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TEMPORAL VARIATIONS OF ENERGY RELEASE BY EARTHQUAKES IN THE BALTIC SHIELD

by

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Abstract

Recalculated magnitudes according to the unified M_L(UPP) concept for Fennoscandia, and a permanent station network with practically unchanged geographical distribution and instrumental equipment since 1967, provide a homogeneous data set suitable for earthquake frequency statistics and seismic energy release in the Baltic Shield area for the time period 1967–1983.

It is shown that there are significant differences in seismic energy release between the intervals of the time period. This can also be expressed as a variation of *b*-values, *i.e.* low *b*-values for high energy release and high *b*-values for low energy release. Present results may provide additional information for the ongoing discussion of the poorly understood relation between the tectonics and the intraplate seismicity in the region.

1. *Introduction*

The seismicity of Fennoscandia is a typical example of intraplate tectonic activity. In an attempt to elucidate intraplate tectonics in Fennoscandia, HUSEBYE *et al.* (1978) described likely stress generating mechanisms, and gave an interpretation of the seismic data. They described a subdivision of conceivable stress generating sources, namely a connection between the driving forces of plate movements (gravitational ridge push, mantle-drag forces, membrane stresses), and remnant stresses in the lithospere due to accumulation over geological periods (loading and unloading of the lithospere due to Tertiary uplift, recent glacial episodes). ANDERSON (1980) outlines the cause of earthquakes around the Gulf of Bothnia as being due to differential strain between land areas and water covered areas. However, the course of seismic activity in Fennoscandia is still poorly understood. This is quite typical for intraplate earthquake occurrence in general. The present paper includes a homogeneous data set concerning seismic activity in the Baltic Shield. The aim is to provide additional information for the ongoing discussion about the cause of earthquakes in the region.

2. *Data collection*

Difficulties in the compilation of homogeneous and complete earthquake catalogues are well known. Homogeneity of the data requires data from a geographically well distributed station network with unchanged instrumentation. Calculation procedures for epicentral location and magnitude estimates must be established and remain constant throughout the investigation period. The above requirements have been fullfilled since 1966, *i.e.* after the finalization of the permanent station networks in Sweden and Finland. See WAHLSTRÖM and AHJOS (1982) for station locations and instrumental constants. Magnitudes are calculated according to the unified M_L(UPP)-concept developed by WAHLSTRÖM and AHJOS (1982) for the Baltic Shield.

Earthquake data for the period 1967–1979 are obtained from the catalogue by WAHLSTRÖM and AHJOS (1982). The data set from 1980 to 1983 was compiled by Ahjos and Meyer. The frequency of occurrence vs magnitude relation reveals that the data are complete for $M_L(\mathrm{UPP}) \geqslant 2.4$. A similar result is obtained by BÅTH (1979), who gives the magnitude threshold for complete data as $M_L \geqslant 2.3$. For $M_L(\mathrm{UPP}) \leqslant 2.3$, the data are incomplete, which reflects the detectability limits of the present stations. Concequently, we have used the magnitude threshold $M_L(\mathrm{UPP}) \geqslant 2.4$. The contribution to the total energy released from events with $M_L(\mathrm{UPP}) < 2.4$ is minor and can be neglected.

We studied earthquakes occurring in Sweden, Finland and the Baltic Shield area of the USSR, within the tectonic division of WAHLSTRÖM and AHJOS (1982). Within the period 1967–1983, the total number of earthquakes recorded was 225, when $M_L(\mathrm{UPP}) \geqslant 2.4$ (Table 1). All events are also shown in Fig. 1.

Table 1. Earthquakes with M_L(UPP) $\geqslant 2.4$ in Finland, Sweden and the Baltic Shield area of the USSR during 1967–1983.
Crosses (X) in the remarks column denote earthquakes in the Swedish coast of the Gulf of Bothnia.

