SEISMOGRAPH RECORDING IN SWEDEN, NORWAY - WITH ARCTIC REGIONS, DENMARK - WITH GREENLAND, AND FINLAND

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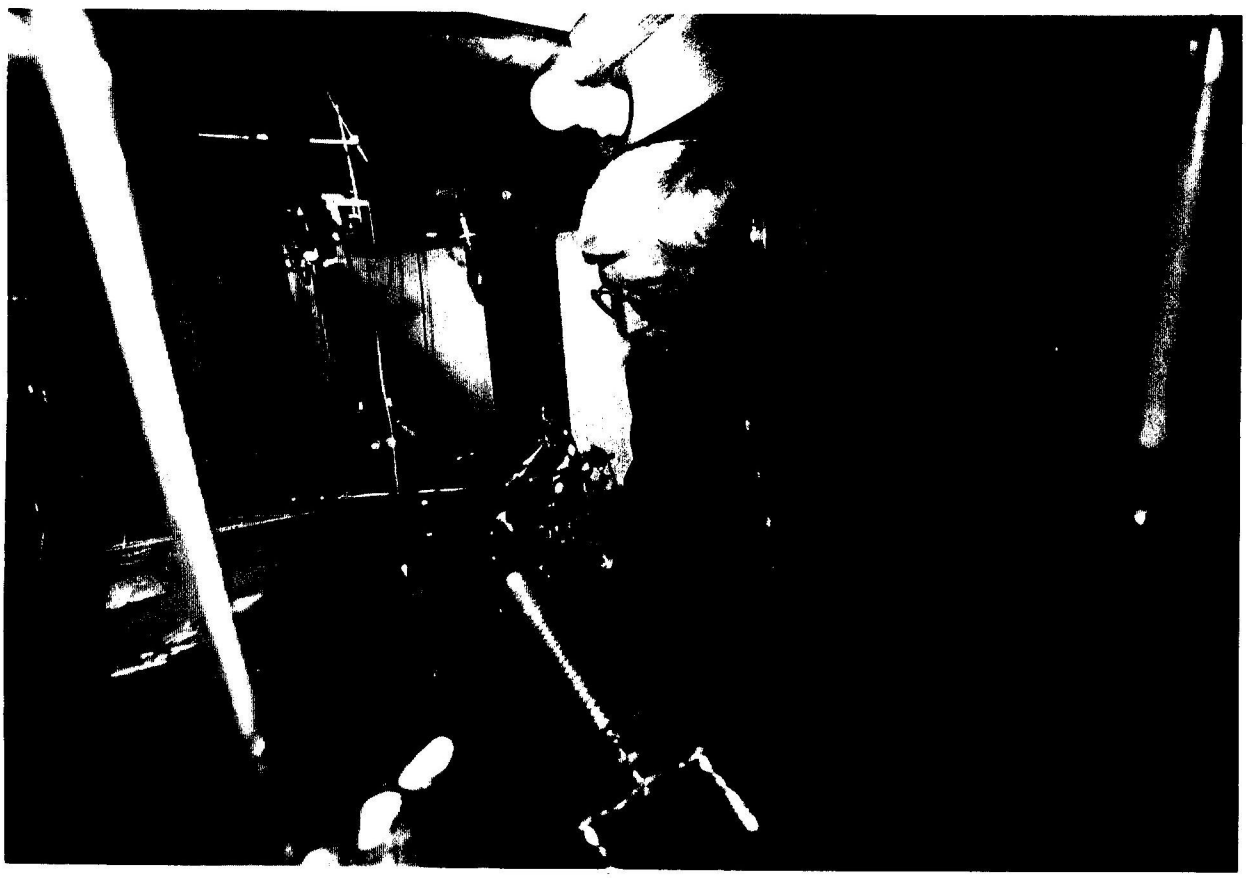

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HISTORY OF SEISMOLOGICAL STATIONS IN DENMARK WITH GREENLAND

by

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Abstract

The first seismographs in Greenland were installed thanks to a private initiative. They were operated in the years 1907-1912. Seismograph stations were installed at two sites in Copenhagen and two sites in Greenland in 1926-1928. In Copenhagen several types of systems were tested. In Greenland, each station, Ivigtut and Scoresbysund, had only one system, each of different type. A short-period, vertical-component seismograph was added to the Copenhagen station in 1936 and to the Scoresbysund station in 1950. Otherwise the stations were kept unchanged until the WWSSN was introduced. During the International Geophysical Year 1957/58 an additional seismograph station was built in Greenland, at Station Nord. In the early 1960s the Danish seismograph network was modernized with equipment from the WWSSN. Since 1977 the local seismicity in Denmark has been studied using mobile seismograph sets. Three tele-operated seismometers were introduced in 1979. In recent time most of the seismograph signals are digital and stored in computers. Broadband sensors are installed in Copenhagen and Søndre Strømfjord, Greenland.

