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REPORT ON THE 1960 AND 1961 EXPLOSION SEISMIC INVESTIGATIONS OF THE EARTH'S CRUST IN FINLAND

by

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Abstract

The crustal structure project, begun in 1957, was continued in the years 1960 and 1961. Six field operations were carried out. The velocities in the various layers of the crust and the topmost part of the mantle were determined, as well as the thickness of the crust and its different layers.

Introduction

Three explosion seismic investigations have been undertaken previously (Fig. 1). In the summer of 1958 an investigation was carried out on the shore of the Gulf of Bothnia (VESANEN *et al.* [6], PENTTILÄ *et al.* [2]) and in the summer of 1959 on the coast of the Gulf of Finland (PENTTILÄ *et al.* [3]).

Field operations

Recording lines and explosion points of 1960—1961 are shown in Fig. 1 (B—B, C—C, D—D, F—F). The charges were sunk into the sea floor, or the bottom of a small lake, to a depth of 5—30 m, and exploded with electrical detonators. The moment of explosion, signalled to the nearest recording stations by radio, was related to the recording of the other stations by means of chronometers synchronized with BBC time.

The stations of the Coastal Line (Fig. 1, B—B, Table 2) were situated within a region where the terrain principally consists of syncinematic and latecinematic granites and granodiorites. Along the seashore, however, stretching from midway between Hanko and Porkkala to the vicinity of Porvoo in the east there is a narrow zone, parallel to the recording line, containing acid schists and migmatites. The inclination is approximately N80E.

The Viipuri rapakivi area (Fig. 1, Lines C—C, F—F) is a homogeneous large young granite intrusive in SE-Finland. From the records of the stations in the rapakivi area three velocities of P-waves and three velocities of S-waves could be computed. The largest of these corresponds to the velocity in the sial, while the other two correspond to the velocity in its superficial part. The velocities, the intercept times, and the layer thicknesses of the superficial part of the sial, in wich the two slowest waves had travelled, are given in Table 7 and Table 15.

In summer 1960 a seismic field investigation was made on the Muhos formation at Tupos (E—E) (KORHONEN [1]). The recordings were made with a 12-channel apparatus (Elektrisk Malmletning Ab) of a type specially designed for shallow refraction work. The following phase velocities were found from the seismograms (Table 15).

In autumn 1960 a working group participated in an explosion seismic research project carried out by the seismological station of Bergen by organizing three field stations in Northern Finland (G—G), viz. at Kilpisjärvi, Muonio and Rovaniemi (SELLEVOLL, in the press).

Results

Coordinates of explosion points and recording stations are given in Tables 1, 2, 8 and 9, charges in Tables 2 and 8, recording instruments and recording types in Tables 1, 9 and 12, and analyses, velocities and layer thicknesses in Tables 3, 4, 5, 6, 7, 10, 11, 12, 13, 14 and 16.

Three explosion seismic investigations have been undertaken on the coast of the Gulf of Finland. In the summer of 1959 the explosions took place at the western end of the Coastal Line (Porkkala), in the summer of 1960 at its eastern end (Kotka), and in the summer of 1961 in the rapakivi area, also at its eastern end (Hamina). The impulse velocities obtained on the second and third occasions were higher than those obtained on the first occasion (Tables 5 and 16; PENTTILÄ [3]). This indicates that