	Origin time Date Y	M	D	Time H M S	Epicentral location Lat. (°N)	Long. (°E)	Country	M_L(UPP)	Energy (ergs) 10^{16}	Remarks
1	1967	01	04	044418	67.9	21.0	Sweden	3.2	2.31	
2	1967	02	04	153456	59.5	13.3	Sweden	3.7	9.98	
3	1967	04	07	160415	67.4	26.3	Finland	2.4	0.22	
4	1967	04	10	051437	65.1	22.9	Sweden	3.2	2.31	X
5	1967	04	13	084619	68.1	20.8	Sweden	3.7	9.98	
6	1967	04	13	090348	63.2	18.9	Sweden	3.6	7.45	X
7	1967	05	20	231812	66.6	33.7	USSR	5.2	801.68	
8	1967	05	24	161426	67.5	21.1	Sweden	2.4	0.22	
9	1967	06	24	150151	60.8	15.0	Sweden	2.4	0.22	
10	1967	07	22	192220	65.9	26.5	Finland	2.7	0.54	
11	1967	08	16	224451	59.3	13.3	Sweden	2.9	0.96	
12	1967	08	24	231157	64.8	21.3	Sweden	2.5	0.30	X
13	1967	10	09	132922	65.4	22.3	Sweden	2.8	0.72	X
14	1967	10	19	085538	62.4	17.1	Sweden	2.6	0.40	X
15	1967	10	22	074314	61.7	14.1	Sweden	2.5	0.30	
16	1967	11	07	063214	66.0	26.4	Finland	2.6	0.40	
17	1967	11	29	092527	60.6	17.7	Sweden	3.0	1.29	X
18	1967	11	30	114717	59.0	13.6	Sweden	3.2	2.31	
19	1967	12	04	045908	66.6	23.4	Sweden	2.5	0.30	
20	1968	02	06	012733	57.3	12.4	Sweden	2.6	0.40	
21	1968	03	12	073241	58.6	13.5	Sweden	3.1	1.73	
22	1968	03	28	034202	60.5	16.0	Sweden	3.0	1.29	X
23	1968	04	09	111258	66.9	23.0	Sweden	2.5	0.30	
24	1968	06	01	045017	68.3	20.7	Sweden	2.5	0.30	
25	1968	06	01	202959	63.4	21.2	Finland	2.6	0.40	
26	1968	06	13	045000	64.4	20.8	Sweden	2.9	0.96	X
27	1968	08	06	211545	66.0	26.3	Finland	2.6	0.40	
28	1968	09	03	223519	58.5	13.8	Sweden	3.4	4.15	
29	1968	09	04	170914	66.9	23.8	Finland	3.4	4.15	
30	1968	09	08	172347	67.9	19.4	Sweden	2.4	0.22	
31	1968	10	24	201225	69.1	32.7	USSR	3.3	3.10	
32	1968	10	24	201351	69.1	32.7	USSR	3.6	7.45	
33	1968	11	22	073937	66.5	32.6	USSR	2.9	0.96	
34	1968	12	25	152820	68.2	20.3	Sweden	2.8	0.72	
35	1969	01	13	180452	67.7	24.7	Finland	2.5	0.30	
36	1969	02	13	180405	59.4	13.1	Sweden	2.7	0.54	
37	1969	03	24	105927	67.2	26.7	Finland	2.8	0.72	
38	1969	05	10	122855	65.0	34.0	USSR	2.6	0.40	
39	1969	05	23	184025	65.6	27.2	Finland	3.3	3.10	
40	1969	06	12	143159	65.8	29.5	Finland	2.7	0.54	
41	1969	07	04	055836	66.8	31.0	USSR	2.4	0.22	
42	1969	07	04	222854	67.6	19.4	Sweden	3.1	1.73	

Table 1 cont.

	Origin time Date Y	M	D	Time H M S	Epicentral location Lat. (°N)	Long. (°E)	Country	M_L(UPP)	Energy (ergs) 10^{16}	Remarks
43	1969	07	20	070053	67.0	22.9	Sweden	2.8	0.72	
44	1969	09	17	093740	64.7	21.6	Sweden	2.4	0.22	X
45	1969	11	30	082937	65.4	22.8	Sweden	2.5	0.30	X
46	1970	01	06	052552	65.3	31.8	USSR	2.6	0.40	
47	1970	01	23	063701	66.2	32.7	USSR	2.7	0.54	
48	1970	03	24	140429	59.0	13.1	Sweden	2.7	0.54	
49	1970	03	27	195337	65.0	20.9	Sweden	2.4	0.22	X
50	1970	03	28	072805	67.3	23.6	Finland	2.4	0.22	
51	1970	05	04	212729	68.1	20.8	Sweden	2.4	0.22	
52	1970	05	12	141413	61.0	12.8	Sweden	3.2	2.31	
53	1970	05	24	002202	59.8	13.7	Sweden	2.8	0.72	
54	1970	06	14	173352	65.1	22.1	Sweden	3.0	1.29	X
55	1970	08	12	192846	61.5	16.4	Sweden	3.0	1.29	X
56	1970	09	11	223556	65.6	22.5	Sweden	2.6	0.40	X
57	1970	09	24	023045	66.4	29.7	USSR	2.6	0.40	
58	1970	10	02	151622	58.3	17.3	Sweden	2.4	0.22	
59	1970	11	20	093049	61.6	17.6	Sweden	2.6	0.40	X
60	1971	03	12	130250	68.2	27.0	Finland	2.5	0.30	
61	1971	04	09	143545	66.2	33.9	USSR	2.8	0.72	
62	1971	04	17	080503	67.8	22.6	Sweden	3.1	1.73	
63	1971	04	20	233337	64.3	20.8	Sweden	3.1	1.73	X
64	1971	07	01	190414	65.8	35.6	USSR	2.7	0.54	
65	1971	07	10	041213	58.3	13.2	Sweden	2.5	0.30	
66	1971	07	28	232454	62.1	17.3	Sweden	3.1	1.73	X
67	1971	08	13	135013	62.8	20.1	Finland	2.4	0.22	
68	1971	09	07	024137	61.2	17.0	Sweden	2.7	0.54	X
69	1971	09	10	110406	66.6	16.4	Sweden	2.4	0.22	
70	1971	09	11	141625	58.9	12.8	Sweden	2.6	0.40	
71	1971	10	05	115615	62.9	17.9	Sweden	2.7	0.54	X
72	1971	10	06	074249	62.6	18.0	Sweden	2.6	0.40	X
73	1971	10	07	093308	58.6	13.0	Sweden	2.7	0.54	
74	1971	10	10	052906	61.9	21.9	Finland	2.5	0.30	
75	1971	11	25	134650	66.8	22.1	Sweden	2.8	0.72	
76	1971	11	28	063923	65.8	28.2	Finland	2.4	0.22	
77	1971	12	12	000105	66.1	29.1	Finland	2.6	0.40	
78	1972	01	09	185331	65.7	25.8	Finland	2.4	0.22	
79	1972	01	28	131122	65.6	25.4	Finland	2.8	0.72	
80	1972	03	06	160304	64.9	20.5	Sweden	2.4	0.22	X
81	1972	04	19	001830	62.6	17.2	Sweden	2.4	0.22	X
82	1972	05	17	153248	65.2	34.2	USSR	2.7	0.54	
83	1972	06	12	043133	60.1	14.5	Sweden	2.8	0.72	
84	1972	08	20	025235	61.9	16.8	Sweden	3.0	1.29	X
85	1972	09	04	002633	57.1	18.4	Sweden	2.4	0.22	
86	1972	09	25	025534	58.9	13.7	Sweden	2.6	0.40	
87	1972	12	16	100927	63.5	19.7	Sweden	2.8	0.72	X

