NORSAR

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Scientific Report No. 2-78/79

SEMIANNUAL TECHNICAL SUMMARY

1 October 1978—31 March 1979

By
H. Gjøystdal (Ed.)

Kjeller, 30 April 1979

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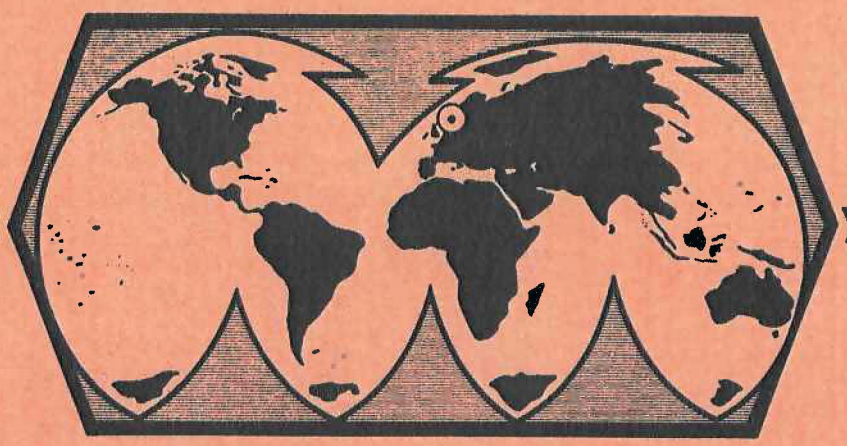

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This report describes the operation and research activities at the Norwegian Seismic Array (NORSAR) for the period from 1 October 1978 to 31 March 1979.

The performance of the NORSAR online DP system has changed very little from the previous reporting period; the uptime was 94.1% as compared to 93.7% for the foregoing half year. The number of stops related to the SPS has increased with more than 50%, however, very few stops lasted for

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several hours. The Event Processor has continued its production of a monthly seismic bulletin; an average of 7.9 events/day have been reported, which is a normal winter-time decrease from 10.8 events/day reported in the foregoing 6 months. The operation of the data center has been characterized by an increased load on the B-computer, which has in many cases forced the users to run their research jobs outside office hours.

Some changes have been made in the operation routines in order to obtain a better utilization of the computer. The performance of the array's communication systems has been approximately the same as in the previous period; 24 outages were observed. As to the ARPA network, the operation can be characterized as reliable, although a few irregularities occurred. A modification of the On-line Event Processor algorithm was introduced 15 January, reducing the problem with 'missing detections'. There has been no modification in the array instrumentation, but the AM personnel have spent a lot of time on the planning and construction of the seismic network in southern Norway. The procedures and criteria for saving NORSAR data permanently have been reconsidered and some important changes have been made. The array instrumentation characteristics have been very stable in the period, with few faults or out of tolerance conditions.

The research activities are described in 6 separate subsections of the last chapter in this report. The first subsection is related to Fennoscandian seismicity 1954-1978 and discusses hypocentral distribution and focal mechanisms. The second one describes an exceptional earthquake sequence in Meløy, Northern Norway, which was observed during 10 weeks from mid-November 1978. The third work deals with a planned digital microearthquake network in southern Norway, and the fourth with microearthquake results from the Stiegler's Gorge seismic network in Tanzania. The fifth subsection discusses crustal thicknesses in Fennoscandia on the basis of spectral ratios found from vertical and radial long-period components of P-wave recordings and the last subsection deals with the propagation of Lg, Li and Sn phases in Eurasia.

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I. SUMMARY

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The performance of the NORSAR online DP system has changed very little from the previous reporting period; the uptime was 94.1% as compared to 93.7% for the foregoing half year. The number of stops related to the SPS has increased with more than 50%, however, very few stops lasted for several hours. The Event Processor has continued its production of a monthly seismic bulletin; an average of 7.9 events/day have been reported, which is a normal winter-time decrease from 10.8 events/day reported in the foregoing 6 months. The operation of the data center has been characterized by an increased load on the B-computer, which has in many cases forced the users to run their research jobs outside office hours.

Some changes have been made in the operation routines in order to obtain a better utilization of the computer. The performance of the array's communication systems has been approximately the same as in the previous period; 24 outages were observed. As to the ARPA network, the operation can be characterized as reliable, although a few irregularities occurred. A modification of the On-line Event Processor algorithm was introduced 15 January, reducing the problem with 'missing detections'. There has been no modification in the array instrumentation, but the AM personnel have spent a lot of time on the planning and construction of the seismic network in southern Norway. The procedures and criteria for saving NORSAR data permanently have been reconsidered and some important changes have been made. The array instrumentation characteristics have been very stable in the period, with few faults or out of tolerance conditions.

The research activities are described in 6 separate subsections of the last chapter in this report. The first subsection is related to Fenno-scandian seismicity 1954-1978 and discusses hypocentral distribution and focal mechanisms. The second one describes an exceptional earthquake sequence in Meløy, Northern Norway, which was observed during 10 weeks from mid-November 1978. The third work deals with a planned digital microearthquake network in southern Norway, and the fourth with micro-earthquake results from the Stiegler's Gorge seismic network in Tanzania.

The fifth subsection discusses crustal thicknesses in Fennoscandia on the basis of spectral ratios found from vertical and radial long-period components of P-wave recordings and the last subsection deals with the propagation of Lg, Li and Sn phases in Eurasia.

H. Gjøystdal

II. OPERATION OF ALL SYSTEMS

II.1 Detection Processor (DP) Operation

There have been 170 breaks in the otherwise continuous operation of the NORSAR Online DP system within the current 6-month reporting interval. The uptime percentage is 94.1%, which is a slight improvement over the 93.7% reported for the previous interval (April - September 1978), even though the number of stops have increased. Fig. II.1.1 and the accompanying Table II.1.1 both show the daily DP downtime for the days between 1 October 1978 and 31 March 1979. The monthly recording times and percentages are given in Table II.1.2. The number of stops related to the SPS have increased with more than 50% compared to the previous reporting interval, but there have been just a few SPS stops that have lasted for hours, the longest ones occurred in the night and lasted up to 11 hours.

The breaks can be grouped as follows:

a)	SPS malfunction	:	115
b)	Error on the Multiplexor Channel	:	11
c)	Stops related to possible program errors	:	1
d)	Maintenance stops	:	12
e)	Power jumps and breaks	:	8
f)	Hardware problems	:	11
g)	Magnetic tape- and disc-drive problems	:	8
h)	Stops related to system operation	:	3
i)	TOD error stops	:	1

But for the number of stops due to SPS malfunction, the number in the other categories is relatively normal.

The total downtime for this period was 258 hours 28 mintues. The mean-time-between-failures (MTBF) was 1.0 days, as compared with 1.2 days for the previous reporting period.

J. Torstveit

Month	DP Uptime (hrs)	DP Uptime (%)	No. of DP Breaks	No. of Days with Breaks	DP MTBF* (days)
Oct	684.7	92.0	44	20	0.6
Nov	699.0	97.1	16	9	1.7
Dec	717.2	96.4	20	14	1.5
Jan	681.5	91.6	40	22	0.7
Feb	620.2	92.3	31	19	0.8
Mar	709.0	95.3	19	12	1.5
The Total Period	4111.6	94.1	170	96	1.1

* Mean-time-between-failures = (Total uptime/No. of Up Intervals)

Table II.1.2

Online System Performance

October 1978 - March 1979

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS
278	10	41	10	47	SPS ERROR
279	1	7	7	49	POWER BREAK
279	12	46	13	5	MPX/LATE
279	13	25	13	47	SPS ERROR
279	17	19	18	48	SPS ERROR
280	13	22	13	44	SPS ERROR
281	13	43	14	10	DISK FAILURE
281	16	48	18	6	SPS ERROR
282	7	44	16	34	DISK FAILURE
282	17	57	18	41	SPS ERROR
282	20	19	20	37	SPS ERROR
283	10	35	10	56	SPS ERROR
283	20	28	21	33	SPS ERROR
284	11	8	11	14	SPS ERROR
284	12	7	12	22	SPS ERROR
284	12	27	12	55	SPS ERROR
285	3	30	6	16	SPS ERROR
285	7	23	8	0	SPS ERROR
285	22	53	23	42	SPS ERROR
286	0	56	1	37	SPS ERROR
286	3	25	6	43	SPS ERROR
286	7	34	9	54	SPS ERROR
286	13	56	14	5	SPS ERROR
286	17	24	19	10	SPS ERROR
286	19	43	20	26	SPS ERROR
286	22	8	22	37	SPS ERROR
287	7	43	8	32	SPS ERROR
287	9	34	11	56	SPS ERROR
288	2	49	3	19	SPS ERROR
288	3	33	7	1	SPS ERROR
288	23	44	24	0	SPS ERROR
289	0	0	0	15	SPS ERROR
289	8	25	8	36	SPS ERROR
291	2	50	7	30	SPS ERROR
292	3	43	4	43	SPS ERROR
292	20	23	21	31	SPS ERROR
293	14	23	14	33	SPS ERROR
294	5	15	6	0	SPS ERROR

Table II.1.1

Sheet 1 of 5

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS.....
295	0	0	0	46	SPS ERROR
295	16	4	17	15	SPS ERROR
295	17	26	20	26	SPS ERROR
296	7	11	10	34	SPS ERROR
296	11	10	12	31	SPS ERROR
298	13	0	14	27	SPS MAINTENANCE
304	15	4	15	10	MT MAINTENANCE
306	17	6	17	54	SPS ERROR
307	16	30	16	59	TOD ERROR
310	14	43	14	57	PROG ERROR
311	8	43	8	58	MPX/LATE
327	20	5	24	0	SPS ERROR
328	0	0	7	0	SPS ERROR
332	13	58	14	26	MPX/LATE
333	3	28	4	22	SPS ERROR
333	10	4	11	11	SPS MAINTENANCE
333	11	17	12	29	SPS ERROR
333	13	47	14	26	SPS ERROR
333	19	52	20	4	SPS ERROR
333	20	46	21	0	SPS ERROR
333	21	14	21	28	SPS ERROR
333	21	43	23	12	SPS ERROR
334	1	4	2	21	SPS ERROR
334	7	55	8	28	SPS ERROR
337	12	15	13	43	MPX/LATE
338	7	56	8	11	1052 FAILURE
339	9	52	9	59	1052 FAILURE
341	13	39	14	5	1052 FAILURE
343	4	19	6	34	SPS ERROR
343	10	16	11	4	SPS ERROR
343	13	56	14	16	SPS ERROR
344	1	45	7	27	SPS ERROR
345	8	55	9	28	MT FAILURE
346	8	51	9	19	MPX/LATE
347	23	37	24	0	SPS ERROR
348	0	0	0	45	SPS ERROR
348	1	43	2	22	SPS ERROR
348	7	56	8	19	POWER FAILURE

Table II.1.1

Sheet 2 of 5

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS.....
353	3	29	4	11	SPS ERROR
353	10	17	10	27	B-COMPUTER MAINTENANCE
353	12	18	14	41	B-COMPUTER MAINTENANCE
356	9	9	9	31	MPX/LATE
362	2	50	3	57	SPS ERROR
365	1	53	9	24	SPS ERROR
365	23	57	24	0	NEW YEAR STOP
1	0	0	0	17	NEW YEAR STOP
1	1	20	12	56	POWER BREAK
1	15	34	21	14	CPU ERROR
2	11	35	12	35	MPX/LATE
7	8	13	11	17	POWER BREAK
8	8	23	8	30	DISC FAILURE
8	12	30	12	58	1052 FAILURE
9	9	20	9	43	1052 MAINTENANCE
10	9	20	10	5	CPU FAILURE
10	19	34	19	42	CPU FAILURE
11	12	4	13	4	PROG. WORK
11	13	42	14	3	PROG. WORK
11	22	18	22	30	CPU FAILURE
12	10	5	10	52	POWER BREAK
13	19	40	20	27	POWER BREAK
14	12	41	13	37	CPU FAILURE
14	22	22	23	47	SPS ERROR
15	12	13	12	23	SPS ERROR
15	16	36	17	14	SPS ERROR
15	18	12	19	23	CPU FAILURE
15	23	49	24	0	SPS ERROR
16	0	0	0	54	SPS ERROR
20	20	3	20	53	SPS ERROR
22	9	0	9	37	MPX LATE
22	13	37	14	45	SPS ERROR
22	15	57	16	50	SPS ERROR
22	20	8	22	20	SPS ERROR
24	8	51	9	20	SPS MAINTENANCE
24	18	37	19	43	SPS ERROR
24	21	40	21	54	SPS ERROR
25	6	45	6	57	SPS ERROR