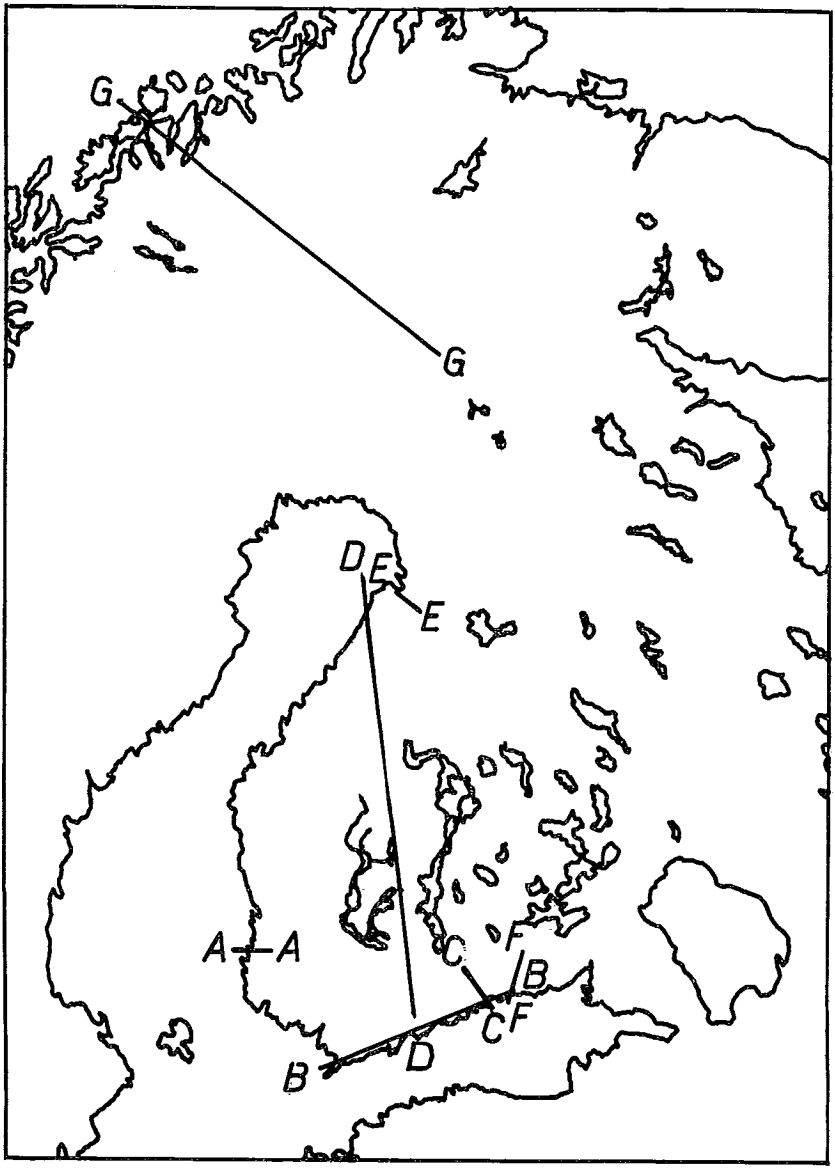

Fig. 1. Explosion seismic investigation lines in Finland in the years 1958—1961.

A—A, Mäntykallo (VESANEN *et al.* [6]; PENTTILÄ *et al.* [2])
B—B, Porkkala, Kotka (PENTTILÄ *et al.* [3], VESANEN *et al.* [7])
C—C, Kotka (VESANEN *et al.* [7])
D—D, Hailuoto (VESANEN *et al.* [7])
E—E, Muhos (KORHONEN [1])
F—F, Hamina (VESANEN *et al.* [7])
G—G, (In cooperation with the seismological station of Bergen)

the layer thicknesses increase eastwards along the line Hanko—Hamina. Results in agreement with these have been obtained from reflexion observations, yielding a value of about 20.7 km for the thickness of the sial at the eastern end of the line, but only 18.4 km to the west of Porkkala. At the western end of the line, within a zero region of the gravitational anomaly, a value of about 29 km was obtained for the total crustal thickness; at the eastern end, where great negative gravitational anomaly (−30 to −40 mgal) has been observed, the corresponding value was about 37 km. Judging from this, in the Viipuri rapakivi region both the sial and the sialma are some kilometres thicker than they are farther to the west, near Hanko, in the region of positive gravitational anomaly.

In the investigation performed in northern Ostrobothnia, where the explosions took place in the northernmost part of the Gulf of Bothnia, the values obtained for the impulse velocities in different layers were also higher than those obtained from the explosions in Porkkala. This also implies greater layer thicknesses, just as does the negative gravitational anomaly of −20 to −30 mgal. In fact, the value for the total crustal thickness, as determined from these explosions, was about 35 km. Two earthquake studies (PENTTILÄ [4] and PORKKA [5]) have given values of the same order of magnitude, viz., 34—36 km. The earthquakes in question occurred in northern Finland and northern Fennoscandia.

The investigations carried out so far suggest that the variations in the thickness of the sial, the mean and the maximum range of variation can be taken as 20 ± 2 km and for the total crustal thickness as 33 ± 4 km. In southern Finland the sial and sialma are thinner than in northern Finland and there may also be local variations in the thickness (VESANEN *et al.* [7]).