Table 1 cont.

	Origin time Date Y	M	D	Time H M S	Epicentral location Lat. (°N)	Long. (°E)	Country	M_L(UPP)	Energy (ergs) 10^{16}	Remarks
88	1973	01	07	163511	67.0	31.3	USSR	3.7	9.98	
89	1973	02	13	000517	66.0	18.3	Sweden	3.2	2.31	
90	1973	04	11	050137	58.8	13.4	Sweden	3.9	17.91	
91	1973	04	17	061759	67.9	20.0	Sweden	3.3	3.10	
92	1973	04	25	021710	61.7	17.8	Sweden	2.4	0.22	X
93	1973	07	02	040711	56.2	12.8	Sweden	2.5	0.30	
94	1973	07	22	040256	58.3	13.8	Sweden	3.0	1.29	
95	1973	09	10	214109	65.7	28.8	Finland	2.7	0.54	
96	1973	10	01	164419	60.0	11.9	Sweden	3.0	1.29	
97	1973	10	27	134044	65.0	33.6	USSR	2.5	0.30	
98	1973	11	26	214538	62.9	18.5	Sweden	3.2	2.31	X
99	1973	12	10	200350	66.6	25.9	Finland	3.6	7.45	
100	1973	12	10	200756	66.6	25.7	Finland	2.9	0.96	
101	1974	01	13	182708	63.5	17.1	Sweden	2.7	0.54	X
102	1974	02	05	223359	58.1	14.0	Sweden	2.4	0.22	
103	1974	03	04	134329	65.5	29.3	Finland	2.5	0.30	
104	1974	03	26	121916	61.4	14.7	Sweden	2.4	0.22	
105	1974	05	21	165121	58.3	12.8	Sweden	3.4	4.15	
106	1974	06	04	231351	62.3	17.2	Sweden	3.6	7.45	X
107	1974	06	08	143355	59.1	12.5	Sweden	2.4	0.22	
108	1974	06	21	063108	66.0	27.3	Finland	3.6	7.45	
109	1974	06	30	143852	67.9	19.8	Sweden	2.4	0.22	
110	1974	07	05	161950	57.3	12.1	Sweden	3.0	1.29	
111	1974	07	10	071721	68.0	28.1	Finland	2.8	0.72	
112	1974	07	21	083242	67.5	22.3	Sweden	2.4	0.22	
113	1974	09	12	003122	66.1	21.7	Sweden	2.6	0.40	X
114	1974	09	12	003206	66.1	21.7	Sweden	2.6	0.40	X
115	1974	09	27	173636	64.3	20.6	Sweden	3.0	1.29	X
116	1974	10	28	215629	57.4	12.1	Sweden	2.7	0.54	
117	1974	11	06	052259	65.7	27.3	Finland	2.4	0.22	
118	1974	12	01	193558	67.8	20.1	Sweden	3.2	2.31	
119	1974	12	09	190824	66.1	23.4	Sweden	2.4	0.22	X
120	1975	01	13	153856	65.9	28.4	Finland	2.4	0.22	
121	1975	02	26	103319	65.5	33.3	USSR	2.9	0.96	
122	1975	07	05	173757	64.5	20.7	Sweden	2.4	0.22	X
123	1975	08	11	182809	67.5	22.5	Sweden	3.9	17.91	
124	1975	08	29	044226	65.8	24.6	Finland	2.4	0.22	
125	1975	09	10	134346	65.4	33.8	USSR	2.5	0.30	
126	1975	10	29	074546	64.6	20.9	Sweden	2.4	0.22	X
127	1975	12	13	152955	66.8	22.4	Sweden	2.9	0.96	
128	1976	01	04	150833	64.3	20.9	Sweden	2.8	0.72	X
129	1976	02	17	231250	66.7	29.0	Finland	2.6	0.40	
130	1976	02	19	052902	65.6	29.5	Finland	3.3	3.10	
131	1976	03	12	232221	61.2	17.0	Sweden	3.3	3.10	X
132	1976	03	16	062708	58.7	13.2	Sweden	2.6	0.40	