Table II.1.1

Sheet 3 of 5

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS.....
26	3	38	4	50	SPS ERROR
26	18	37	20	5	SPS ERROR
26	20	19	24	0	SPS ERROR
27	0	0	7	40	SPS ERROR
28	20	32	22	55	SPS ERROR
29	1	27	2	28	SPS ERROR
29	5	37	7	33	SPS ERROR
29	14	0	14	31	SPS ERROR
30	0	52	1	57	SPS ERROR
31	10	42	10	47	MPX/LATE
31	14	34	14	48	SPS ERROR
31	16	17	16	28	SPS ERROR
32	0	58	1	41	SPS ERROR
32	3	19	7	51	SPS ERROR
32	8	33	16	15	SPS ERROR
33	10	53	13	0	SPS ERROR
35	20	51	21	46	SPS ERROR
36	7	30	7	48	SPS ERROR
36	9	26	9	39	SPS ERROR
36	10	16	10	28	SPS ERROR
36	16	2	20	47	SPS ERROR
37	1	19	7	22	SPS ERROR
37	9	4	12	29	SPS ERROR
38	2	31	3	44	SPS ERROR
38	4	46	4	55	SPS ERROR
38	5	11	5	19	SPS ERROR
39	23	9	24	0	SPS ERROR
40	0	0	0	7	SPS ERROR
43	9	24	10	20	POWER BREAK
45	14	27	14	40	MODCOMP TESTOUT
46	6	52	6	58	SPS ERROR
50	8	27	8	41	SPS ERROR
52	6	51	7	19	DISK DRIVE FAILURE
52	13	10	13	16	DISK DRIVE FAILURE
53	13	36	13	54	DISK DRIVE FAILURE
53	14	38	14	44	DISK DRIVE FAILURE
54	8	57	9	5	MPX LATE
55	2	19	3	31	SPS ERROR

Table II.1.1

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LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS
55	12	23	12	39	SPS ERROR
56	21	29	24	0	SPS ERROR
57	0	0	7	26	SPS ERROR
57	8	41	8	48	MPX LATE
57	22	1	23	9	SPS ERROR
59	4	55	7	38	POWER BREAK
59	14	38	15	5	SPS ERROR
60	4	26	6	49	SPS ERROR
60	12	5	12	13	MT MAINTENANCE
65	1	53	2	52	SPS ERROR
66	5	55	6	45	SPS ERROR
66	8	50	9	0	SPS ERROR
68	7	41	9	21	WORK ON POWER LINE
70	22	34	24	0	SPS ERROR
71	0	0	7	39	SPS ERROR
71	13	3	14	18	B COMPUTER MAINTENANCE
72	4	10	7	31	SPS ERROR
72	8	48	9	10	MACHINE FAILURE
72	9	35	10	29	SPS ERROR
73	2	5	8	5	SPS ERROR
73	9	25	10	17	B COMUTER MAINTENANCE
73	16	38	20	17	SPS ERROR
77	10	58	11	11	SPS ERROR
80	9	13	9	21	SPS ERROR
80	10	35	11	7	SPS ERROR
81	0	32	1	26	SPS ERROR
85	17	20	18	0	SPS ERROR

Table II.1.1

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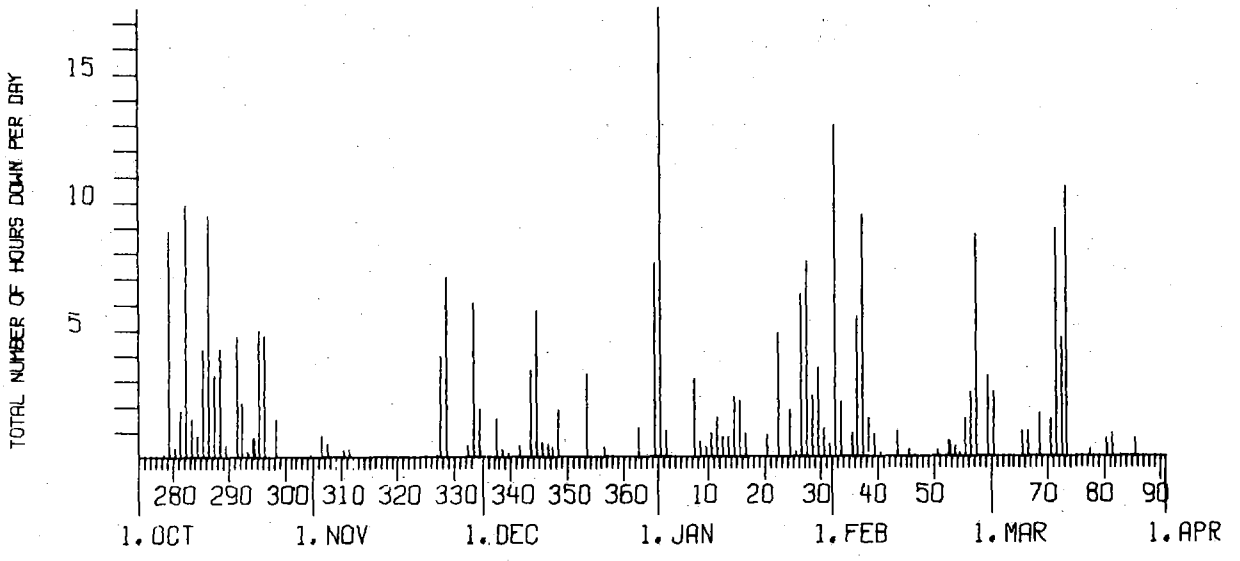

Fig. II.1.1 Online System Downtime, October 1978 - March 1979.

II.2 Event Processor Operation

The operation of the Event Processor, with the production of a monthly seismic bulletin, has continued as outlined in the previous Scientific Report No. 1-78/79 (Section II.2, III.2, VI.1, VI.2). Some statistics for the present reporting period are given in Table II.2.1, where it is seen that an average of 7.9 events per day have been reported. This is a normal winter-time decrease from the 10.8 events/day reported in the foregoing 6 months.

No significant earthquake swarm activity has been recorded in this period except for the outstanding Meløy earthquake sequence in Northern Norway from which about 30 events were recorded at NORSAR and consequently reported in the bulletin (see Section VI.2).

H. Bungum

P. Engebretsen

	Teleseismic	Core Phases	Sum	Daily
Oct 78	137	38	175	5.6
Nov 78	200	50	250	8.3
Dec 78	244	42	286	9.2
Jan 79	197	56	253	8.2
Feb 79	178	44	222	7.9
Mar 79	200	59	259	8.4
	1156	289	1445	7.9

Table II.2.1

II.3 NORSAR Data Processing Center (NDPC) Operation

Data Center

The heavy load of work at the B-computer forced through a thorough examination of the operation routines and the routine jobs, in the beginning of February this year. Not much could be done to the jobs on a short term, but some changes were made in the operation routines which so far have led to a better utilization. It is still necessary for the users to run jobs outside office hours, however. In periods the computers are busy all evening throughout the week and in the weekends.

The DP uptime for the period is 94.1% which is 0.4% better than last period. There have been no major breakdowns on the SPS, but the number of stops due to the SPS have increased by more than 50%.

J. Torstveit

Array Communications

Outages when all subarray circuits have been affected simultaneously are approximately the same as the previous period. Twenty-four outages were observed, of which 2 lasted more than one hour.

Oct	6 outages (of which 1 lasted approx. 1.3 hours)
Nov	5 outages (short duration)
Dec	5 outages (short duration)
Jan	5 outages (one lasted approx. 1 hour)
Feb	2 outages (short duration)
Mar	1 outage (short duration)

Individual subarrays have been affected as follows:

03C	Week 41/78	2.4%
04C	Week 41/78	11.3%
06C	Week 42/78	3.0%
02C	Week 43/78	14.9%
02B	Week 47/78	13.7%
06C	Week 47/78	3.3%
01A	Week 1/79	29.8%
04C	Week 1/79	23.8%
04C	Week 1/79	14.3%
04C	Week 10/79	3.3%
06C	Week 10/79	0.8%
03C	Week 13/79	6.2%

In most cases damaged/broken cables or telephone lines have caused the outages. Other reasons have been: faulty equalizer/amplifier and power failure.

Table II.3.1 shows outages/degraded performance related to communication circuit.

O.A. Hansen

Sub-array	OCT (4) (2-29.10)		NOV (5) (30.10-3.12)		DEC (4) (4-31.12)		JAN (5) (1.1-4.2)		FEB (4) (5.2-4.3)		MARS (4) (5.3-1.4)		AVER.	½ YEAR
	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200
01A	0.6	1.6	0.6	1.1	1.0	0.4	1.4	30.3	0.2	0.4	0.2		0.7	5.6
01B	0.4	1.7	0.4	0.6	0.8	0.6	1.5	2.2	0.2	0.4	0.4		0.6	0.9
02B	0.4	1.7	0.4	14.7	0.8	0.6	1.3	1.5	0.2	0.4	0.2		0.6	3.2
02C	1.2	17.6	0.8	1.2	0.8	0.9	1.3	0.8	0.2	0.4	0.5	0.7	0.8	3.6
03C	0.4	4.4	1.7	1.0	0.8	0.4	1.3	1.5	2.3	0.4	0.2	6.4	1.1	2.4
04C	0.8	13.5	0.8	1.6	0.6	1.5	2.7	27.8	-	0.4	7.2	4.0	2.0	8.1
06C	0.4	5.4	1.2	3.9	1.0	0.8	1.8	15.0	-	0.4	0.5	0.8	0.8	4.4
AVER	0.6	6.6	0.8	3.4	0.8	0.7	1.6	11.3	0.2	0.4	1.3	1.7	0.9	4.0
LESS	02C/04C 3.0		02B 1.6				01A/04C/06C 1.5							

Table II.3.1

Communications (degraded performance >20/outages >200). Figures in per cen of total time. Month - 4 or 5 weeks as indicated.

II.4 The ARPA Subnetwork (TIP to TIP, incl. modems, lines and interfaces)

The London Communication Circuit can, as for the last reporting period, be characterized as reliable, although a few irregularities have occurred. In October (30th) the carrier was lost, caused by link trouble toward Kristiansand S. On November 18th NCC claimed bad performance. NTA/Oslo found a bad contact in equipment located on their premises. On November 23rd NTA initiated fault tracing on NCC request. No data received from London, as British Post Office personnel in London had not removed test equipment. There were no irregularities in December. On January 16th lost carrier once. In February NCC claimed they had lost the connection with London. In March the 'Marginal Circuit' indicator was observed on quite frequently, but as 'Good Data' indicator was on simultaneously, the error rate was within specifications (which permits one error per 100,000 bits).

The SDAC Communication Circuit has been more reliable than the previous period, although we know that problems have existed. Irregularities not directly observed here, but apparent from tests carried out on NCC request (10 October). On November 3rd we observed 'Loss of Carrier' a couple of times. Maintenance work at Tanum (Nov. 16th) broke the connection with SDAC for about 1.5 hours. On the night between 2-3 December a break in the data path between the US and Europe was announced by NCC for about 3 hours. Icing at the Tanum Ground Station's antenna caused communiations problems between December 30th and January 1st. On January 2nd NCC claimed no contact with the TIP. Modem indicated error rate too high. In February no problems were encountered. The only irregularity observed in March was a too-high error rate (March 1st) proved by 'Marg. CCT' indicator on, and 'Good Data' indicator off.

The Terminal Interface Message Processor (TIP)

Preventive maintenance (PM) was carried out according to the schedule. Apart from a few restarts the machine has been running more or less continuously. On December 7th the TIP was restarted after an unexplainable stop. The IMPLINK mechanism did not work on January 4th. NCC assumed a software problem. On January 30th reloaded the TIP from London in connection with 'software release'. The NCC lost connection to London in February. The TIP was halted and restarted after a few tests.

