HISTORY OF INSTRUMENTAL SEISMOLOGICAL OBSERVATIONS IN SWEDEN

by

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Abstract

Instrumental seismology in the Nordic coutries started with the installation of the Wiechert horizontal-component seismograph in Uppsala in 1904. This instrument is still in operation with practically unchanged characteristics. Other early seismograph stations in Sweden were located at Vassijaure (Wiechert 1906-1915), Abisko (Wiechert 1915-1951; Golitzin 1919-1943) and Lund (Wiechert 1917-1953). A modernization and extension of the Swedish Seismograph Station Network took place in the 1950s and 1960s with the installation of many electromagnetic seismometers. The current (1996) network run by the Seismological Department, Uppsala University, consists of stations at six sites, Uppsala, Kiruna, Umeå, Uddeholm, Delary and Myrviken. During a one-year period, 1969-1970, Uppsala University also operated a telemetric triangular array with an aperture of 100 km and the main station in Uppsala.

Seismic monitoring has also been performed by the National Defence Research Institute (FOA). The Hagfors array, with the main task to detect and analyse underground nuclear explosions, opened in 1969. Since 1994, the basic record analysis is made at NORSAR, Norway. A mini-array was opened at Näsudden (Malå), Lappland, in 1989. In 1979-1980 a regional telemetric network of 17 stations was installed in the southern part of Sweden, with the purpose to record the local seismicity and analyse its impact for the safety of nuclear power plants and the storage of radioactive waste in the bedrock. The stations were operated until 1985 (first station closed) to 1994 (last station closed). Local telemetric networks were operated in northern Sweden 1987-1989 (six stations), and in southeastern Sweden 1987-1988 (three stations) and 1987-1993/1994 (three stations).

1 The Uppsala Wiechert seismograph

The birth of seismological instrumental observations in Sweden - and Fennoscandia - dates back to the beginning of the 20th century or, to be more specific, to October 4, 1904, when a Wiechert-type mechanical instrument, a 1000 kg inverted horizontal pendulum, started operating in the Observatory Park in *Uppsala*, in a building erected specially for this purpose. The installation of the seismograph was a result of a fruitful cooperation between the universities in Göttingen and Uppsala (see Schröder, 1988). Professor (in meteorology) H. H. Hildebrandsson (1838-1925) was in contact with professor E. Wiechert (1861-1928) through works on atmospherical electricity. Due to this acquaintance and also to results of the International Seismological Conference in Strassburg in 1901, Hildebrandsson tried and succeeded to establish convenient conditions for seismological observations in Uppsala. Wiechert, who in 1898 became director of the Geophysical Institute in Göttingen, started seismological observations already at the end of the last century. F. Åkerblom (1869-1942), the assistant of Hildebrandsson, visited Göttingen to learn about the seismological instrumentation and seismogram interpretation. After his return to Uppsala, he prepared the installation of a seismograph within the premises of the Meteorological Institute. As mentioned above, the instrument was deployed in October 1904 under the supervision of G. Bartels, an engineer from Göttingen. Åkerblom later became professor of meteorology and the first to carry out seismological research in Sweden.

The Uppsala Wiechert seismograph has been in continuous operation since 1904. The practically unchanged characteristics during the entire period of nine decades allow immediate comparison between earthquakes from the beginning of the century and more recent events (Kulhánek, 1988). Amplitude characteristics of the two horizontal components are shown in Figure 1. For comparison, the response curve of a Golitzin electromagnetic seismograph is also displayed in the figure. This type of instrument was installed in Abisko in Swedish Lapland in 1919 (see below). As seen in the figure, the response of electromagnetic instruments decays with f^3 at very long periods, whereas the corresponding decay for mechanical systems is f^2. Therefore, Golitzin historical seismograms are preferred for studies of waves in the period range 5-20 s and Wiechert records are used for waves with longer periods, e.g., mantle waves (see Okal, 1992).