Table 1 cont.

	Origin time Date Y	M	D	Time H M S	Epicentral location Lat. (°N)	Long. (°E)	Country	M_L(UPP)	Energy (ergs) 10^{16}	Remarks
133	1976	03	29	141439	59.9	12.6	Sweden	3.3	3.10	
134	1976	04	30	125353	64.4	21.1	Sweden	3.1	1.73	X
135	1976	07	03	072601	58.4	13.8	Sweden	2.9	0.96	
136	1976	08	17	053554	62.9	17.8	Sweden	3.5	5.56	X
137	1976	08	17	223248	65.7	22.6	Sweden	2.4	0.22	X
138	1976	08	25	212428	58.9	15.1	Sweden	3.0	1.29	
139	1976	09	03	042800	58.4	13.9	Sweden	3.7	9.98	
140	1976	09	07	152156	59.6	13.4	Sweden	2.8	0.72	
141	1976	09	09	031041	65.2	31.3	USSR	2.8	0.72	
142	1976	10	03	072657	67.8	27.4	Finland	2.6	0.40	
143	1976	10	25	083945	59.3	23.3	USSR	4.9	333.43	
144	1976	12	16	155933	67.9	26.4	Finland	2.5	0.30	
145	1977	01	29	093608	64.3	27.0	Finland	2.6	0.40	
146	1977	04	20	222052	55.6	14.1	Sweden	2.5	0.30	
147	1977	06	01	103848	65.8	30.0	Finland	3.2	2.31	
148	1977	06	01	121639	65.9	29.8	Finland	2.5	0.30	
149	1977	09	05	234021	57.0	13.0	Sweden	3.4	4.15	
150	1977	10	14	034149	67.0	23.4	Sweden	2.9	0.96	
151	1977	11	06	071554	68.2	26.4	Finland	2.5	0.30	
152	1977	11	07	003432	68.8	27.5	Finland	3.5	5.56	
153	1977	11	10	154033	65.6	22.9	Sweden	3.3	3.10	X
154	1978	01	16	022824	67.9	22.6	Sweden	3.2	2.31	
155	1978	04	27	200833	65.1	33.5	USSR	2.4	0.22	
156	1978	07	02	174830	64.0	20.8	Sweden	2.5	0.30	X
157	1978	07	04	164930	63.7	22.0	Finland	2.6	0.40	
158	1978	07	24	152951	67.0	31.0	USSR	2.6	0.40	
159	1978	08	03	111531	66.7	30.2	USSR	2.7	0.54	
160	1978	08	17	130244	69.2	26.8	Finland	2.4	0.22	
161	1978	10	12	212409	64.2	20.4	Sweden	2.5	0.30	X
162	1978	12	14	142448	63.7	21.1	Sweden	2.9	0.96	X
163	1979	01	01	071729	63.5	16.0	Sweden	2.5	0.30	
164	1979	02	17	173122	63.2	23.9	Finland	3.8	13.37	
165	1979	02	17	174058	63.2	23.9	Finland	2.6	0.40	
166	1979	04	02	124034	62.2	17.5	Sweden	2.5	0.30	X
167	1979	05	07	062022	68.1	26.3	Finland	2.5	0.30	
168	1979	08	15	180828	61.7	16.4	Sweden	2.5	0.30	X
169	1979	09	06	170819	65.2	19.4	Sweden	2.4	0.22	
170	1979	10	10	074418	68.5	24.3	Finland	2.9	0.96	
171	1979	11	11	235814	61.1	16.9	Sweden	2.4	0.22	X
172	1979	12	21	084854	67.5	22.0	Sweden	2.5	0.30	
173	1979	12	23	140913	59.6	18.7	Sweden	3.1	1.73	X
174	1979	12	23	141241	59.6	18.7	Sweden	2.6	0.40	X
175	1979	12	24	221019	64.2	20.0	Sweden	2.4	0.22	X
176	1980	01	09	012453	59.0	22.7	USSR	2.5	0.30	
177	1980	03	17	221554	66.5	28.8	Finland	2.5	0.30	
178	1980	04	11	041911	57.9	12.1	Sweden	2.7	0.54	

Table 1 cont.