TIP Connections.

Norsk Regnesentral A/S has been connected to port no. 55.

A NORSAR terminal was disconnected from port no. 6 in late March.

O.A. Hansen

III. IMPROVEMENTS AND MODIFICATIONS

III.1 The On-line System

A modification of the On-line Event Processor algorithm was introduced 15 January. Its purpose was to correct an error that would cause large detections to be occasionally missed by the OEP threshold check. In particular, whenever a small detection (false alarm) was followed by a large detection a few seconds later, the OEP might erroneously reject both detections.

After the correction was introduced, the problem of 'missing detections' has been reduced. There are still, however, situations when two detections closely follow each other, and the second one is not processed by the OEP. Ways to solve this problem are being studied.

F. Ringdal

III.2 Event Processor

There have been no major changes in the Event Processor (AUTOEP) during this reporting period.

H. Bungum

III.3 Array Instrumentation and Facilities

There have been no modifications in the array instrumentation in the period, but AM personnel have participated in the erection of the Stiegler's Gorge Seismic Network in Tanzania (Fall 1978) and subsequent maintenance, the Norwegian Antarctic Expedition 1978/79 (December 78/ January 79) and the American expedition FRAM I in the eastern Arctic from March this year. Also much work has been accomplished in planning and construction of the seismic network for southern Norway.

A. Kr. Nilsen

III.4 Data Retention

The procedures and criteria for saving NORSAR data permanently (data retention) have been reconsidered and some important changes have been made. The reason why this was done now was that

- the criteria have been unchanged for many years and did not reflect our increased interest in regional and local events
- data have been saved since March 1971 so that most earthquake regions should by now be very well covered, making possible a relaxation in the retention criteria for such events
- the data retention has started to become a significant burden on tape costs, storage space, computer time and man-hours, and some reduction was therefore desired also from this point of view.

In consequence of this, the following changes have been made:

1. The criteria for selecting teleseismic events have been made stricter in order to reduce the amount of permanently saved data from seismically active regions.
2. The distance limit between local and teleseismic events was lowered to 10 degrees and the lower magnitude limit for local events was reduced from 3.5 to 1.0, which means that data for all close events will be saved.
3. Changes were made (in the SEIS routine) to take proper care of all events in the 'special interest' areas (i.e., mostly explosions). The retention interval for these events was previously partially dependent on whether a zero depth was given in the bulletin record or not.
4. An error (in the PATIME routine) which resulted in too late 'start saving time' for close events (i.e., $\Delta<12^{o}$) has been corrected.

In testing the new criteria on the time interval October-December 1977, we found the saved time to be reduced from 5.7% to 2.9% of real time, or a reduction of about 50%.

The details of the new retention criteria are given in Table III.4.1.

H. Bungum

P. Engebretsen

Source Region	Distance (Δ)	Magntidue (m_b)	Retention Interval
'Aseismic' (0) areas	$0^o \leq \Delta \leq 10^o$	$m_b > 1.0$	1
	$10^o \leq \Delta \leq 105^o$	$m_b < 5.0$	1
	$10^o \leq \Delta \leq 105^o$	$m_b \geq 5.0$	2
	$0^o \leq \Delta \leq 180^o$	$m_b > 6.8$	3
Seismically (1) active areas	$0^o \leq \Delta \leq 10^o$	$m_b > 1.0$	1
	$10^o \leq \Delta \leq 105^o$	$m_b > 5.1$	1
	$0^o \leq \Delta \leq 180^o$	$m_b > 6.0$	2
	$0^o \leq \Delta \leq 180^o$	$m_b > 6.8$	3
Special (2) interest areas	$0^o \leq \Delta \leq 105^o$	$m_b < 4.5$	1
	$0^o \leq \Delta \leq 105^o$	$m_b \geq 4.5$	2
	$0^o \leq \Delta \leq 180^o$	$m_b > 5.0$	2
	$0^o \leq \Delta \leq 180^o$	$m_b > 6.8$	3
Events (3) selected by analyst			3

Retention Intervals:
1 - (P-2 min) to (P+10 min)
2 - (P-2 min) to (P'P'+10 min)
3 - (P-2 min) to (P'P'+40 min)

Table III.4.1

Criteria for retaining SP data at NORSAR

Effective on data starting from October 1977

IV. MAINTENANCE ACTIVITY

A brief review of the maintenance activity at the subarrays by the field technicians as a result of the remote array monitoring and routine inspection is given. The main preventive work in the period is replacement of seismometer amplifiers due to decaying battery power.

Maintenance Visits

Fig. IV.1 shows the number of visits to the subarrays in the period, in average each subarray has been visited 1.7 times.

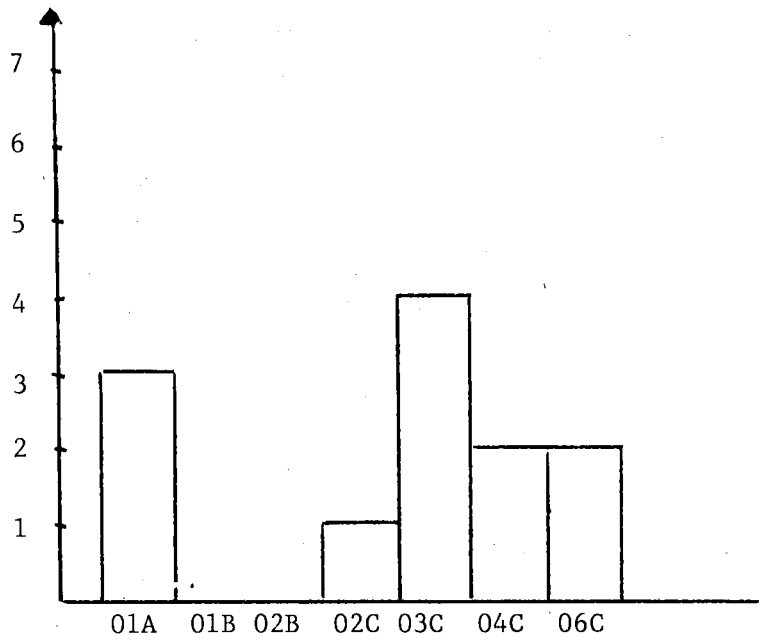

Fig. IV.1 Number of visits to the NORSAR subarrays in the period 1 October 1978 to 31 March 1979.

Preventive Maintenance Projects

The preventive maintenance work in the array is described in Table IV.1. The adjustments are corrections of characteristics within the tolerance limits.

Unit	Action		No. of Actions
LTA	Adjustment of DC offset	SP	5
		LP	2
	Adjustment of channel gain	SP	3
		LP	2
Seism. Amplifier	RA-5 replaced due to decaying battery power		18
Seis-mometer	MP adjustment (in field)		5

Table IV.1

Preventive Maintenance Work in the Period
1 October 1978 to 31 March 1979

Disclosed Malfunctions on Instrumentation and Electronics

Table IV.2 gives the number of accomplished adjustments and replacements of field equipment in the array with the exception of those mentioned in Table IV.1.

Unit	Characteristic	SP		LP	
		Repl.	Adj.	Repl.	Adj.
Seis-mometer	MP (field)				4
Seism. Amplifier RA-5/ Ithaco	Balance	1			
	Gain		1		
	Input card	1			
LTA	Distortion	1			
	Ch. gain		4		1
	CMR		1		
SLEM	Test gen.	3	1		
	ADC/MUX	1			

Table IV.2

Total number of required adjustments and replacements in the NORSAR data channels and SLEM electronics
(1 Oct 1978 - 31 Mar 1979)

Malfunction of Rectifiers, Power Loss, Cable Breakages

There has been no malfunction of the rectifiers in the period, or power loss requiring action of the field technicians. One cable fault was investigated requiring one day's work.

Array Status

The array instrumentation characteristics have been very stable in the period with few faults or out of tolerance conditions.

A. Kr. Nilsen

ABBREVIATIONS

ADC	-	Analog to digital converter
CMR	-	Common mode rejection
DC	-	Direct current
LP	-	Long period
LTA	-	Line termination amplifier
MP	-	Mass position
MUX	-	Multiplexer
SLEM	-	Short and long period electronics module
SP	-	Short period.

V. DOCUMENTATION DEVELOPED

V.1 Reports, Papers

Bungum, H., B.K. Hokland, E.S. Husebye, F. Ringdal: An exceptional intraplate earthquake sequence in Meløy, Northern Norway, Nature, in press.

Bungum, H., and E.S. Husebye: The Meløy, N. Norway, earthquake sequence - A unique intraplate phenomenon, Norges Geol. Tidsskrift, in press.

Bungum, H., T. Risbo and E. Hjortenberg: Precise continuous monitoring of seismic velocity variations using vibrations from a hydroelectric power plant, To appear in Russian, published by the Soviet Academy of Sciences, in press.

Bungum, H., and Y. Kristoffersen: The seismicity of Spitsbergen: Preliminary results, Norsk Polarinstitutt Årbok 1977, 237-246.

Christoffersson, A., and E.S. Husebye: On 3-D inversion of P-wave time residuals - Option for geological modeling, in press.

Rieber-Mohn, D.: Final Technical Summary, 1 April - 31 September 1978, NORSAR Scientific Rep. No. 1-78/79, NTNF/NORSAR, Kjeller.

L.B. Tronrud

V.2 Program Documentation

No program documentation has been written during this period.

VI. SUMMARY OF SPECIAL TECHNICAL REPORTS/PAPERS PRESENTED

VI.1 Fennoscandian Seismicity 1954-1978: Hypocentral Distribution and Focal Mechanisms

A comprehensive collection and analysis of seismicity data for Fennoscandia has resulted in a catalogue for the years 1954-1978 comprising 604 earthquakes, with location predominantly based on instrumental recordings. The catalogue has been obtained by (1) collecting all available epicenter location estimates for the region, (2) deciding whether the event is a natural earthquake or an explosion, and (3) arranging the available epicentral estimates for each event in order of priority on the basis of assumed reliability. Following this procedure, we have constructed a new epicenter map for Fennoscandia covering the time interval 1954-1978 (Fig. VI.1.1). The new and extended catalogue in comparison to that of Husebye et al (1978) has given some new features which deserve some comments. First of all we notice that the main zones are now even more clearly outlined. This applies in particular to the Norwegian Sea zone north of the Lofoten islands, and even more clearly the western Norway zone where a number of events farther out and along the continental margin now have been added to the catalogue. The seismicity of southeastern Norway now seems to correlate better with the Oslo Graben (see also Fig. VI.1.2) and the southward extending Oslo Rift zone, with a concentration of activity at the hypothesized Skagerrak triple junction. With the previously available data (Husebye et al, 1978) this area exhibited a rather diffuse seismicity pattern. In Sweden we notice that the Vänern area seismicity is now better defined, as well as the Bothnian zone, which extends all the way from Vänern to Lappland.

The possibilities of meaningful seismotectonic interpretation are usually significantly improved by the availability of fault-plane solutions, and in particular so for intraplate earthquakes (Sykes, 1978). The first such solution is only recently published in connection with the Meløy earthquakes (See Section VI.2), and three more solutions are now presented here (Bungum and Fyen, 1979). Fault plane solutions for local earthquakes using first motion data require a relatively dense network of stations surrounding the epicenter, and that the horizontal extent of the network is properly scaled to the focal depth. This has been the case for three earthquakes which occurred inside the NORSAR array in 1971 (19 Jul, 00.59.12)

in 1973 (23 Nov, 06.49.37) and in 1977 (11 Dec, 21.46.12). Their locations are shown in Fig. VI.1.2 and the details of the solutions are presented in Fig. VI.1.3. For the 1971 event the given solution is the only one (within $\pm 2^{o}$ variation in strike and dip) that avoids discordant points and simultaneously keeps the two planes orthogonal. The faulting is normal with a significant strike slip component, while for the 1973 event the faulting is strike slip with a significant normal component (within a variation of about 5° in strike and 10° in dip). The result for the 1977 event is also quite good, even if two of the quadrants have no data and the third has only one point. The reason for this is that the epicenter is surrounded by compressional first motions which have to be placed in one and the same quadrant, and there is consequently room for practically no change in the solution when subjected to the orthogonality condition. The faulting for this event is almost purely normal. It is important to keep in mind that all fault plane solutions obtained in this way are critically dependent on precise hypocentral solutions. This being the case, we conclude that the obtained solutions have a very high degree of reliability.

