isostatic equilibrium, the mass values for each line of investigation were computed by multiplying the layer thicknesses by the mean densities. After HEISKANEN [1] the following values were used as densities: layer 1: 2.67; layer 2: 2.98; under the Moho 3.30. The mass values, thereby obtained, calculated for a constant depth of 42 km, are shown in Table 1. The table also shows that no thickness data are available for considerable sections of this area. The result computed as mass values are marked in Fig. 3, where points of equal value have been joined with curves. The resultant system of curves

Table I. Mass values and average land uplift (mm per annum) obtained along different investigation lines on the basis of the crustal structure, as equalized for a depth of 42 km.

Line		Thickness	Mass values	mm per annum
1	Denmark	8+23=31+11=42	21.4+68.6+36.4=126.4	0
2	Grimstad	17+18=35+ 7=42	45.4+53.7+23.1=122.2	2
3	Fedje	0+32=32+10=42	0.0+95.4+33.0=128.4	1
4	Åsnäs	18+18=36+ 6=42	48.1+53.7+19.8=121.6	4.5
5	Flora	13+23=36+ 6=42	34.7+68.6+19.8=123.1	1.5
6	Bergen	16+ 8=24+18=42	42.7+23.9+59.5=126.1	0
7	Lofoten Is. S	9+21=30+12=42	24.0+62.6+39.6=126.2	0
8	Lofoten Is. N	17+14=31+11=42	45.4+41.7+36.4=123.5	1.5
9	Tromsö	14+19=33+ 9=42	37.4+56.7+29.7=123.8	3
10	Kiruna	19+15=34+ 8=42	50.8+44.7+26.4=121.9	5
11	Central Fennosc.	12+27=39+ 3=42	32.1+80.5+ 9.9=122.5	5
12	Sweden	16+22=38+ 4=42	42.7+65.6+13.2=121.5	6
13	Uhtua USSR	13+24=37+ 4=42	34.7+71.6+16.5=122.8	4
14	Kemi USSR	17+17=34+ 8=42	45.4+50.7+26.4=122.5	3
15	Tromsö—Joensuu	24+16=40+ 2=42	64.1+47.7+ 6.6=188.4	7.5
16	Siipyy—Kajaani	18+24=42+ 0=42	48.1+71.6+ 0.0=119.7	7.4
17	Ahlainen—Tampere	18+24=42+ 0=42	48.1+71.6+ 0.0=119.7	7.4
18	Katanpää—Kajaani	21+17=38+ 4=42	56.1+50.7+13.2=120.0	7
19	Pyhäranta—Porvoo	12+30=42+ 0=42	32.1+89.4+ 0.0=121.5	5.5
20	Katanpää—Luumäki	15+26=41+ 1=42	40.1+77.5+ 3.3=120.9	5.5
21	Katanpää—Hanko	19+18=37+ 5=42	50.8+53.7+16.5=121.0	0
22	Hailuoto—Helsinki	18+18=36+ 6=42	48.1+53.7+19.8=121.6	6
23	Porkkala—Hanko	19+ 8=27+15=42	50.8+23.9+49.6=124.3	3.4
24	Porkkala—Kotka	21+ 8=29+13=42	56.1+23.9+42.9=122.9	2.8
25	Kotka—Nurmijärvi	21+17=38+ 4=42	56.1+50.7+13.2=120.0	3
26	Kuusamo	23+12=35+ 7=42	61.4+36.7+23.1=121.2	6.2
27	Bothnian Bay	19+16=35+ 7=42	50.8+47.7+23.1=121.6	7
28	Sodankylä	19+15=34+ 8=42	50.8+44.7+26.4=121.9	6.1
29	Kuopio	22+ 9=31+11=42	58.8+26.8+36.4=122.0	6.8
30	Kola peninsula	17+25=42+ 0=42	45.4+74.5+ 0.0=119.9	6
31	Kola peninsula	20+22=42+ 0=42	53.5+65.6+ 0.0=119.1	6

represents the relative differences in isostatic equilibrium. The greatest deviations from values obtained along the margins of the entire region occur in the areas of the Gulf of Bothnia and the rapakivi mass of Viipuri.