	Origin time Date			Time	Epicentral location			M_L(UPP)	Energy (ergs)	Remarks
	Y	M	D	H M S	Lat. (°N)	Long. (°E)	Country		10^{16}	
179	1980	04	20	042238	66.4	23.1	Sweden	2.5	0.30	
180	1980	05	24	030252	58.8	18.3	Sweden	2.4	0.22	
181	1980	05	28	103645	67.7	24.5	Finland	3.1	1.73	
182	1980	07	29	093222	68.6	23.6	Finland	2.5	0.30	
183	1980	09	09	080749	67.7	22.6	Sweden	2.5	0.30	
184	1980	09	13	075957	64.6	20.7	Sweden	2.6	0.40	X
185	1980	09	29	020215	66.2	23.7	Sweden	2.5	0.30	
186	1980	11	25	023952	58.4	13.8	Sweden	2.6	0.40	
187	1981	02	13	063911	58.9	13.9	Sweden	3.3	3.10	
188	1981	02	20	183122	60.2	15.9	Sweden	2.5	0.30	X
189	1981	02	26	174352	60.2	16.0	Sweden	2.4	0.22	X
190	1981	03	05	072033	66.9	24.2	Finland	2.4	0.22	
191	1981	04	10	194336	68.8	36.0	USSR	4.5	103.51	
192	1981	05	22	034230	65.5	23.4	Sweden	2.9	0.96	X
193	1981	06	03	141038	64.2	37.5	USSR	2.5	0.30	
194	1981	06	22	185319	59.7	22.6	Finland	3.1	1.73	
195	1981	06	22	192740	59.7	22.6	Finland	2.6	0.40	
196	1981	07	04	094752	65.0	21.0	Sweden	2.8	0.72	X
197	1981	07	10	151011	63.6	16.7	Sweden	2.5	0.30	X
198	1981	08	09	102918	68.4	24.0	Finland	2.4	0.22	
199	1981	08	17	130917	67.5	21.9	Sweden	2.6	0.40	
200	1981	08	21	125457	63.8	37.6	USSR	2.8	0.72	
201	1981	10	30	095256	55.7	13.9	Sweden	2.8	0.72	
202	1981	11	11	024852	57.1	13.1	Sweden	2.9	0.96	
203	1981	11	11	120301	62.5	17.5	Sweden	2.8	0.72	X
204	1981	11	15	230303	67.4	32.5	USSR	2.4	0.22	
205	1982	01	31	033851	68.7	23.2	Finland	3.1	1.73	
206	1982	02	03	070843	67.3	24.0	Finland	2.7	0.54	
207	1982	02	15	065528	61.6	17.3	Sweden	2.5	0.30	X
208	1982	03	24	145540	66.8	27.2	Finland	2.5	0.30	
209	1982	06	04	132929	67.8	19.7	Sweden	2.6	0.40	
210	1982	06	19	070051	66.5	30.6	USSR	2.6	0.40	
211	1982	06	30	171512	55.9	15.4	Sweden	2.8	0.72	
212	1982	07	21	045947	60.9	26.3	Finland	2.9	0.96	
213	1982	10	08	052856	64.5	20.7	Sweden	2.9	0.96	X
214	1982	10	22	174420	66.9	20.3	Sweden	2.4	0.22	
215	1983	01	04	205104	68.6	22.9	Finland	3.4	4.15	
216	1983	04	07	035444	66.9	26.4	Finland	2.7	0.54	
217	1983	04	18	092639	66.4	21.9	Sweden	2.7	0.54	
218	1983	05	15	142419	65.6	27.5	Finland	2.8	0.72	
219	1983	06	18	124344	64.3	20.8	Sweden	3.0	1.29	X
220	1983	07	12	190430	58.1	14.6	Sweden	2.8	0.72	
221	1983	08	18	060608	65.4	22.5	Sweden	2.4	0.22	X
222	1983	08	25	233632	63.3	22.6	Finland	2.6	0.40	
223	1983	09	11	094739	66.8	31.0	USSR	2.8	0.72	
224	1983	09	29	050325	63.8	17.5	Sweden	4.1	32.14	
225	1983	11	26	123338	65.9	28.5	Finland	2.9	0.96	