H. Bungum

J. Fyen

References

Bungum, H., and J. Fyen, 1979: Fennoscandian seismicity 1954-1978: Hypocentral distribution and focal mechanisms with a tectonic framework. Manuscript in preparation.

Husebye, E.S., H. Bungum, J. Fyen and H. Gjøystdal, 1978: Earthquake activity in Fennoscandia between 1497 and 1975 and intraplate tectonics. Nor. Geol. Tidsskr., 58, 51-68.

Sykes, L.R., 1978: Intraplate seismicity, reactivation of preexisting zones of weakness, alkaline magmatism and other tectonism postdating continental fragmentation. Rev. Geophys. Space Phys., 16, 621-688.

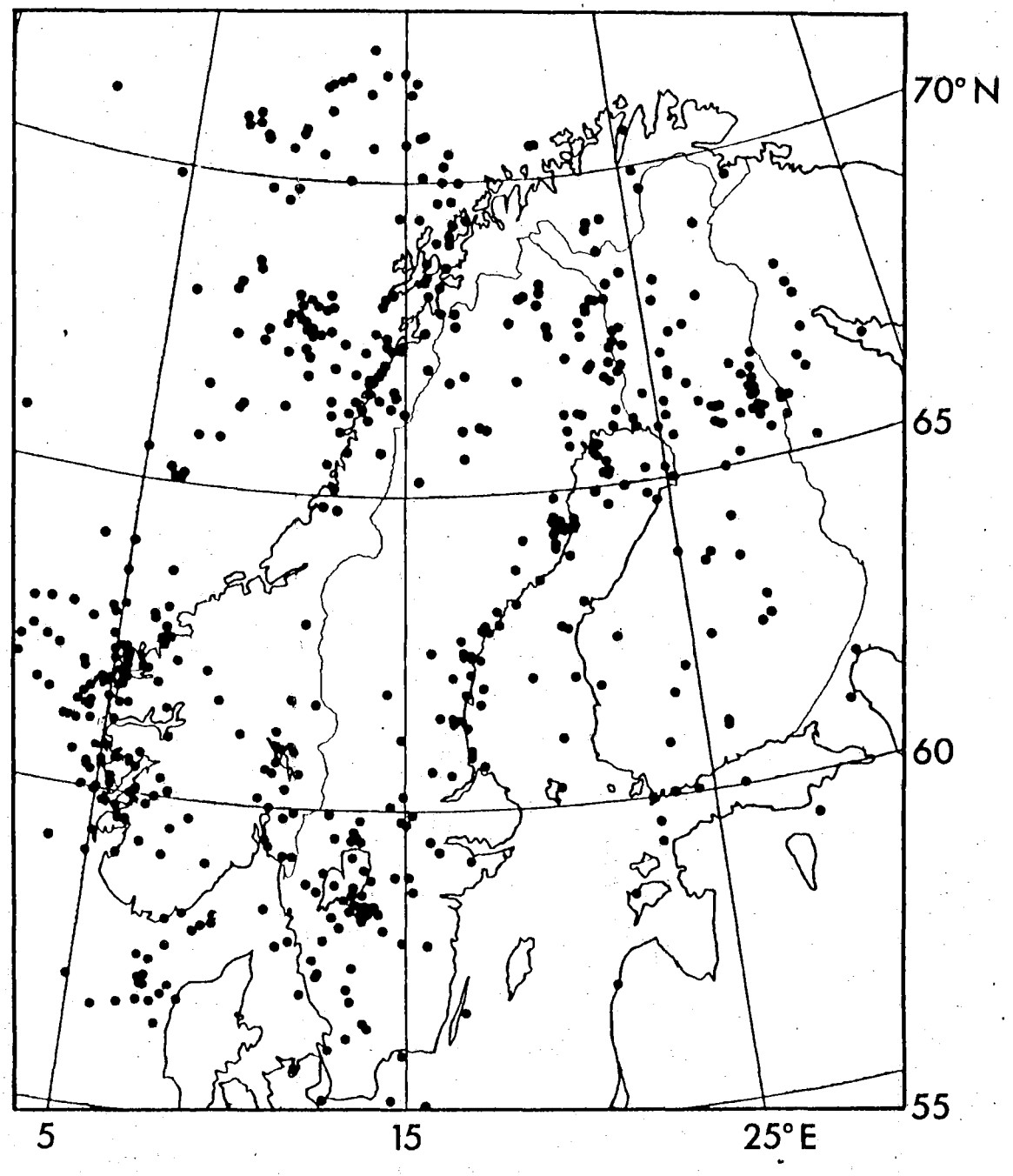

Fig. VI.1.1 Fennoscandian earthquakes, 1954-1978 (604 epicenters).

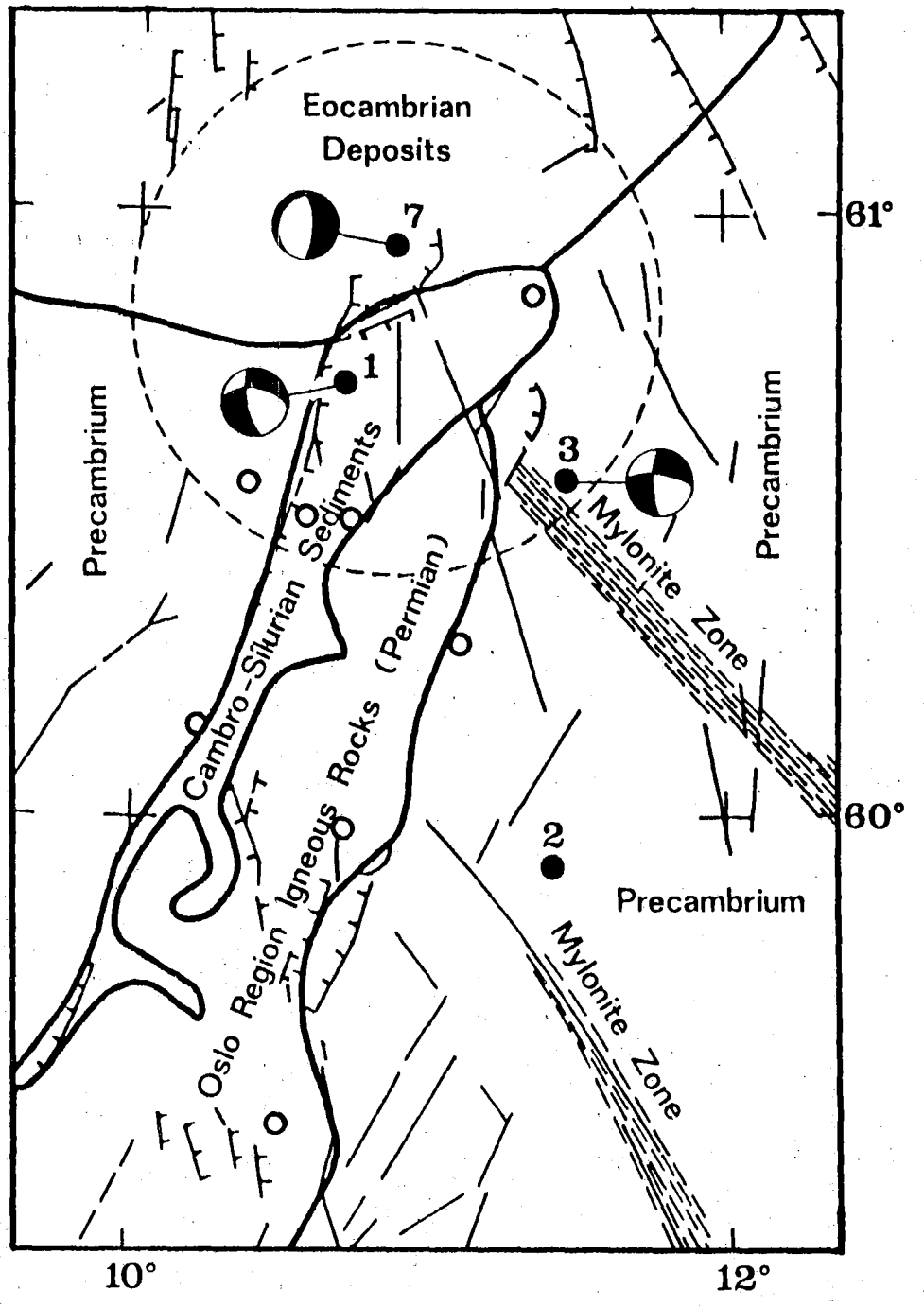

Fig. VI.1.2 The Oslo Region with an outline of the structural geology. The three focal mechanism solutions presented in Fig. VI. 1.3 are also shown (Events 1, 3, 7), as well as the locations of other earthquakes in our catalogue. The area covered by the NORSAR seismometers is indicated by a dashed circle.

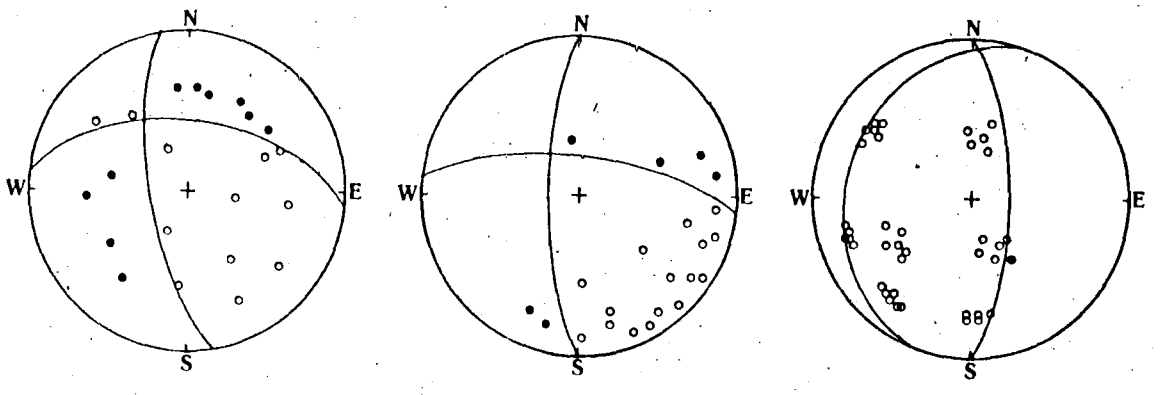

Fig. VI.1.3 Fault plane solutions for 3 events whose locations are shown in Fig. VI.1.2, plotted in a stereographic projection of the lower hemisphere, with solid and open circles indicating compressions and dilatations, respectively.

VI.2 An Earthquake Sequence in Meløy, Northern Norway - A Unique Intraplate Phenomenon

A unique earthquake sequence began in Meløy, Northern Norway, in mid-November 1978, and 10 weeks later about 10,000 shocks had been recorded from a volume not larger than 10x8x6 km^3. So far, the largest earthquake had an estimated ML magnitude of 3.2 units and a maximum MM intensity of 6. The strike of the estimated faulting plane is N25^{o}E with a dip of 63°E (Bungum et al, 1979; Bungum and Husebye, 1979).

This paper summarizes our studies on the spatial and temporal patterns of the Meløy earthquake sequence, and also gives a discussion of possible source mechanisms. In our continuing studies, we will use these well-recorded events in an evaluation of various event detection and discrimination techniques at near distances.