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TABLES

Table 1. The stations for the recording of the underwater explosions south of Kotka, their coordinates, distances from the explosion points, instruments, paper speeds and types of recording

Station	Coordinates	Distance km	Equipment	Recording speed mm/sec	Recording type
Coastal Line:					
Norrkulla	60°14′10.0″ N 25°20′25.0″ E	90.51	gf	50	[4])
Helsinki	60°10′32.3″ N 24°57′25.2″ E	112.51	Z	5	[2])
Nurmijärvi	60°30′32.3″ N 24°39′18.1″ E	127.94	Z, N, E	5; 1; 1/2	[2]), [3])
Porkkala	60°00′27.0″ N 24°31′03.0″ E	140.05	Z	5	[2])
Hanko	59°46′19.7″ N 22°57′07.4″ E	231.83	Z	5	[2])
Rapakivi Line:					
Rankki	60°22′34.5″ N 26°57′43.0″ E	6.89	Z	1	[2])
Kiviniemi S	60°27′10.0″ N 26°43′35.0″ E	20.17 20.32 20.47	Z	30	[1])
Kiviniemi M	60°27′34.4″ N 26°43′43.7″ E	20.67 20.82 20.97	H, gf	30	[1])
Kiviniemi N	60°28′00.6″ N 26°43′34.9″ E	21.37 21.52 21.67	Z	30	[1])
Lapinjärvi	60°37′24.0″ N 26°12′21.0″ E	52.92	Z, gf	25	[4])

[1]) Four-channel oscillograph
[2]) Transistorized smoked-paper recording
[3]) Galvanometric photographic recording
[4]) ECG recorder

Table 2. The underwater explosions south of Kotka; the times, explosion sites and sizes of charges.

Shot no.	Date	Time (GMT)	Coordinates	Charge kg
1	3.6.60	08—00—00.5	60°18′55″ N 26°58′06″ E	300
2	»	10—00—03.8	60°19′02″ N 26°58′06″ E	150
3	»	12—00—00.3	60°18′52″ N 26°58′10″ E	70
4	»	14—00—00.8	60°18′55″ N 26°58′06″ E	300

Table 3. Results of the analysis of the seismograms from the underwater explosions south of Kotka, obtained at the stations of the Coastal Line, B—B. Travel times in seconds.

Norrkulla 90.51 km		Helsinki 112.51 km		Nurmijärvi 127.94 km		Porkkala 140.05 km		Hanko 231.83 km	
P_{g2}	14.85	P_{g2}	18.4	P_{g2}	20.90	P_{g2}	22.75	P_n	36.45
	15.05	P_b	19.2	P_b	21.35	P_b	23.25	P_b	37.05
P_{g1}	15.35	C_I	19.7	P_{g1}	21.70	P_{g1}	23.85	P_{g2}	37.60
	15.50		20.3	C_I	22.80		24.40		38.55
P_b	15.75	P_n	22.0		23.30	P_n	25.25		38.95
	15.95	C_{II}	22.8	P_n	23.75		25.70	P_{g1}	39.35
C_I	16.05		25.9	C_{II}	24.80	C_{II}	26.60		40.45
	16.85	C_{III}	26.9		25.40		27.05		41.15
	17.65	S_{g2}	31.8		27.60		27.70	C_{III}	42.65
	18.45	S_b	32.7	C_{III}	29.90		29.50		52.05
P_n	19.35	S_n	35.9		33.40		30.35		56.25
C_{II}	20.05	R_g	36.7		34.50	C_{III}	31.05	S_n	61.45
C_{III}	24.20			S_{g2}	36.50		31.75	S_b	63.15
S_{g2}	26.15			S_b	37.10	S_{g2}	40.05		64.65
S_b	27.55			S_n	39.10	S_b	40.55	S_{g2}	65.75
R_g	29.65				40.80	S_n	41.95		69.25
				R_g	41.70		43.15		71.55
						R_g	45.55	R_g	75.55

Table 4. Results of the analysis of the seismograms from the underwater explosions south of Kotka, obtained at the stations on the Rapakivi Line I, C—C. Travel times in seconds.

	Rankki			Kiviniemi						Lapinj.
Shot	IV	II	IV	III	II	IV	III	IV	III	IV
no.	Z	Z	Z	Z	gf	gf	gf	Z	Z	Z
Dist.										
km	6.89	20.17	20.32	20.47	20.67	20.82	20.97	21.52	21.67	52.90
P_{g2}		3.60	3.61	3.62	3.64	3.65	3.72	3.81	3.82	8.93
P_{g1}				3.71	3.74	3.78	3.80	3.92	3.92	9.38
P_{g0}	1.25	3.72	3.81	3.83		3.85	3.90	4.02	4.02	9.78
			4.05	4.03		4.10	4.07	4.18	4.17	
							4.20	4.28	4.36	
			4.30	4.30	4.31	4.38	4.43		4.50	
		4.43	4.46		4.53			4.57		
		4.73	4.74			4.96	5.08		5.35	
			5.41	5.32		5.47	5.34			
		5.75	5.91			5.87	5.87			
S_{g2}			6.28	6.28	6.37	6.39	6.64	6.60	6.64	15.62
S_{g1}			6.39	6.48	6.51	6.59	6.67	6.80	6.83	16.31
S_{g0}		6.53	6.59	6.67	6.72	6.78	6.84			16.78
		6.83	6.88	7.10	7.18	7.04	7.08	7.22	7.23	
R_g		7.17	7.20	7.22		7.31	7.35	7.65	7.67	17.85
					7.52		7.57			
					9.40	9.52	9.33	9.60	9.80	

Table 5. The velocities (km/sec) of waves, intercept times (sec) and layer thicknesses (km), as computed from the results of the analysis of the records of the underwater explosions south of Kotka (Coastal Line, B—B).