1 The early years

The Danish history of seismology began in 1906 when the biologist M. P. Porsild was ready to leave for Greenland to set up an Arctic Station on the island of Disko near the settlement Godhavn. He was approached by Lt.Colonel E. G. Harboe who proposed to include a seismograph at the station. But not until 1907 was the observatory ready. Professor Gerland in Strassburg offered to lend him two seismographs for a period of five years. But private means and a donation from the Carlsberg Foundation made it possible to buy from J & A Bosch two 100 kg horizontal pendulums with recording on smoked paper. Seismograph operation continued until at least 1912.

E. G. Harboe (1845-1919) wrote several papers on seismology. He attended the first international meeting of seismologists in Strassburg 11 - 13 April 1901, where the International Association of Seismology was proposed. The Danish government approved, on 21 July 1914, his application for Denmark to join the association. But then the first world war came.

2 The Inge Lehmann period

The next development did not come until 1926, when the new director of Den Danske Gradmaaling, N. E. Nørlund (1885-1981), planned to make geodetic measurements in Greenland and to supplement the results with geophysical observations. He proposed seismograph stations to be installed in Greenland. But in order to gain experience with seismographs he also initiated the Copenhagen seismograph station. He found a quiet place

in the abandoned fortification around the town.

In two caponnières he put several different seismographs, probably in order to test the performance. The most impressive seismographs were the Wiechert 1000 kg inverted pendulum (horizontal) and the corresponding 1300 kg astatic vertical pendulum, both recording on smoked paper. The installation of the horizontal pendulum was finished in November 1926 but the vertical seismograph was not ready until July 1927. In opposition to these heavy mass mastodons, a pair of Wood-Anderson torsion seismographs possessed the smallest mass. The mass is a small cylinder of copper which rotates about a vertical axis in a magnetic field providing the damping, and a small mirror on the mass reflects light on photographic paper. Two horizontal-component Milne-Shaw seismographs also belonged to the group of recording the movement of small mass direct on photographic paper.

However, the "Russian Pendulums", a set of Galitzin-Wilip electromagnetic seismographs, were superior to the above "mechanical" seismographs. With a band-pass shaped response centered around 6 s, they were very well fitted to study the P-wave and especially the S-wave groups of teleseismic events. These records were the basis for many of I. Lehmann's important papers.

Geodætisk Institut succeeded in April 1928 Den Danske Gradmaaling, and I. Lehmann (1888-1993) became chief of a new "Seismisk Afdeling".

Beside the seismograph station in Copenhagen two stations were also installed in Greenland. In the southern part, a mining town, Ivigtut, was built around an open pit. Here in an underground cave the large Wiechert seismographs similar to those in Copenhagen were installed in 1927. The wire-less operator changed the records and took care of the clock corrections.

The other seismograph station was equipped with the Galitzin-Wilip system. It was put up in the "middle of nowhere". A new colony, Scoresbysund, had recently been founded based on 10 families moving almost a thousand km to the north from the overpopulated Angmagssalik. A wire-less station was planned for this new colony . With assistance from the Carlsberg Foundation a seismograph station was incorporated in these plans. An expedition arrived in Greenland in August 1927 and began building the houses, excavating the pendulum cellar, and erecting the antenna. The pendulums were installed in a cellar on the rim of the rocky hill the station was built on. The roof was covered with plenty of very large stones to keep the temperature constant. The galvanometers and the recording drums were situated at one end of the station house, and the radio and electricity generator were at the other end. Another house was built for the operator. Recording of the horizontal components began 12 January 1928, and in July the vertical component was also ready to start recording. The station building in Scoresbysund was rebuilt in 1933 after the first one was burnt down in 1932. Figure 1 shows seismographs in Scoresbysund.

The presence of the Galitzin seismographs in Copenhagen provoked the study of the behavior of the electric circuit in these seismographs. The Operational Calculus developed by Heaviside was applied in 1931 by J. Rybner (1902-1973), who later became professor at the Technical University of Denmark. He proposed use of electric filters in seismographs, but he was too early. The technology was not ready, and his work seems not to have influenced the later developments. Also some studies on calibration of the seismographs seem not to have had any impact.