The first positively recorded earthquake in the Meløy sequence occurred on 3 November 1978 and was measured at ML=2.4, using data from the NORSAR array which has an epicentral distance of about 700 km. The first reports out of Meløy itself came a few days later, and during the week 12-19 November ground shakings were widely felt many times. The first local seismographs were installed by NTNF/NORSAR 19 November, altogether 7 different sites were used (see Fig. VI.2.1), and at any one time a maximum of five stations were in operation. The earthquake sequence time history between 11 November 1978 and 18 February 1979 for station Neverdal is presented in Fig. VI.2.2. The main concentration of larger shocks was in the time period 11-18 November, and we also notice the interesting predominance of night-time shocks during this interval. After 5 December, the activity decreased having a minimum around 20 December, whereafter new outbursts of microtremors occurred on 27-28 December, 3-4, 8-10 and 18-20 January. A characteristic feature of the sequence is that of 'major' earthquakes followed by aftershocks lasting sometimes a few hours, sometimes a few days. The largest number of events recorded in one single day occurred on 2 December with 820 at ENG, 750 at NEV and 270 at ORN. We have computed hypocenters for 255 events evenly distributed in time throughout the recording period and on the basis of Pg-Sg time difference and also absolute Pg travel times when such were available.

In Fig. VI.2.1, 66 events with at least 5 readings (phases), and RMS values less than 0.15 s are plotted. The epicenters are confined within an area of roughly 10 km N/S, 8 km E/W, with a concentration around 66.81°N, 13.63°E. The computed hypocenter depths are in the range 3-9 km, and the corresponding uncertainty is of the same order as for the epicentral coordinates, which is usually within ± 1 km. The hypocentral 'time development' indicates that essentially all of the 10 x 8 x 6 km^3 volume has been activated all of the time. However, some migrations in the earthquake activity are apparent, predominantly in the N-S direction. A composite focal mechanism solution for the Meløy earthquakes are presented in Fig. VI.2.1. The solution indicates predominantly normal faulting, where the plane striking N25°E and dipping 60°E is the one which gives the best fit to hypocentral solutions, therefore also being the probable faulting plane. Most of the events above ML=2.0 were felt, and the maximum intensity on the Modified Mercalli scale was 6. Very many earthquakes were heard, and the reported sounds can be classified in three groups: (i) sounds without any felt tremor, (ii) sounds associated with earthquakes felt, and (iii) sounds generated in the epicentral area. The latter sounds (described as when a load of snow rushes off roofs) were quite different from group (ii). The above information was partly derived from newspaper ads.

The Meløy earthquake sequence is in our opinion an outstanding example of intraplate seismic activity. The main problem is to fit this phenomenon into the tectonic framework of the area, which briefly can be described as follows: From the inserted seismicity map for Fennoscandia in Fig. VI.2.1 it is seen that Meløy is located in the middle of a distinct seismicity zone along the coastal area between 65°-70°N. One of the largest events in Fennoscandia so far took place here in 1819, the so-called Lurøy earthquake, with a presumed location of about 50 km SW of Meløy and an estimated magnitude of the order of 6.0-6.5 on the Richter scale. Further to the west of the Meløy area there is another seismicity zone which coincides with the passive continental margin. The seas between these two seismicity zones are part of an epicontinental basin with maximum sedimentary thicknesses of the order of 8-9 km, and with clear evidence of block faulting. The early Eocene uplift of western Fennoscandia, contemporaneous with the Norwegian Sea opening, amounted to a maximum of

2 km. A striking neo-tectonic feature is found some 200 km to the north-west in Swedish Lappland, namely, the so-called post-glacial Pärve fault, with a length of approximately 150 km and a maximum height of around 30 m. The on-going presumed glacial rebound of Fennoscandia is also rated a spectacular neo-tectonic feature.

It is interesting to note that the indicated strike direction of N(20-30°)E of the Meløy earthquakes is coincident with the Caledonian folding axis, the sedimentary basin axes and also that of the Pärve fault. The normal faulting with an eastward dipping angle of 60° appears to rule out a causal connection both to the on-going glacial rebound and the Eocene uplift having positive gradients for onshore areas. A direct relationship to the off-coast sedimentary basin block tectonics appears somewhat doubtful as here the fault walls nearest to the coast face westward. However, a more subtle relationship to the off-coast sedimentary basins is possible, through the following hypothesis: After an initial rifting/graben formation process the sedimentary depository potential of the area in question is maintained due to continuous subsidence of the area as part of an isostatic compensation mechanism on a lithosphere whose loading response is either elastic or visco-elastic. Such a process could be associated with an 'overshoot' effect on the flanks, and in our particular case normal faulting facing eastwards. A detailed discussion of the Meløy sequence in a geological context is presented by Gabrielsen and Ramberg (1979).

Usually an earthquake activity as reported here will intuitively be suspected as being precursory for a significantly larger event. The exceptional nature of this intraplate earthquake sequence makes it difficult, however, to argue convincingly either in favor of or against such a hypothesis. From the magnitude-frequency relationship, which shows a near perfect linearity up to about ML=3.0 (with a non-anomalous slope of 1.1), we may argue that the release of energy seems 'complete', an assumption supported by the gradual decrease in activity for the last 2 of the 3 months displayed in Fig. VI.2.2. However, a downward bend in the high-magnitude end of the recurrence curve (above ML=3.0) might indicate the 'lack' of a few somewhat larger earthquakes (ML~3.4-3.6). Therefore, even if we know from historical records that the general Meløy area has

the potential of large earthquakes, we have no firm evidence whether or not the on-going microearthquake activity is precursory to somewhat larger earthquake(s) in the near future. The large Lurøy earthquake of 1819 is not considered conclusive in this context as the lack of foreshocks there may simply reflect poor reporting practices.

H. Bungum, B.Kr. Hokland,
E.S. Husebye, F. Ringdal

References

Bungum, H., B.Kr. Hokland, E.S. Husebye and F. Ringdal, 1979: An exceptional earthquake sequence in Meløy, northern Norway. Nature, in press.

Bungum, H., and E.S. Husebye, 1979: The Meløy, N. Norway, earthquake sequence - a unique intraplate phenomenon. Nor. Geol. Tidsskr., in press.

Gabrielsen, R.H., and I.B. Ramberg, 1979: Tectonic analysis of the Meløy earthquake area based on Landsat, lineaments and mappings. Nor. Geol. Tidsskr. in press.

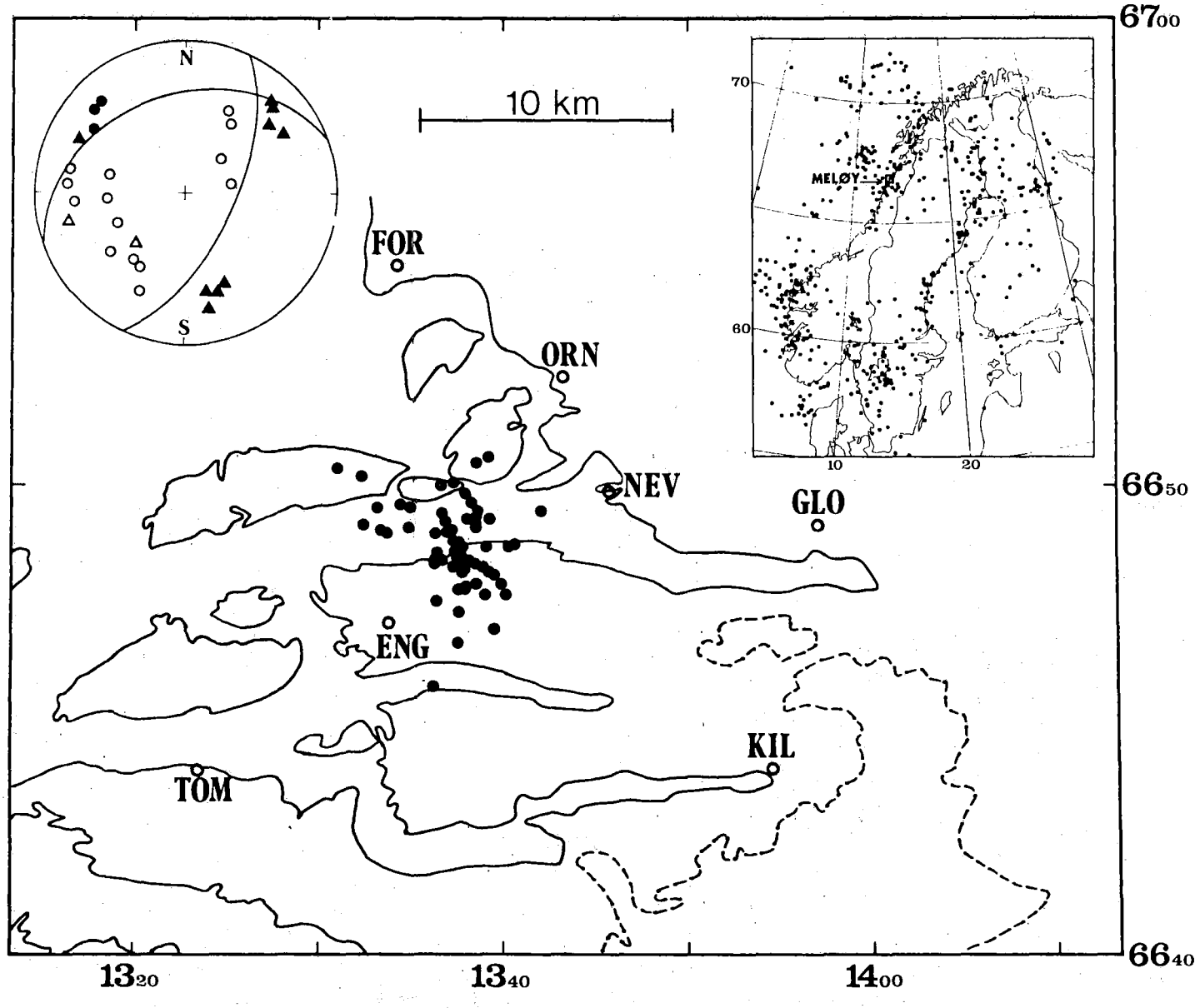

Fig. VI.2.1 Map of the Melφy area with the 7 locations used as sites for the portable seismographs. The black dots are computed epicenters for 66 earthquakes for which the depth range is 3-9 km. In the upper right corner a map shows Scandinavia with instrumentally located earthquakes for the time period 1951-1978, and in the upper left corner is inserted a composite focal mechanism solution for the Melφy earthquakes.

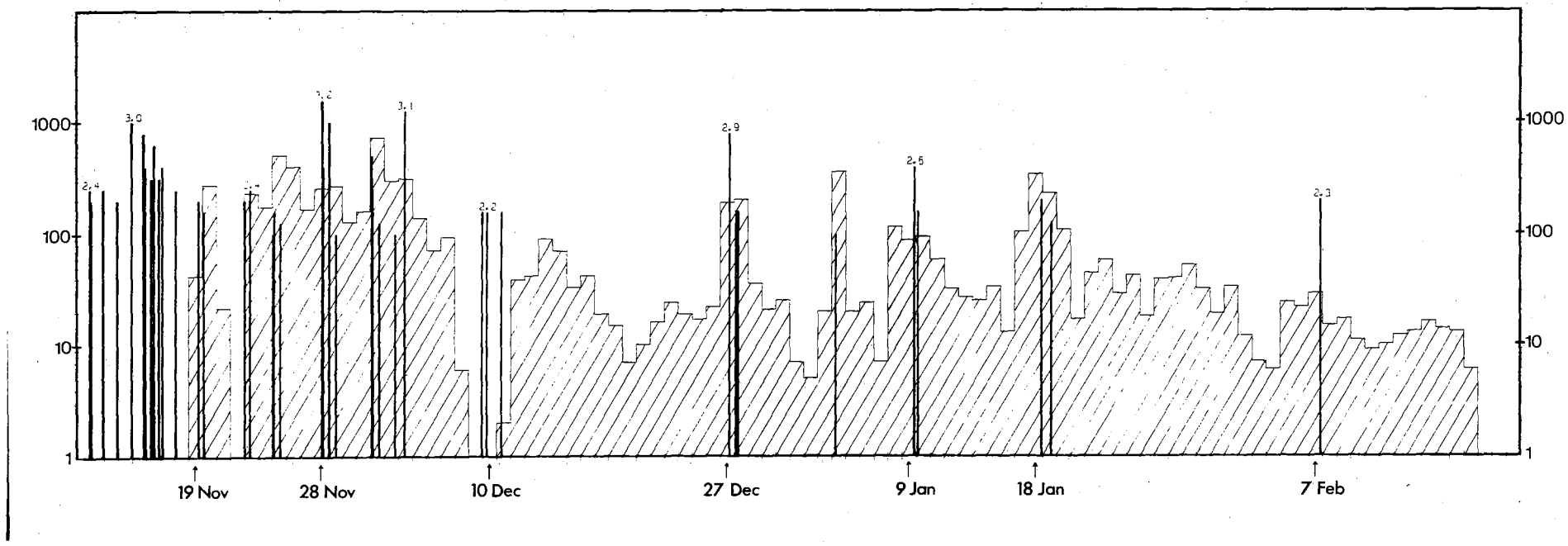

Fig. VI.2.2 Time development of the Meløy earthquake sequence as recorded at the Neverdal station. The histogram shows number of events on a daily basis, and all events with an ML magnitude at 2.0 or above are plotted separately as vertical lines with height proportional to magnitude.