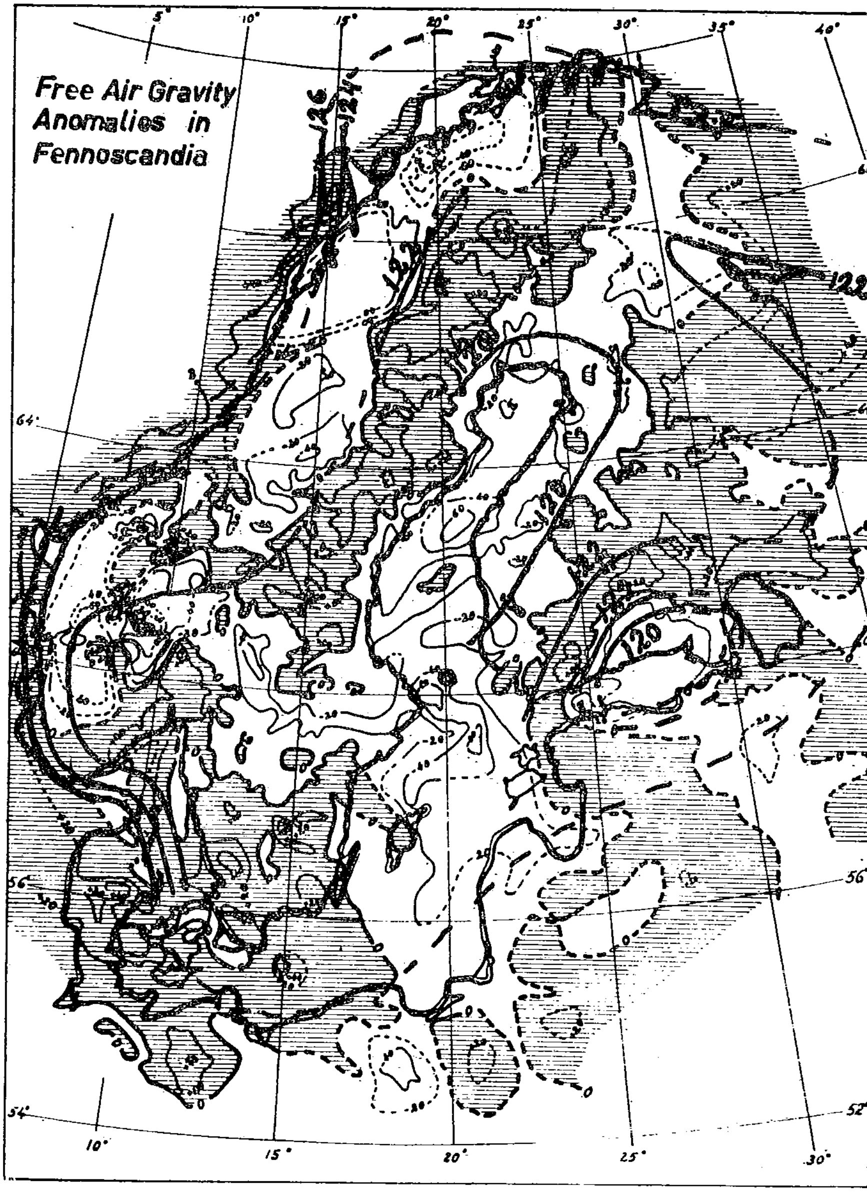

Fig. 3. Mass-value curves in the Baltic Shield based on the values for the crustal structure in different regions.

4. *Comparison of the land uplift, the crustal structure and the isostatic equilibrium*

It appears from Figures 1, 2, and 3 that the curves representing the rates of land uplift conform very well with the curves combining the calculated mass values.

In Figure 4, the means of the mass values computed from different areas are compared with the mean land uplift observed in these areas. Here, too, a clear consistency can be seen between the computed mass values and the rates of uplift. An exception is the result obtained for

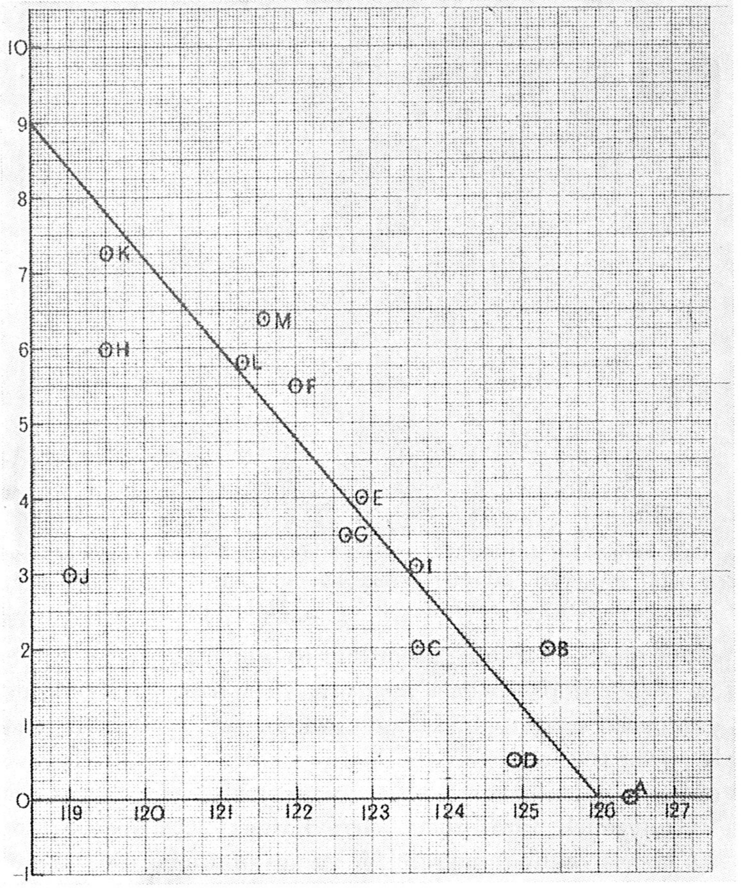

Fig. 4. Mass values in different regions based on the values for the crustal structure (abscissa) and average land uplift (mm per annum, ordinate). Names of areas A-M are shown in Table 2.