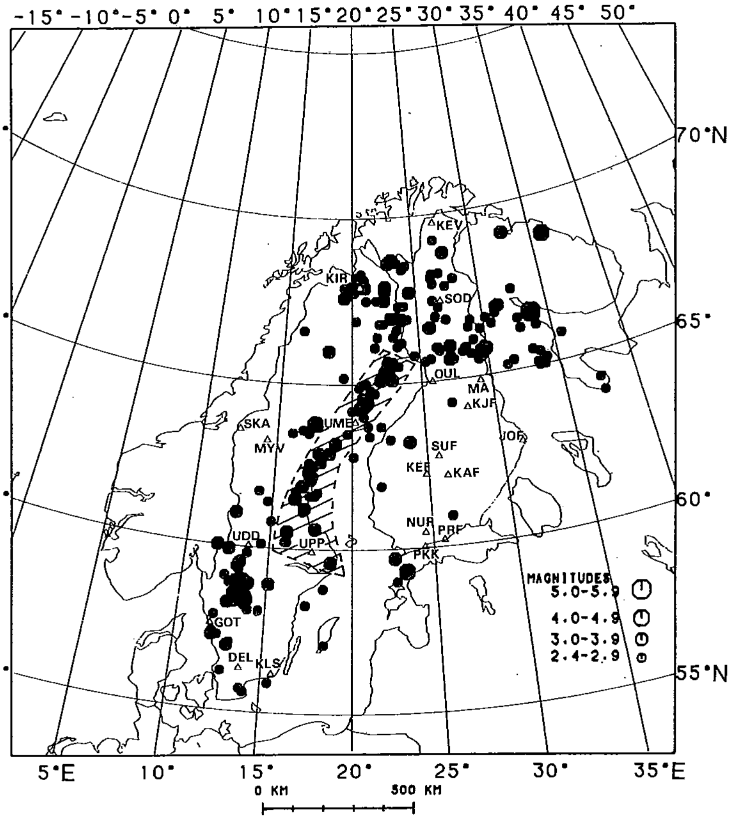

Fig. 1. Earthquakes with M_L(UPP) ⩾2.4 during the period 1967–1983 in Sweden, Finland, and the Baltic Shield area of the USSR. The Swedish coast of the Baltic Sea between latitudes 59.4°–66.1°N (shaded area), includes 27 % of all events. Triangles show seismic stations employed and corresponding station name abbreviations.

3. *Seismic energy release and corresponding b-values*

Calculations of *b*-values are carried out for consecutive time intervals employing the well-known formula

$$\log N = a - b\,M_L(\mathrm{UPP}), \qquad (1)$$

where N = number of earthquakes and a, b = constants.

Time intervals of 5 years were found by trial-and-error to provide a sufficient number of events for the computation of b. Magnitude intervals of 0.3 units are used. The number of earthquakes within time intervals is roughly constant: about

Table 2. Seismic energy release and b-values for different time intervals.

Time interval ΔT	Number of earthquakes within ΔT	Seismic energy (10^{16} ergs)		b-value *
1967–1971	76 (77)	96.18	(897.86)	0.86 ±0.13
1968–1972	68	61.25		1.25 ±0.14
1969–1973	66	82.68		1.06 ±0.14
1970–1974	74	102.29		1.00 ±0.19
1971–1975	68	114.14		0.82 ±0.18
1972–1976	66 (67)	135.29	(468.72)	0.70 ±0.06
1973–1977	65 (66)	147.40	(480.83)	0.65 ±0.10
1974–1978	61 (62)	105.10	(438.53)	0.87 ±0.13
1975–1979	55 (56)	95.74	(429.17)	0.89 ±0.14
1976–1980	58 (59)	79.79	(413.22)	0.86 ±0.21
1977–1981	59 (60)	59.33	(162.84)	1.20 ±0.15
1978–1982	60 (61)	48.47	(151.98)	1.44 ±0.19
1979–1983	62 (63)	85.21	(188.72)	1.13 ±0.14
1967–1983	222 (225)	339.71	(1578.33)	0.98 ±0.07

* b-values are calculated according to the formula (1): $\log N = a - b\, M_L$(UPP). Numbers in parenthesis include magnitude ⩾4.5 earthquakes (May 20, 1967, Oct. 25, 1976 and Apr. 10, 1981). These earthquakes occurred in the Baltic Shield area of the USSR and are not included in the computation of b. The two maxima and minimum are underlined.

65 events per interval (see Table 2). On the other hand, computed b-values (Table 2 change significantly, from $b = 0.65 \pm 0.10$ to $b = 1.44 \pm 0.19$ for different time periods. This rather large fluctuation of b-values around $b = 0.98 \pm 0.07$ for the whole data set reflects different magnitude distributions within the investigated time intervals. In Fig. 2, the distribution of magnitudes for three time intervals, which provide extreme values of b (two maxima and one minimum underlined in Table 2) are shown. It is obvious (Fig. 2) that the intervals 1968–1972 ($b = 1.25$), 1973–1977 ($b = 0.65$) and 1978–1982 ($b = 1.44$) reveal quite varying magnitude contents.

Seismic energy (E) released has been calculated from a formula according to Båth *et al.* (1976):

$$\log E = 12.30 + 1.27\, M_L(\text{UPP}), \qquad (2)$$

E is expressed in ergs and is given in Table 2 for consecutive five-year intervals sliding by one year. The negative correlation between seismic energy released and b-values can be clearly seen (Table 2, Fig. 3). A small energy release corresponds to large b-values, and vice versa due to the magnitude distribution within the time intervals.