VI.3 A Digital Microearthquake Network in Southern Norway

Two major trends in earthquake seismology have been evident over the last few years. The first one is a change of interest from interplate to both inter- and intraplate earthquakes, and the other is an increased interest in microearthquake studies, often triggered by the need for more reliable information about seismic risk for industrial installations such as large dams and nuclear power plants. Scandinavia is no exception in this respect, as the above two points are covered by projects which will result in considerable improvements with respect to the deployment of seismic stations in the area (see also Section VI.1). The conventional seismic stations and the array stations (NORSAR, Hagfors) which have been operated so far have all been directed primarily towards teleseismic events, leaving much to be desired as far as the local seismicity is concerned. This situation will now be greatly improved with the installation of 27 new microearthquake stations, organized in a Swedish/Danish and a Norwegian project (see Fig. VI.3.1).

Seventeen Swedish and the 3 Danish stations are expected to be in full operation this year, with a central processing center in Stockholm operated by the Swedish Defense Research Establishment (also responsible for the Hagfors array). The data will pass a real-time detection system and selected time intervals will be recorded with a dynamic range of 140 dB (gain-ranging amplifiers) and a sampling rate of 60 Hz. The project is planned for a 3-year period.

The Norwegian project is a joint undertaking between NTNF/NORSAR and the Norwegian Water Resources and Electricity Board (NVE), and it is not expected to be in operation until the first half of 1980. There are 7 stations as shown in Fig. VI.3.1, one of which (the westernmost) is a three-component station to be located very near a large dam (Blåsjø). The seismometers will be Geotech S-13, the data will be passed through two amplifiers (one high-gain and one low-gain) simultaneously in order to increase dynamic range, and then transmitted in analog form to our data center at Kjeller. A minicomputer will there digitize and analyze the

data in real time, and selected time intervals will be recorded and stored on digital 9-track (800 bpi) magnetic tape for later offline analysis. The planned operational period for the Norwegian project is also 3 years, with a total cost estimate of 1.9 million N.kr., to be covered jointly by NVE and NTNF. There will be options for continuing the surveillance at Blåsjø beyond the 3-year period.

It is evident from these plans that we are now facing a unique possibility to study the southern Scandinavian seismicity (where earthquakes with m_b=6.0-6.5 have occurred) with a much greater accuracy than before (location accuracy 1-5 km, detection threshold near to m_b=1.0). Furthermore, this network of 27 high-quality stations (large dynamic range and high sampling rate) will also provide great possibilities for research within regional detection and discrimination and to some extent also for studying teleseismic events. The greatest problem expected for the data analysis is that more than 90% of the recorded local events will be man-made explosions.

H. Bungum
P.W. Larsen
F. Ringdal

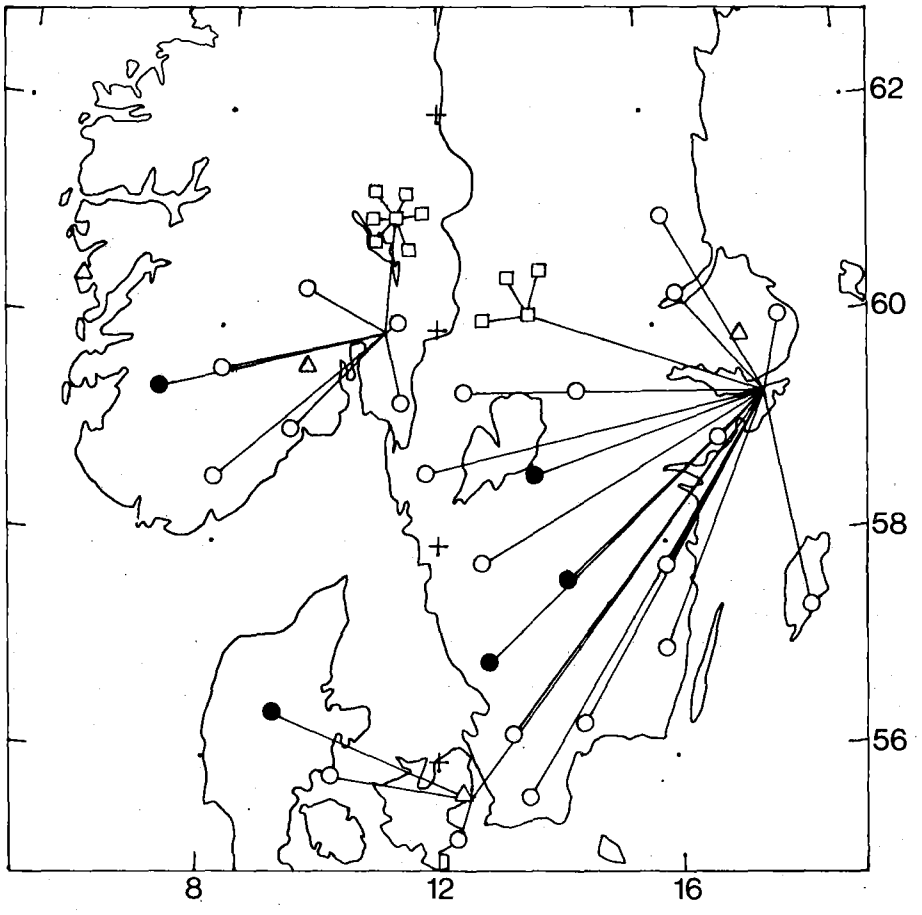

Fig. VI. 3.1 Map showing existing conventional seismic stations (triangles), array stations (squares) and planned microearthquake stations (circles, solid for three-component) in Scandinavia. The 3 microearthquake stations in Denmark and the 17 in Sweden will all have data transmitted to Stockholm, while the 7 in Norway will have data transmitted to Kjeller.

VI.4 Microearthquake Results from Tanzania

In the previous semiannual report a description was given of a new seismic array for microearthquake studies which now is in operation in Stiegler's Gorge, Tanzania (with NTNF/NORSAR as seismological consultants). Since then, a good amount of high-quality data have been received (although operational problems are frequent too), and the results show that there is a considerable microearthquake activity. In Fig. VI.4.1 we have plotted the epicenters of 80 earthquakes occurring in the area between 23 September 1978 and 5 February 1979, and we have also plotted the seismic stations and the rivers in the area. The proposed dam site is shown just SE of station 2, and we see that the site is surrounded by a large number of events. This activity is striking NW-SE and is connected to a prominent fault system called Tagalala. Connected to this fault system is also a prominent eastward-facing escarpment and several hot springs. A composite fault plane solution for the Tagalala earthquakes is presented in Fig. VI.4.2, where the plane striking N26^{o}W and dipping 46°E fits very well to the above-mentioned geologic information. The solution is furthermore supported by the hypocentral depths, these are all in the range 0-25 km with the deepest events to the east. The fault plane parameters for the N-S trending events near stations 5 and 6 are clearly different from those of Tagalala, which shows that the tectonic regime in the area is fairly complicated. It is moreover interesting to note that the events plotted in Fig. VI.4.1 are the only ones recorded within the area covered by the map.

The magnitudes of the Stiegler's Gorge events have not so far been studied in any detail (a magnitude scale will be developed), but we have fairly good indications that most of the magnitudes are in the range from 0 to 4 ML units. Another interesting question which remains to be answered is to what extent the Stiegler's Gorge seismic activity can be considered a part of the general N-S epicenter trend in this part of Tanzania, and as such may be interpreted as an extension of the Gregory Rift.

The digital data recorded so far comprises a large number of earthquakes at all distances from 0-15 degrees. We plan to analyze some of these events further with the aim of developing regional signal attenuation characteristics for Central and Southern Africa.

H. Bungum

B. Kr. Hokland

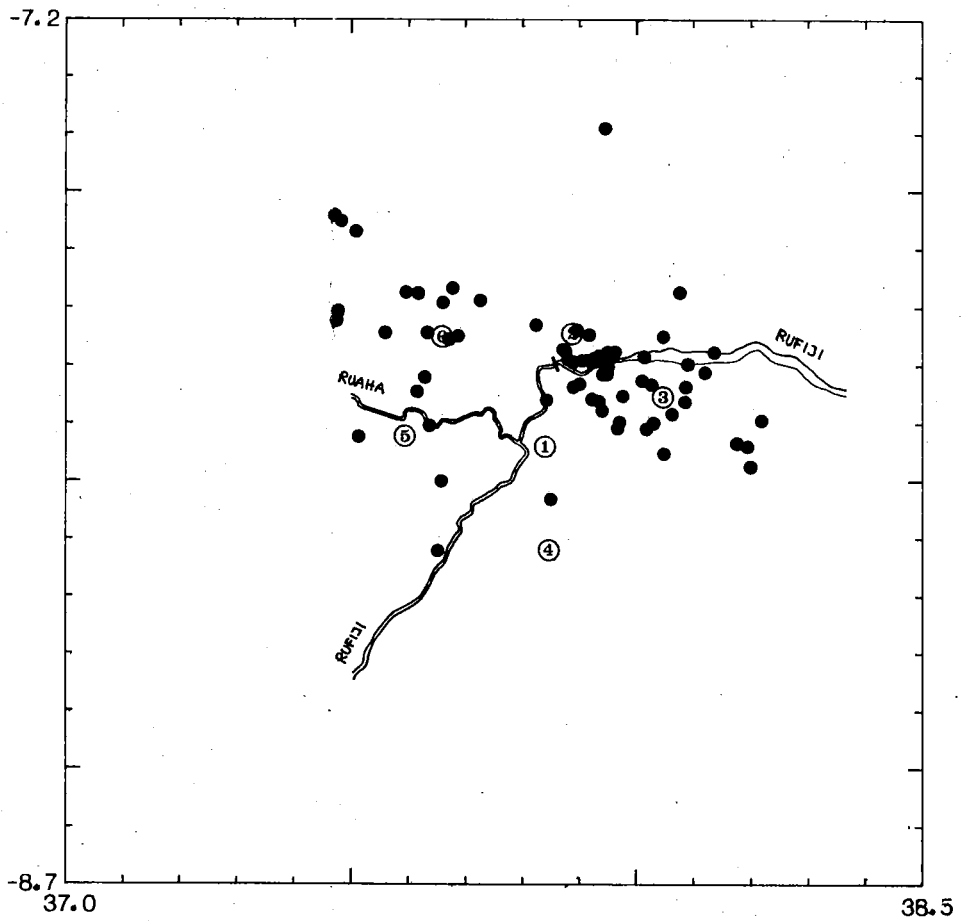

Fig. VI. 4.1 Epicenter locations for 80 earthquakes near Stiegler's Gorge, Tanzania. The 6 stations in the microearthquake network are marked with encircled numbers, and the proposed dam site is indicated with a bar crossing the Rufiji river just SE of station 2.