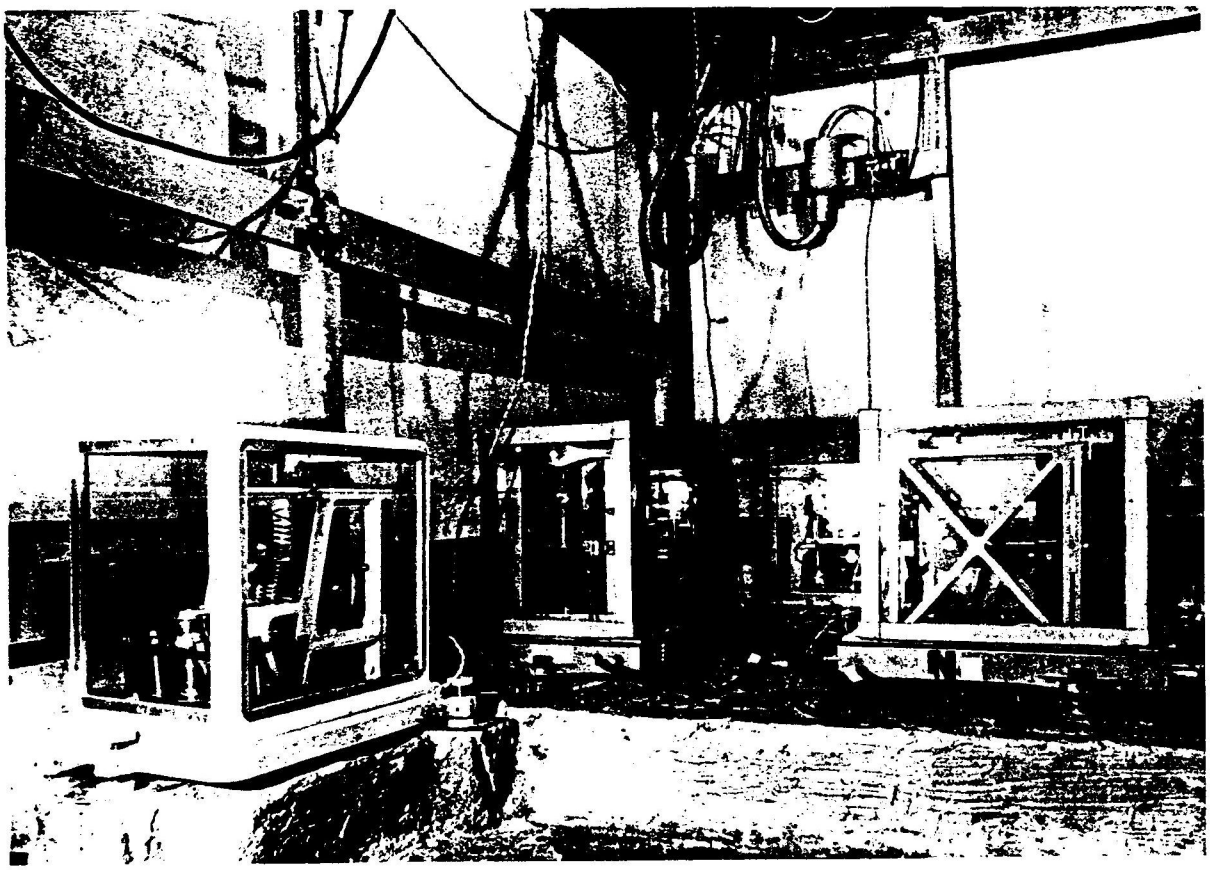

Figure 1
Seismographs in cave at Scoresbysund, Greenland.

The park of instruments in Copenhagen was expanded in 1936 with a new short-period, vertical-component Benioff seismograph from Pasadena, probably the first one to be installed in Europe.

During the 2nd World War the communication with the stations in Greenland was broken. The stations in Greenland got supplies from the US Coast and Geodetic Survey, where the seismograms also were analyzed. However, the Scoresbysund station had problems and recording was interrupted between 1944 and 1946. In Copenhagen the station was kept running most of the time except for a few dramatic episodes. Since November 1943 access to the station was denied to anybody except the normal operator, who was known to the soldiers. The most serious interruption came in the chaotic period when Germany capitulated to the allied.

After the war foreign currency was very sparse, but with some effort Danish manufactured magnetometers were traded for a short-period, vertical-component Grenet seismograph, which was sent to Scoresbysund in 1950 to extend the period range of this station to short periods.

In 1953 Lehmann retired from the institute to devote her time fully to scientific work, mainly in Canada and the USA. Except for one assistant, who was occupied with the practical work at the Copenhagen station, Lehmann was working alone in the later years, and nobody had been prepared to succeed her.

3 1950s: Expansion of the network

Lehmann was succeeded by H. Jensen (1915-1974), an experienced geodesist. However, Lehmann transferred almost no tradition in seismology to her successor.