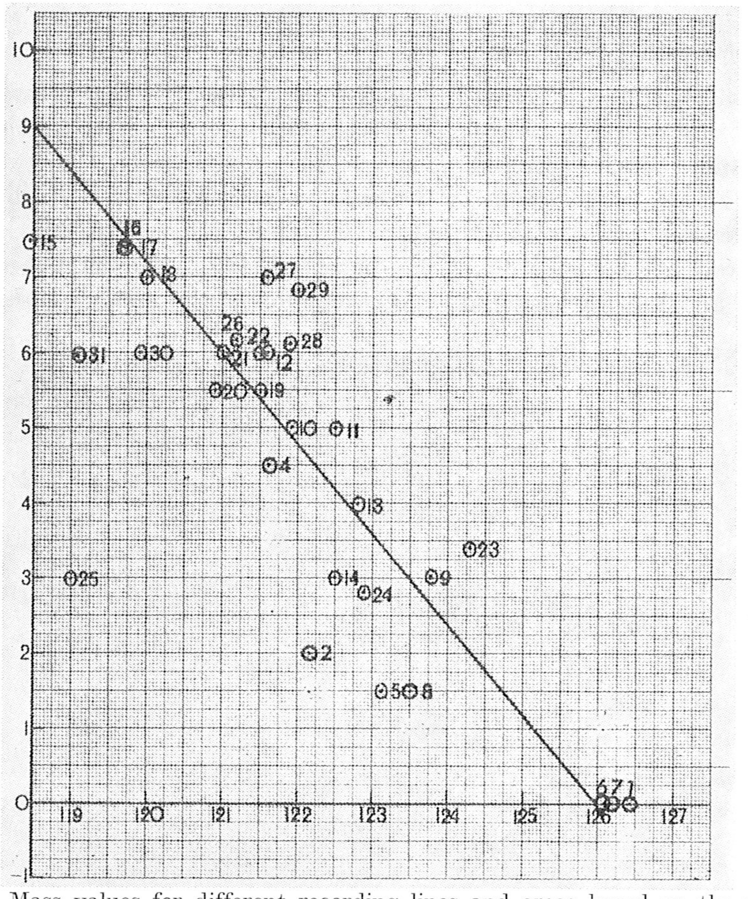

Fig. 5. Mass values for different recording lines and areas based on the values for the crustal structure (abscissa) and average land uplift (mm per annum, ordinate). Sites of recording lines 1—31 are given in Table 1.

the rapakivi mass of Viipuri, according to which the local rate of uplift should be higher than the rate measured. The same lack of consistency is also evidenced by the twists and turns of the land uplift curves and especially from the curves of the higher values, which arch toward the center of the area. The mass-deficient areas are evidently too small to deviate very much from their surroundings with respect to uplift. Fig. 5 is a corresponding diagram for values obtained from the different profiles investigated. The marked deviations from the main trend revealed by this diagram are probably due, at least in part, to errors in the calculations of the crustal structure.

Table 2. Mean values. Mass values obtained in different regions on the basis of the crustal structure and average land uplift (mm per annum).

	Region	Mass value	mm per annum
A	Denmark	126.4	0.0
B	S Norway, bedrock	125.3	2.0
C	S Norway, Caledonian	123.6	2.0
D	Lofoten, Caledonian	124.9	0.5
E	N Norway/Sweden	122.9	4.0
F	Sweden	122.0	5.5
G	Kemi—Uhtua USSR	122.7	3.5
H	Kola peninsula USSR	119.5	6.0
I	Porkkala	123.6	3.1
J	Rapakivi (Kotka)	119.0	3.0
K	Gulf of Bothnia	119.5	7.3
L	S Finland	121.3	5.8
M	N Finland (earthquakes)	121.6	6.4

It will also be noted from Tables 1 and 2 as well as Figs. 1 and 2 that, according to the mass values calculated from earthquake observations made in northern Finland and the explosion-seismic study carried out along the line Kemi-Uhtua, the land uplift ought to be smaller than the value measured in the Kantalahti-Kuusamo zone and greater than that measured in the Kola Peninsula. In this context, however, no detailed consideration will be given to the division of the region into sectors of different types. But it does appear evident that the weak earthquakes that occur in Finland are a consequence of the stress differences between these various sectors, although land uplift takes place mainly in toto, in the shape of a cupola.

5. *Conclusions*

The results seem to indicate that the crustal thicknesses in various areas, ranging from 32 to 42 km (and in the Kola Peninsula possibly up to 50 km), signify considerable differences in isostatic equilibrium.

Taking 0.9 as the density of the ice sheet and using the mass value differences presented in Table 1, it appears that, at equilibrium, the ice layer must have been 5 to 6 km thicker at the center of the Baltic Shield than at its margins. However, geological studies afford no evidence of such great thicknesses of continental ice sheets in the region of the Baltic Shield.

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