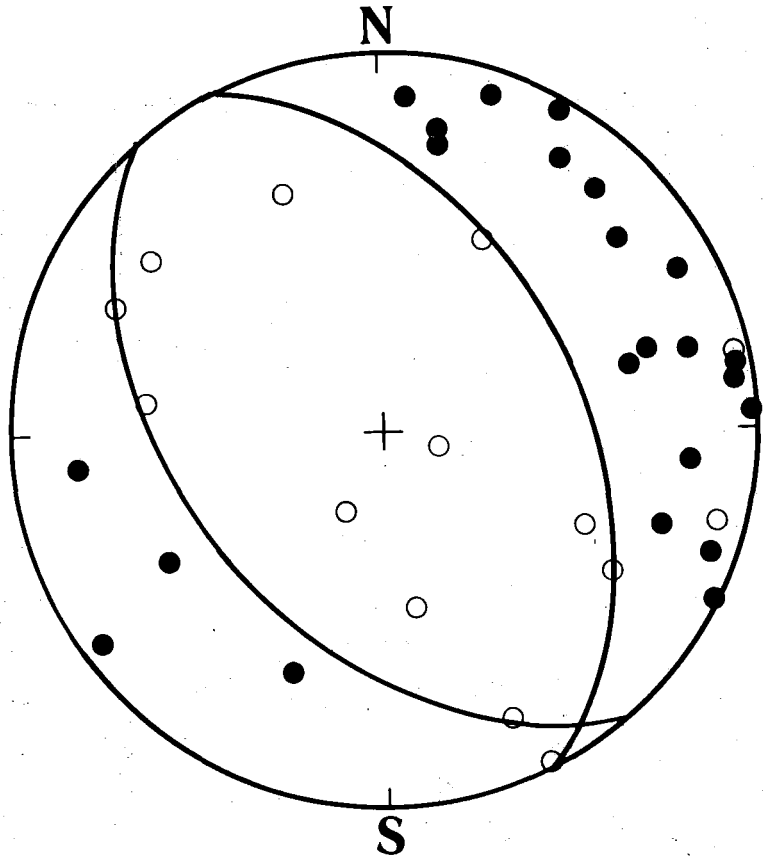

Fig. VI.4.2 Composite fault plane solution based on first motion readings from 7 earthquakes of the Tagalala fault system (near stations 2 and 3 in Fig. VI.4.1). Solid and open circles represent compressions and dilatations, respectively, plotted in a lower hemisphere stereographic projection. Strikes/dips for the two planes are $140^{o}/45^{o}$W and $154^{o}/46^{o}$E, with the latter one most probably being the faulting plane.

VI.5 Crustal Thicknesses of Fennoscandia

As a possible clue to a better understanding of problems related to exceptional propagation efficiency of Lg-type of surface waves along certain paths from Central Asia to Fennoscandia, we have undertaken an investigation of crustal thicknesses of the latter region. In the past this type of investigations, with emphasis on seismic profiling surveys, have flourished in this region, though the results obtained in our opinion are not entirely satisfactory. The reason for the latter statement is two-fold: i) the various profiling survey data have repeatedly been reinterpreted and the associated crustal models may comprise two to four layers; ii) derived crustal parameters for areas with intersecting profiles are sometimes rather dissimilar. A possible alternative to the traditional profiling surveys is to take advantage of the easily available data from the high-quality seismograph network of Fennoscandia. A suitable and proven technique for crustal studies with this kind of data is the technique of spectral ratios found from vertical and radial long-period components of P-wave recordings (Phinney, 1964; Berteussen, 1977). The essence of this method is to compare observed spectral ratios with theoretical ones based on 'response' calculations of a large number of crustal models (see Fig. VI.5.1). In practice the class of possible crustal models is rather limited as the dominant parameters here are the crustal thicknesses for the stable part of the P-wave spectrum, i.e., up to 0.15 Hz.

Altogether, we analyzed 45 events (see Table VI.5.1) with 5-12 events per station in different distance and azimuth ranges for 10 stations equipped with appropriate LP instruments. The results obtained, that is, essentially crustal thicknesses at each station, are listed in Table VI.5.2. The spectral ratio method is taken to provide rather accurate Moho depth values, as the standard error of these estimates seldom exceeds ± 0.3 km. For details on the NORSAR siting area, we refer to Berteussen (1977). Also the analysis of the Hagfors (HFS) and Bergen (BER) stations have not been completed yet.

When examining Table VI.5.2, an obvious question may be how well the spectral ratio results correlate with corresponding ones derived from profiling surveys, that is, as regards crustal thicknesses. We do consider

that such a correlation is rather good if the profiling results are subjected to two conditions, namely, i) profile length should exceed 300 km and ii) only the crustal thicknesses estimated from the central part of a profile are considered reliable.

The crustal thickness estimates obtained in this study and also corresponding results from profiling surveys are displayed in Fig. VI.5.2. Our comments here are as follows: The dominant feature is the Moho bulge in the Bothnian Bay which roughly coincides with the area of maximum uplift rate and prominent free-air gravity anomalies as well. From the Umeå (UME) area where the Moho depth reaches a maximum of approx. 48 km, the crustal thickness decreases slowly to the west, north and east, but relatively more rapidly towards south-southwest. The NORSAR array is overlying an area of relatively modest crustal thickness of around 33 km though rapidly thickening westward.

Our data do not extend to the Kola Peninsula nor to the Barents Sea, but other studies here indicate crustal thicknesses of the order of 45 km (e.g., Levshin and Berteussen, 1979, McCowan et al, 1978). An underground nuclear explosion in the Kola Peninsula indicated extremely efficient Lg propagation southward at least as far as Copenhagen, while explosion farther northeast indicate significantly less efficient Lg-propagation paths.

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NO	DATE	OT	LAT	LONG	DEP	MB	DIST UME	AZI UME	REGION
1	670527	1722560	51.86	176.09	11	5.9	63.1	16.5	RAT ISLANDS
2	670729	1024247	6.84	-73.09	160	6.6	85.4	276.0	COLOMBIA
3	670826	0036474	12.18	140.80	78	6.1	91.9	57.4	CAROLINE ISLANDS
4	671015	0800526	11.91	-85.98	181	6.2	86.4	289.7	NICARAGUA
5	671025	0059233	24.43	122.25	73	6.0	73.5	68.4	TAIWAN
6	680409	0229002	33.22	-116.19	12	6.0	77.3	323.7	CALIFORNIA
7	680514	1405054	29.93	129.39	162	5.9	71.4	59.9	RYUKYU ISLANDS
8	680702	0344517	17.61	-100.24	66	5.7	86.9	304.6	MEXICO
9	680805	1617055	33.31	132.31	48	6.2	69.5	55.9	SHIKOKU JAPAN
10	680920	0600033	10.76	-62.70	103	6.2	77.3	268.5	VENETZUELA
11	690328	0148295	38.55	28.46	4	5.9	25.8	165.1	TURKEY
12	690421	0719270	32.15	131.98	39	6.1	70.4	56.8	KYUHU JAPAN
13	700228	1052313	52.59	-175.04	161	6.0	63.3	10.4	ALASKA
14	700407	0534062	15.78	121.71	40	6.5	81.0	72.8	LUZON
15	700412	0401446	15.08	122.01	25	5.8	81.7	72.9	PHILIPPINES
16	700527	1205083	27.22	140.29	406	6.0	77.9	52.0	BONIN ISLANDS
17	700725	2241126	32.26	131.78	47	6.1	70.2	56.9	JAPAN
18	700726	0710379	32.31	131.83	47	6.0	70.2	56.8	KYUSHU,JAPAN
19	700729	1016204	26.02	95.37	68	6.4	60.4	90.9	BURMA-INDIA BORDER
20	700830	1746089	52.36	151.64	643	6.5	58.1	32.8	OKHOTSK
21	700826	1202304	6.37	-77.48	8	6.0	87.7	279.7	COLOMBIA
22	700927	0838369	6.52	-77.40	6	5.8	87.6	279.7	COLOMBIA
23	710518	2244390	63.92	146.10	0	5.9	46.4	29.6	EAST SIBERIA
24	711124	1935285	52.85	159.22	99	6.4	59.4	27.6	KAMCHATKA
25	711202	1718240	44.77	153.33	38	6.2	65.6	34.8	KURILE ISLANDS
26	720410	0206500	28.39	52.78	11	6.0	41.1	133.9	IRAN
27	720424	0957212	23.60	121.55	29	6.1	73.9	69.4	TAIWAN
28	720425	1930080	13.38	120.34	38	6.4	82.5	75.1	MINDORO,PHILIPPINES
29	720803	0440529	51.20	-178.13	24	5.7	64.4	12.7	ANDREANOF ISLANDS
30	720903	1648295	35.94	73.33	45	6.2	42.3	105.3	KASHMIR
31	730130	2101138	18.53	-102.93	48	6.1	87.0	307.3	MEXICO
32	730531	2339520	24.31	93.52	1	5.8	61.1	93.5	BURMA
33	730626	2331550	43.01	146.66	10	5.8	65.4	40.5	KURILE ISLANDS
34	730828	0950391	18.25	-96.58	75	6.6	84.9	301.6	MEXICO
35	740713	0118232	7.76	-77.57	12	6.4	86.5	280.4	COLOMBIA
36	750119	0801580	32.39	78.50	10	6.2	47.5	102.7	KASMIR-TIBET BORDER
37	750613	1808178	43.26	147.39	72	5.9	65.4	39.8	KURIL ISLANDS
38	750629	1037406	38.79	130.09	549	6.1	63.8	55.0	SEA OF JAPAN
39	750710	1829158	6.51	126.65	81	5.9	91.4	72.4	MINDANAO
40	750802	1018197	53.48	-161.39	46	6.0	63.0	1.1	SOUTH OF ALASKA
41	750815	0728245	54.92	167.87	41	5.8	59.0	21.1	KOMANDORSKY ISLANDS
42	751001	0330014	-4.83	102.24	47	6.0	90.8	99.3	SOUTHERN SUMATRA
43	760408	0240239	40.31	63.72	10	6.2	34.5	111.9	UZBEKISTAN
44	760511	1659482	37.56	20.35	33	5.8	26.3	179.8	IONIAN SEA
45	760727	1942540	39.56	117.87	10	6.1	58.5	64.0	NORTHEASTERN CHINA

Table VI.5.1

List of earthquakes used in this study.
Distance and azimuth are computed relative to UME,
which is the central station in our network.

Event	COP	KEV	KIR	KJF	KON	KRK	NUR	SOD	UME	UPP
1						40				
2						44				
3						44				
4						43				
5						44				
6						44				
7						44				
8						44				
9						44				
10						43				
11						45				
12						44				
13					35					
14			45		35					
15		43	45		35		45		47	43
16		41			35		45			
17			45		35					
18									46	
19			45							41
20	31	46		46			45			
21	30			46	32		44			
22		42		46			44			
23		47		49	35		44		48	
24		46					44			
25		47		43			45			
26	29	44	45	48	32		47		48	42
27										
28			43	45			46			
29	30			48	35					42
30			47		31				49	
31										42
32				46					48	
33	29				33		46		47	40
34				47	34		43			
35										43
36								43		
37								45		
38								45		
39								44		
40								46		
41								44		
42								46		
43								47		
44								45		
45								47		
Mean	29.8	44.5	45.0	45.4	33.9	43.6	44.8	45.2	47.6	41.9
St. err.	0.4	0.8	0.4	0.5	0.4	0.4	0.3	0.4	0.4	0.4
N	5	8	7	10	12	12	12	10	7	7

Table VI.5.2

Moho depths for our ten stations as derived from each individual event. The event numbers correspond to those of Table VI.5.1.