Both in Copenhagen and in Scoresbysund the vertical component of the Galitzin-Wilip seismometers showed instability when tuned to periods larger than about 10 s. However, the galvanometers were designed with a 12.5 s period, and the theory of the Galitzin seismograph was based on seismometer and galvanometer having the same period. In the 1950s the Askania Werke in Germany began production of slightly improved copies of the old Galitzin-Wilip seismographs. A vertical component of this type of instrument was ordered and in 1955 the new instrument was installed in Copenhagen and ready for tests.

Jensen combined the three components of the Galitzin records into ground movement vectors in his studies of microseisms. But this was difficult when the records were made on separate drums. A triple drum recorder was constructed and replaced the older recorders in 1959. After several years overlap with the new WWSSN seismographs (see below), the recording of the Galitzin-Wilip seismographs in Copenhagen were stopped in 1972.

From England came, in 1955, a new handy short-period electromagnetic transportable seismograph, the Willmore (later: Mark I). The galvanometer had a very small mirror and fitted into a sturdy recording box designed for easy moving around. For some time this seismograph was tested at a new astronomical observatory, Brorfelde, some 50 km west of Copenhagen. However, the underground of thick glacial deposits showed to be very noisy and the seismograph was soon removed. It was later used in Ivigtut.

In Ivigtut the open pit had been enlarged considerably since 1927. The wall approached the seismographs and as the mining explosions also grew larger the sensible mechanical Wiechert seismographs suffered damage and were taken out of operation in 1953. They were replaced, in 1955, by one of the Milne-Shaw instruments from Copenhagen. Also a Willmore seismograph was operated during the International Geophysical Year (IGY) 1957/58. However, due to the very large seismic noise in southern Greenland the station was closed in 1960.

In preparation for the IGY Professor H. Menzel, Hamburg proposed intensive observations of microseisms in the Arctic. His assistant, K. Strobach, had constructed a vector recording seismograph, which was proposed to be installed at several places in the Arctic. The planning committees also recommended studies of the seismicity in the Arctic. H. Jensen proposed a seismograph station to be added to Station Nord, an airstrip in northeast Greenland. The Strobach seismograph was modified to record on the usual photographic recorder drum. A Willmore seismograph was added to the station. The station was very competently operated during the IGY. The site had shown to be so well suited that the seismograph station was maintained also after the IGY.

4 1960s: The WWSSN modernization

The US Coast and Geodetic Survey announced in 1960 the World Wide Standardized Seismograph Network (WWSSN) consisting of equal equipment for about 100 stations worldwide. Equipment for four of these stations went to Denmark. One unit was installed at the Copenhagen station. The three other units went to Greenland, where they were installed

in three new buildings, all equal. Two units replaced the seismographs at Station Nord and in Scoresbysund. At the latter site the new building was put at the meteorological station Kap Tobin just south of Scoresbysund. The third unit went to a new site near the Arctic Station in Godhavn.

5 1970s and 1980s: Substitution and further development

Station Nord was closed down in 1972 and the instruments were moved to Danmarkshavn. Kap Tobin was closed down in 1980 and the old station in Scoresbysund was reopened in 1982, but only with short-period and long-period, vertical-component seismographs. In 1988 the WWSSN stations were upgraded to record on heat sensitive paper instead of photographic paper.

Since 1977 three MEQ-800 units with Geotech-Teledyne S-13 seismometers have been used temporarily at different places, Mønsted (Århus Univ.), Gøttrup, Tingbæk and also during two months of a Canadian experiment in 1978 in Upernavik, Greenland. One unit is still in use on Bornholm, where the recording began in 1981.

In the late 1970s the Swedish Nuclear Power Inspectorate (SKI) requested the Swedish National Defence Research Institute (FOA) to conduct a seismicity study of the southern part of Sweden. Danish power plant companies arranged to extend the area of investigation to incorporate also Denmark. Three stations in Denmark were thus added to the network. One station, Mønsted, situated in an underground limestone mine, comprised three-component S-13 seismometers and electronics to send frequency modulated signals by rented telephone lines to a central data center in Stockholm. The other two stations, one at Sondrup near Gylling Næs in Jutland and one at Lille Linde on Stevns, Zealand, were only equipped with a vertical-component S-13. The signals were digitized and utilized at the data center in Stockholm. The digital data were archived on magnetic tapes. The signals from the Danish stations were also recorded at the Danish data center at the Geodætisk Institut, Copenhagen. The station Sondrup often recorded a type of events not seen elsewhere in the network. A substation, Kalsemade, was set up to operate for a few months to study these events. The SKI network was operated for about five years. Operation of the three Danish stations was continued, with recording only at the Geodætisk Institut (today: Kort- og Matrikelstyrelsen). Sondrup was closed down in 1986.