P_{g1}	5.89	T_{01}	0.00	h_1	2.5
P_{g2}	6.21	T_{02}	0.28	h_2	18.0
P_b	6.65	T_{03}	2.50	h_3	17.0
P_n	8.25	T_{04}	8.33	Total	37.5
S_{g2}	3.55	T_{02}	0.46	h_2	19.0
S_b	3.96	T_{03}	4.68	h_3	18.5
S_n	4.67	T_{04}	11.80	Total	37.5

Table 6. The values for the thickness (km) of the sial layer, as determined from the reflexions recorded at different stations in connexion with the underwater explosions south of Kotka.

Station	C_I	C_{II}	C_{III}
Norrkulla	20.8	20.4	19.6
Helsinki		21.1	20.4
Nurmijärvi		20.6	21.9
Porkkala		20.5	20.9
Hanko			20.8
Mean 20.8			

Table 7. The layer thicknesses (km), and the velocities (km/sec) of the waves in the different layers, as determined from the records of the stations on the Rapakivi Line I, C—C.

P_{g0}	5.44	0.00	$h_1 = 1.1$
P_{g1}	5.73	0.14	$h_2 = 0.9$
P_{g2}	6.13	0.28	
S_{g0}	3.20	0.00	
S_{g1}	3.30	0.27	
S_{g2}	3.48	0.42	

Table 8. The underwater explosions west of Hailuoto in the Gulf of Bothnia; the times, explosion sites and sizes of charges.

Shot no.	Date	Time (GMT)	Coordinates	Charge kg
1	13.6.60	22—15—17.6	65°00′20″ N 23°57′50″ E	300
2	16.6.60	09—20—02.4	—»—	1200
3	—»—	12—00—00.0	—»—	900
4	—»—	12—39—59.8	—»—	600

Table 9. The stations that recorded the underwater explosions west of Hailuoto, in the Gulf of Bothnia; their coordinates, distances from the explosion site, instruments, paper speeds and types of recording.

Station	Coordinates	Distance km	Equipment	Recording speed mm/sec	Recording type
Oulu	65°01.1′ N 25°29.1′ E	72.7	Z	60	[1]
Kajaani	64°06.0° N 27°42.0′ E	205.6	Z	300; 60	[1]
Sodankylä	67°22.3′ N 26°37.7′ E	292.5	Z, N, E	60	[1], [2]
Nurmijärvi	60°30.5′ N 24°39.3′ E	505.0	Z, N, E	60	[1], [2]
Kotka	60°22.5′ N 24°57.7′ E	530.0	Z	60	[1]
Helsinki	60°10.5′ N 26°57.7′ E	542.7	Z	60	[1]

[1]) Smoked-paper recording
[2]) Photographic recording

Table 10. Travel times of impulses, as determined from the seismograms of the stations recording the explosions west of Hailuoto in the Gulf of Bothnia.

Oulu 72.7	Kajaani 205.6	Sodankylä 292.6	Nurmijärvi 505.0	Kotka 520.3	Helsinki 542.7
P_{g2} 13.1	P_n 32.3	P_n 42.5	P_n 68.1	P_n 70.0	S_b 148.7
P_b 13.9	P_b 32.9	44.0	70.9	P_b 80.0	S_{g2} 154.0
P_n 16.7	P_{g2} 34.3	P_b 46.7	74.9	P_{g2} 83.1	158.3
S_{g2} 21.1	P_{g1} 35.4	P_{g2} 48.8	P_b 77.5	95.3	
S_{g1} 21.9	53.0	58.5	P_{g2} 83.1	102.3	
S_b 23.1	S_n 57.0	73.3	P_{g1} 87.4	131.3	
25.3	S_b 58.3	S_n 75.3	93.2	S_b 144.0	
S_n 27.1	S_{g2} 59.6	S_b 80.0	116.4	S_{g2} 148.5	
35.5	60.4	S_{g2} 84.7	S_n 119.5	S_{g1} 158.5	
	S_{g1} 61.8	86.5	125.3	162.0	
	63.3	91.2	S_b 137.5	167.3	
	64.3	95.5	S_{g2} 145.3	R_g 175.0	
	R_g 67.0	R_g 100.0	S_{g1} 153.5		
			R_g 171.5		

Table 11. Impulse velocities (km/sec), intercept times (sec) and layer thicknesses (km) as determined from the records of the explosions west of Hailuoto in the Gulf of Bothnia, obtained by seismographic stations in Finland.