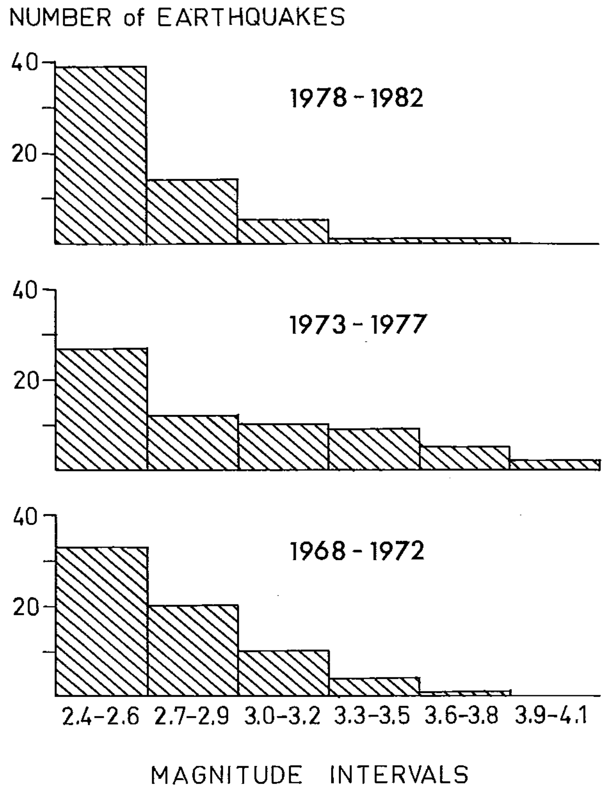

Fig. 2. Number of earthquakes for different magnitude intervals, and for three different time periods corresponding to the maxima and minimum of *b*-values in Table 2.

Changes in energy release for different time periods are quite significant. The question arises whether these changes occur within the entire Baltic Shield, or whether regional variations of seismic energy release should be considered. This has been tested for a part of the Baltic Shield, namely, within the seismic belt along the Swedish coast of the Gulf of Bothnia between latitudes 59.4°–66.1°N (see Fig. 1), an area which includes about 27 % of the total number of earthquakes (1967–1983) considered in this study. Comparing the entire region with the subregion along the Swedish coast, specified above, we can see that the corresponding energy release curves per time interval resemble each other (see Table 2 and Fig. 3). In other words, the temporal changes of seismic activity in the subregion follow in general the temporal changes of the seismicity of the whole area.

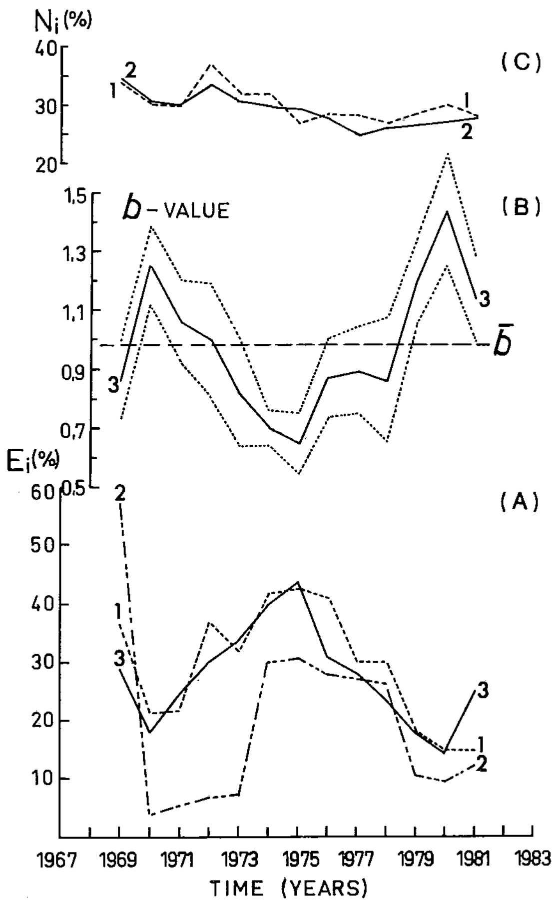

Fig. 3. A) Relative energy E_i (%) for consecutive time intervals, plotted at the middle of each 5-year interval which slide by one year. E_i is the ratio of the seismic energy of each interval to the total seismic energy. 1 denotes the subregion, *i.e.* the Swedish coast of the Baltic Sea (shaded area in Fig. 1), 2 denotes the Baltic Shield and 3 denotes the Baltic Shield excluding the three large events in the northwestern area of the USSR (May 20, 1967, Oct. 25, 1976 and Apr. 10, 1981).

B) b-values with standard deviations (dotted lines) (Table 2). The dashed line gives the mean, $\bar{b}$ = 0.98.

C) Relative number of earthquakes N_i (%). N_i gives the ratio of the number of earthquakes in each time interval to the total number of earthquakes during 1967–1983. 1 denotes the subregion, *i.e.* the Swedish coast of the Baltic Sea (dashed line) and 2 denotes the Baltic Shield.