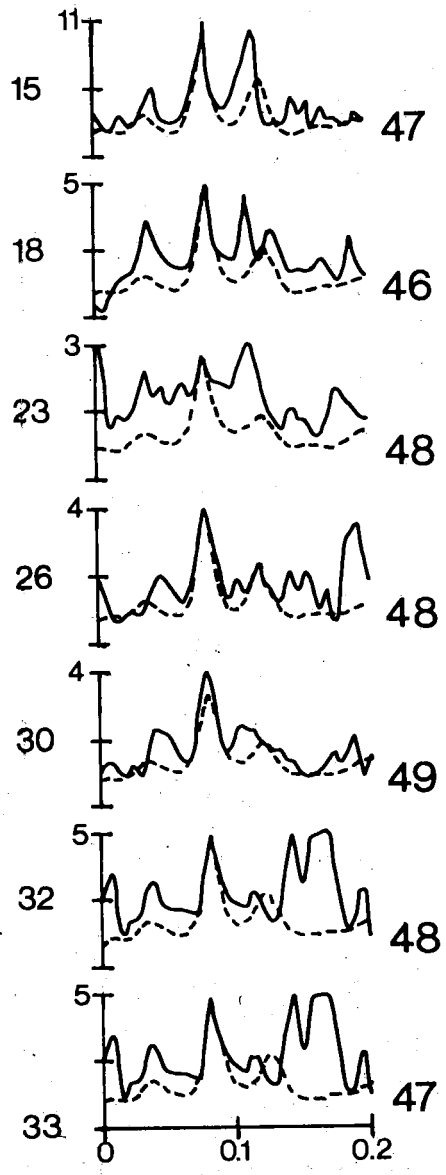

Fig. VI.5.1 Example of observed (full line) and theoretical (dashed line) spectral ratio for the seven events from UME. Event numbers are given to the left, and the corresponding Moho depths to the right.

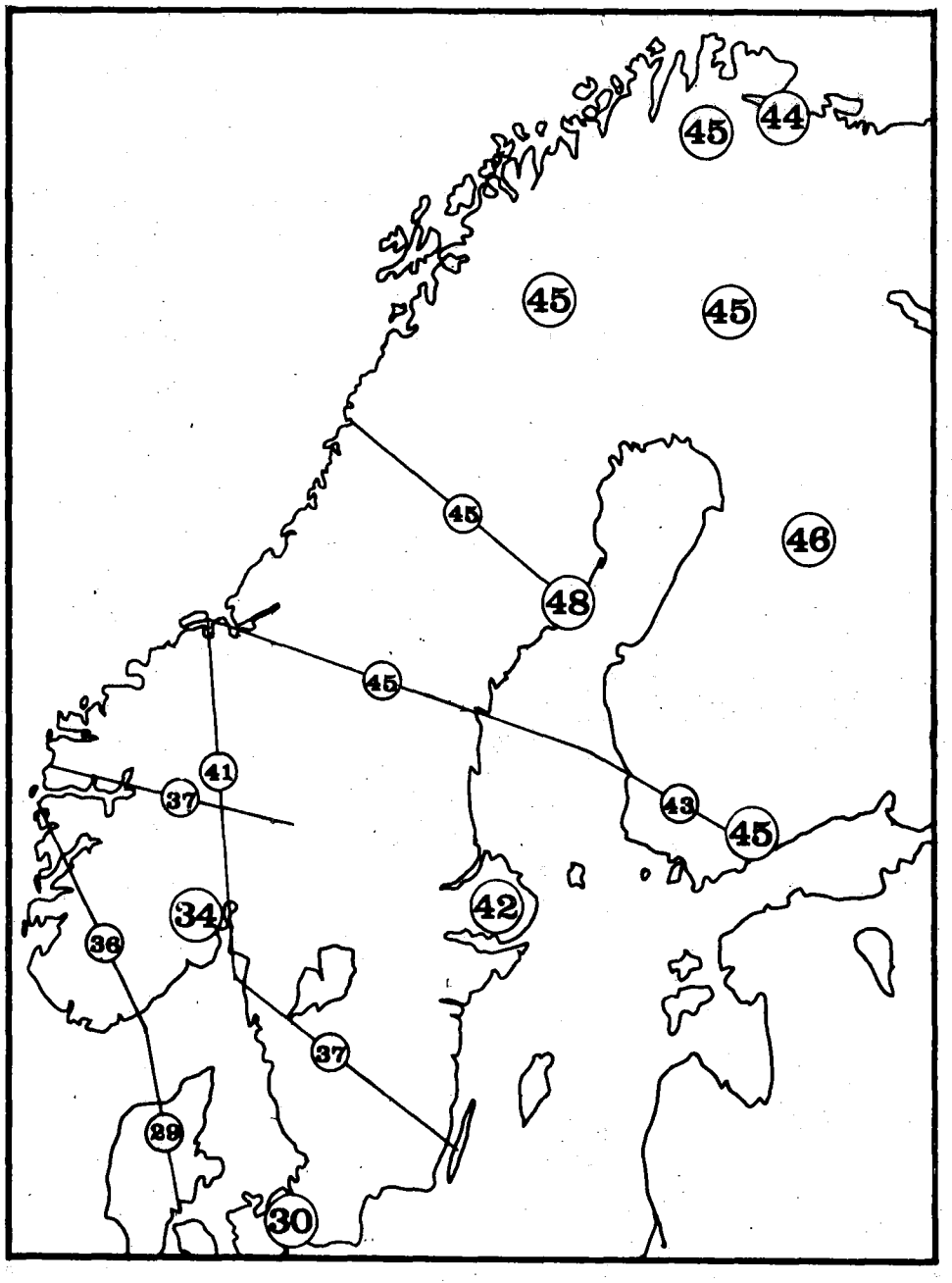

Fig. VI.5.2 Moho depths for Fennoscandia. The depths derived in this study are plotted as large encircled numbers, and the smaller numbers refer to average depths from refraction studies, where also the profile is indicated by a straight line.

VI.6 Lg, Li and Sn Propagation Characteristics Across Eurasia

WWSSN SP and LP records from some 40 earthquakes and presumed nuclear explosions in Western Russia and Central Asia have been examined thoroughly. The corresponding data base, travel times and amplitudes/periods for all prominent phases comprises readings from some 15 stations in the distance range 5° to 35°. Preliminary results are as follows: distinct and prominent Lg, Li and Sn arrivals are seldom observed beyond 15°. In the distance range 5°-15° first P arrivals are generally stronger than Lg type of waves. A notable exception here is a presumed explosion in the Kola peninsula while propagation across the Ural mountains is less efficient though better than for propagation paths across the Himalayas. The phase velocities of the Lg, Li and Sn phases are relatively stabel; typical values being 3.50 km s^{-1}, 3.80 km s^{-1} and 4.50 km s^{-1} (see Fig. VI.6.1). Notwithstanding the fact that the amplitude observations exhibit considerable scattering, making it difficult to assess the discrimination potential of these phases, amplitude decay curves as a function of epicentral distance have been constructed. One example of such a curve is given in Fig. VI.6.2. Also, these decay curves are 'matched' to those of P-waves, enabling us to estimate m_b-detection thresholds for these phases as well. To provide a better understanding of Lg-propagation characteristics, structural investigations based on ISC-reported time residuals will also be attempted.

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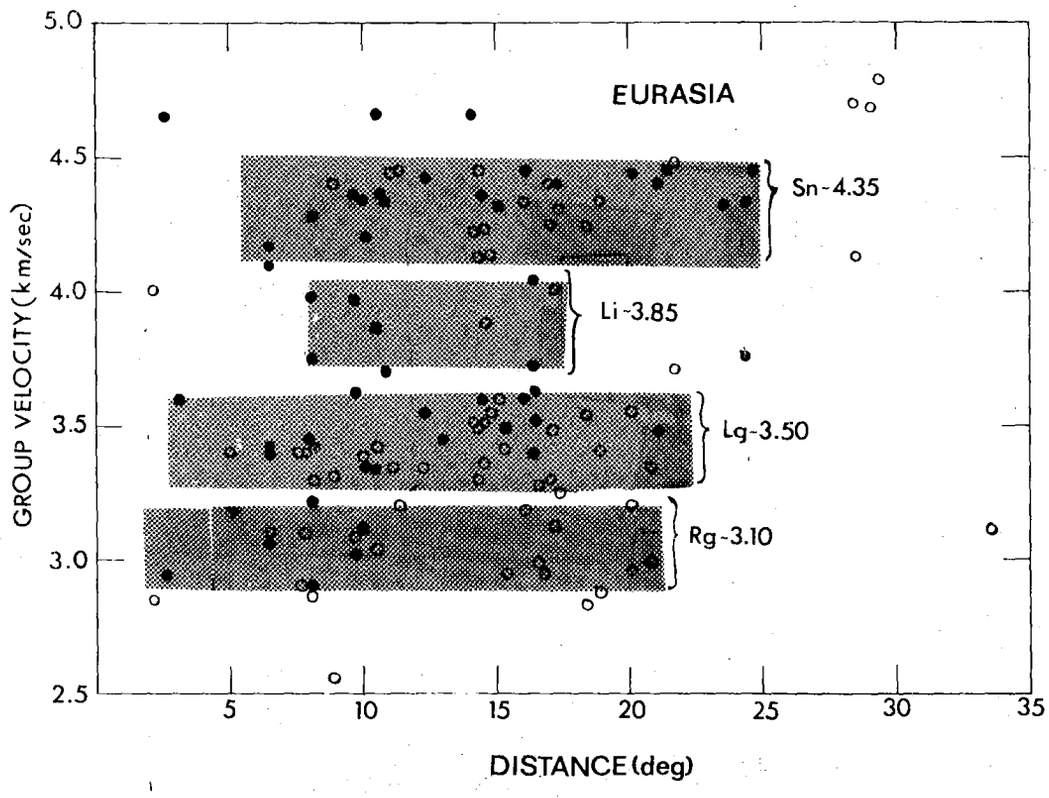

Fig. VI.6.1 Observed phase velocities for the phases Sn, Li, Lg and Rg.

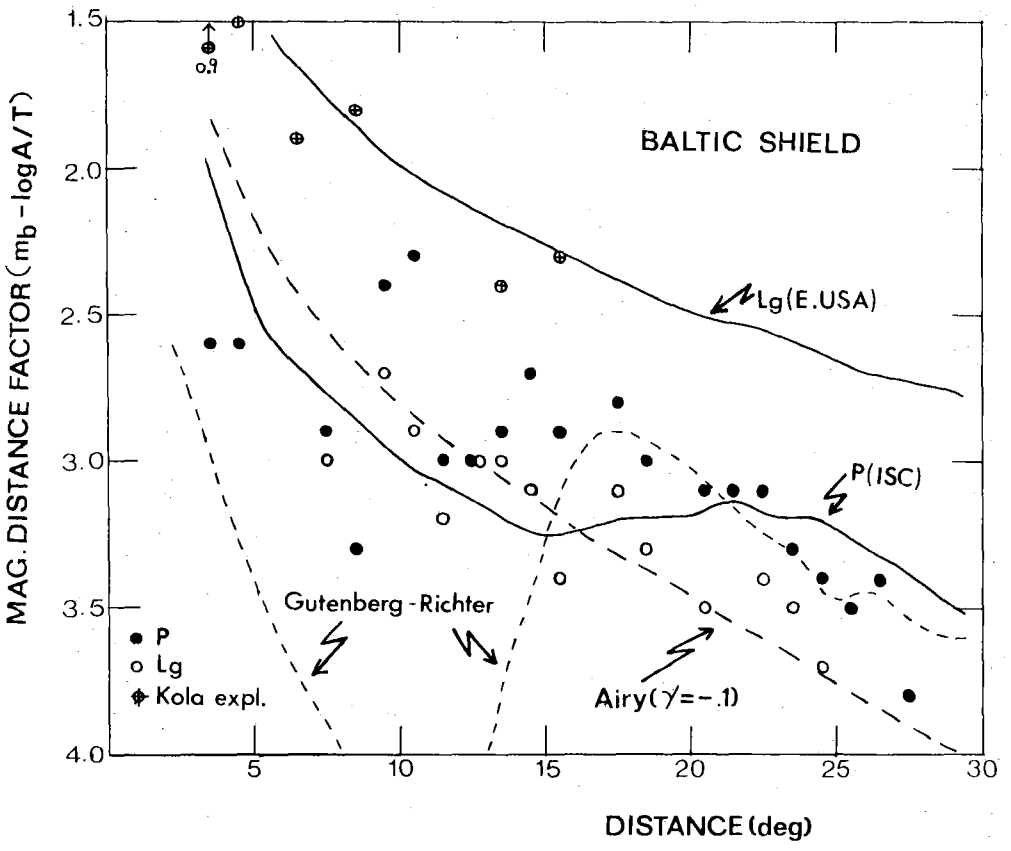

Fig. VI.6.2 Amplitude decay curves for P and Lg phases from explosions observed on Finnish stations.