6 Experimental stations and digital seismographs

After the LASA experiment US experts were looking around for other places in the world to test the array concept. Low noise was expected in northern Greenland, but the influence of the ice-cap on the seismic waves was unknown. In 1966 a US-Danish project installed a mini-array on the top of the northern part of the ice-cap. It was named the Inge Lehmann station. The results were very promising, but the logistics made continued operation of this station too expensive.

In another project studying seismic noise three automatic recording stations were installed in northeast Greenland at Station Nord, Daneborg, and Scoresbysund during the summer of 1991. Data were recorded on DAT tapes, which were changed bi-weekly by local people. After a few years the equipment was returned to the Lawrence Livermore National Laboratory,

California.

The station in Godhavn was upgraded in 1982 to be a DWWSSN station, i.e., a WWSSN station with added digital recording on magnetic tape.

Broadband seismographs with digital recording would give new opportunities, and a set of three-component VBB instruments were ordered from G. Streckeisen & Co., Switzerland. The sensors were installed in Copenhagen during 1987, but programs for collecting the data were only slowly developing.

Just before an international technical test in 1991 (GSETT-2) some programs from NORSAR were installed, and Copenhagen could participate in this test with digital data. Unfortunately, lightning from a thunderstorm later smashed the electronics. Repair in Copenhagen of the complicated digitizing system failed, but experiments showed the feed-back system was not harmed. A Nanometrics RD3 digitizer was added to the system in 1994 and digital data were again collected.

In 1994 the telemetered stations Mønsted (MUD) and Lille Linde (LLD) were also equipped with Nanometrics RD3 digitizers. All Nanometrics data streams are sent to NORAC, a multiplexer constructed at and installed in Copenhagen by NORSAR.

In 1993 the US Geological Survey proposed a modernization of the DWWSSN station in Godhavn with STS1 seismometers and new IRIS data acquisition equipment. However, the station is not situated on the Greenland mainland and heavy storms in the sea disturb the records. A new site was chosen near the international airport upstream Søndre Strømfjord. An airport has good telecommunication and easy access, and the airport technicians can look after the instruments. The instruments were installed at the new site (SFJ) in March 1996.

A SEISLOG system is procured from Bergen University to be used on Bornholm. The system is still (1996) being tested before installation.

Table 1 lists site locations and time periods of operation of Danish seismograph stations.

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TABLE 1. List of Danish Seismograph Stations

Name	Code 1)	Lat. (°N)	Long. (°E)	Alt. (m)	Time of operation
Station Nord	NOR	81.6000	-16.6833	36	1957-1972, 1991-1993
Inge Lehmann	ILG	77.9167	-39.2333	2400	1966-1967
Danmarkshavn	DAG	76.7714	-18.6547	30	1972-
Daneborg (dbg)		74.3000	-20.2333	50	1991
Upernavik		72.7850	-56.1517	95	1978
Scoresbysund	SCO	70.4833	-21.9500	69	1928-1944, 1946-1963, 1982-
Kap Tobin	KTG	70.4194	-21.9844	6	1963-1980
Godhavn	GDH	69.2500	-53.5333	23	1962-1996
Arctic Station 2)		69.2472	-53.3903	1	1907-1912
Søndre Strømfjord	SFJ	66.9967	-50.6156	331	1996-
Ivigtut	IVI	61.2000	-48.1833	20	1927-1953, 1955-1960
Gøttrup		57.0350	9.2250	5	1977-1989
Thingbæk		56.8350	9.8083	50	1977-1978
Mønsted (Århus Univ.)		56.4603	9.1650	27	1974-1982
Mønsted (mine)	MUD	56.4550	9.1733	12	1977-
Sondrup		55.9047	10.0717	72	1979-1986
Kalsemade		55.8567	10.1881	1	1980-1981
Copenhagen 3) Kap. XIV	COP	55.6853	12.4325	13	1927-
Copenhagen 3) Kap. XIII	(COP)	55.6800	12.4297	13	1927-1972

TABLE 1. (cont).

Name	Code 1)	Lat. (°N)	Long. (°E)	Alt. (m)	Time of operation
Lille Linde	LLD	55.3331	12.2150	8	1979-
Bornholm	BSD	55.1139	14.9147	88	1981-

1) Registered by ISC/NEIS.
2) Time of end of operation uncertain.
3) Both site locations are within 0.4 km (0.2') from the usually given coordinates: 55°41'N, 12°26'E.