Table 3. Seismic energy, E (10^{16} ergs), and relative seismic energy, RE = E/E_t (%), number of events, N, and relative number of events, RN = N/N_t (%), per time interval.

E1, RE1, N1, RN1: for the subarea, *i.e.* the Swedish coast of the Gulf of Bothnia between 59.4°N–66.1°N.

E2, RE2, N2, RN2: for the Baltic Shield (see Fig. 1). Numbers are in parenthesis.

E3, RE3, N3, RN3: for the Baltic Shield excluding the three events with M_L (UPP) ⩾4.5. in northwestern USSR.

Time int.	E1	E3 (E2)	N1	N3 (N2)	RE1	RE3 (RE2)	RN1	RN3 (RN2)
1967–1971	23.78	96.18 (897.86)	20	76 (77)	36.6	28.3 (56.9)	33.3	34.2 (34.2)
1968–1972	13.76	61.25	18	68	21.2	18.0 (3.9)	30.0	30.6 (30.2)
1969–1973	14.04	82.68	18	66	21.6	24.3 (5.2)	29.7	29.7 (29.3)
1970–1974	23.82	102.29	22	74	36.6	30.1 (6.5)	36.7	33.3 (32.9)
1971–1975	20.66	114.14	19	68	31.8	33.6 (7.2)	31.7	30.6 (30.2)
1972–1976	27.05	135.29 (468.72)	19	66 (67)	41.6	39.8 (29.7)	31.7	29.7 (29.8)
1973–1977	27.70	147.40 (480.83)	16	65 (66)	42.6	43.4 (30.5)	26.7	29.3 (29.3)
1974–1978	26.73	105.10 (438.53)	17	61 (62)	41.1	30.9 (27.8)	28.3	27.5 (27.6)
1975–1979	19.60	95.74 (429.17)	17	55 (56)	30.1	28.2 (27.2)	28.3	24.8 (24.9)
1976–1980	19.56	79.79 (413.22)	16	58 (59)	30.1	23.5 (26.2)	26.7	26.1 (26.2)
1977–1981	11.45	59.33 (162.84)	17	59 (60)	17.6	17.5 (10.3)	28.3	26.6 (26.7)
1978–1982	9.61	48.47 (151.98)	18	60 (61)	14.8	14.3 (9.6)	30.0	27.0 (27.1)
1979–1983	9.56	85.21 (188.72)	17	62 (63)	14.7	25.1 (12.0)	28.3	27.9 (28.0)
1967–1983	65.03	339.71 (1578.33)	60	222 (225)				

E_t = total seismic energy release during 1967–1983.
N_t = total number of earthquakes, M_L(UPP) ⩾2.4, during 1967–1983.

4. *Discussion*

The present data analysis reveals significant temporal changes of seismic energy release, which can also be expressed as a change of the *b*-values (Fig. 3). Unfortunately, the length of the time window, 1967–1983 (16 years), is rather short, due to the requirement of a homogeneous data set. The period of the observed (energy or *b*-value) variation is about ten years, with a low seismic energy release (high *b*-value) around 1970–1971 and 1980–1981, and a high energy release (low *b*-value) for the time interval 1973–1977. The present data cover a total of only 16 years and, therefore, does not permit any conclusions outside the time period used. On the other hand, it seems reasonable to assume that energy release variations, due to temporal changes of stresses generated in the region, may vary considerably within shorter (decennial) time periods, as have been observed also in other regions (HATTORI, 1975, CARRICK & GIBOWICZ, 1983). An indication of a drop of the *b* -values (increase of seismic energy release) in the Baltic Shield area for the present time period can be seen from the results obtained here and also from the occurrence of a large earthquake, M_L(UPP) = 4.1, on September 29, 1983, in Ångermanland, Sweden.

The course (triggering) of earthquakes in the Baltic Shield area is certainly not easy to explain. Two results obtained here may be worthwhile mentioning. Firstly, temporal changes of seismic energy release in the subregion follow the tendency for the whole area. This implies that local stress-generating forces within the Baltic Shield area are not very likely to influence the seismicity as a whole. Secondly, the significant change of the energy release in general is possibly an effect of a more complex stress accumulation process, involving stress generating sources: the driving forces of plate movements and the remnant stresses in the lithosphere.

5. *Conclusions*

1. For a time period of 16 years with a homogeneous data set, we find a significant variation of seismic energy release and *b*-values, lasting a 10-year period within the area of the Baltic Shield.

2. Temporal changes of seismic energy release in a subregion, *i.e.* the seismic belt along the Swedish coast of the Baltic Sea, generally follow the changes of seismic energy release in the whole area of the Baltic Shield. This may suggest that local stress-generating forces, *e.g.* the land-uplift maximum observed in the subregion (ANDERSON, 1980), have a minor impact on the seismicity of the Baltic Shield.

3. Correlation with other geophysical data, employing, *e.g.* fault plane solutions and a longer time periods, will certainly improve the understanding of the *b*-value variation and associated tectonic forces in the region.

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