P_{g1}	5.80	T_{01}	0.30	h_{1-2}	18
P_{g2}	6.17	T_{02}	1.25	h_3	18
P_b	6.77	T_{03}	3.02		
P_n	8.39	T_{04}	7.86	Total	36
S_{g1}	3.28	T_{01}	0.56	h_{1-2}	13
S_{g2}	3.52	T_{02}	1.04	h_3	21
S_b	3.73	T_{03}	2.95		
S_n	4.69	T_{04}	12.42	Total	34

Table 12. Stations, recording instrument, distances (km) from the explosion points and recording types.

Station		Distance (km) from the lake	Distance (km) from the sea	Equipm.	Recordings speed mm/sec	type
Kettuvuori	I		23.38	gf	400	[1]
»	IV		24.96	gf	400	[1]
»	VI		25.97	gf	400	[1]
Pyhältö	I	53.15	46.49	Z	60	[2]
»	II	52.76	47.96	Z	60	[2]
»	III	51.63	49.10	Z	60	[2]
»	IV	50.26	49.52	gf	60	[2]
Luumäki		29.17	65.51	Z	2	[4]
Lemi	I	7.36	92.12	Z	60	[2]
»	II	6.00	93.38	Z	60	[2]
»	III	4.88	94.54	Z	60	[2]
»	IV	4.27	95.14	gf	60	[2]
Nurmijärvi			142.89	Z	2	[3]
Savonlinna			200.24	Z	5	[3]

[1]) Six-channel prospecting apparatus
[2]) Four-channel oscillograph
[3]) Transistorized smoked-paper recording
[4]) Transistorized ink recording

Table 13. Results of the analyses of the seismograms from the underwater explosions south of Hamina, obtained at all stations. Travel times in seconds.

Stations		Pg2	Pg1	Pg0	Sg2	Sg1	Sg0
Kettuvuori	I	4.33	4.38	4.45			
»	II	4.40	4.47	4.55			
»	III	4.48	4.55	4.62			
»	IV	4.56	4.64	4.73			
»	V	4.60	4.67	4.75			
	VI	4.75	4.82	4.91			
Pyhältö	I	8.30	8.63	8.86	14.46	14.78	15.05
	II	8.35	8.67	8.95	14.22	14.52	14.88
	III	8.57	8.83	9.20	14.72	15.14	15.53
	IV	8.67	8.92	9.33	14.83	15.26	15.62
Luumäki		11.3				19.9	
Nurmijärvi		23.8	25.6		42.1	44.8	
Savonlinna		32.2	34.5		59.2	61.4	
		Pn	Pb		Sn	Sb	Rg
Luumäki					27.8		23.2
Nurmijärvi			24.8		41.3	42.1	50.2
Savonlinna		31.0	31.8		55.3	56.7	70.0

Table 14. Results of the analyses of the seismograms from the explosions at Lemi.

		Pg2	Pg1	Pg0
Lemi	III	0.9	1.1	0.9
	II		1.3	1.1
Luumäki		5.0		5.6
Pyhältö	IV	8.62	8.80	9.28
	III	8.70	8.90	9.50
	II	8.87	9.02	9.73
	I	8.97	9.12	9.97

Table 15. Phase velocities (m/sec) of the Muhos siltstone formation at Tupos.

Direct sound wave through the air	V0	340
Direct longitudinal wave through the overburden	Vi	1100—1900
Direct longitudinal wave through the siltstone	Vs	3000—3600
Direct longitudinal wave through the granitic rock	Vg	~5500

Table 16. Layer thicknesses (km) and velocities (km/sec) recorded from the explosions on the sea bottom at the southern end of the Rapakivi Line II as computed from a) the observations at all stations and b) the observations at the stations within the rapakivi region c) velocities recorded from the explosions in a lake at Lemi as computed from the observations within the rapakivi region.

	a		b		c	
	V	h	V	h	V	h
Pg0			5.40	0.5	5.41	0.5
Pg1	5.79	8.5	5.72	1.0	5.85	1.0
Pg2	6.15	12	6.03		6.02	
Pb	6.61	16				
Pn	8.20					

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