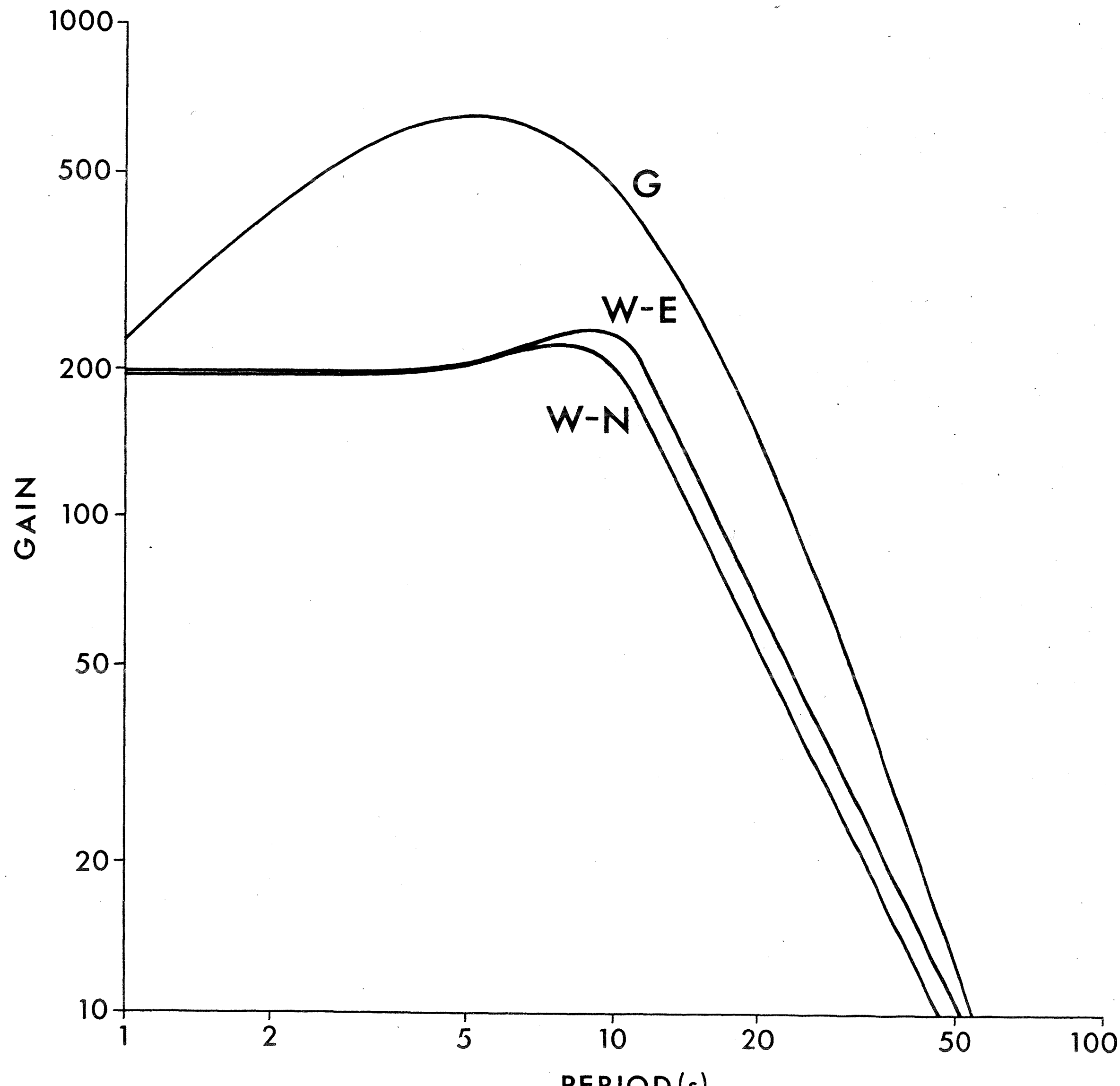

Figure 1
Amplitude response curves for the Uppsala Wiechert horizontal components, W-E and W-N, and the Abisko-Kiruna Golitzin vertical component, G (prior to February 1972).

At this writing (1996), more than 65,000 Wiechert records have been produced in Uppsala, all stored in archives at the Seismological Department. Uppsala Wiechert seismograms were systematically analysed from October 1904 to December 1955, except for the time from June 1905 to June 1906. All collected relevant information is summarized in annual Seismological Bulletins from Uppsala. The Bulletin provides the date, phase identification(s) and corresponding arrival time(s) for each recorded event. For a large event, the period(s) and amplitude(s), epicental distance, focal region and often a brief commentary are also given. Exceptionally (more recent events), information on the focal depth and first-motion polarity is included. The Bulletin also includes calibration constants, which were determined annually or more frequently. After 1959, the regular calibration tests were discontinued, leaving some uncertainty as to the instrumental response. However, frequent parallel magnitude determinations from Wiechert and other seismograms indicate that the response characteristics are rather stable[*)].

Uppsala Wiechert records constitute one of the most extensive, almost uninterrupted, homogeneous and well documented seismogram series available in the world, this in respect to the long time of operation, practically unchanged instrument constants and regular record analysis. This and similar series are invaluable for studying earthquake history of various regions and for comparative investigations of large historical earthquakes. The Seismological Department obtains frequent requests for record copies from observatories around the world.

2 Other seismograph stations before 1950

Several other seismograph stations operated in Sweden early in this century. In 1906, an 80 kg vertical-component Wiechert seismograph was deployed at *Vassijaure* in northern Sweden. In 1915, the apparatus was moved to *Abisko* where its operation ceased in 1951. In 1919-1943, the Abisko station was also equipped with a three-component Golitzin system with photographic recording via mirror galvanometers.

During the period 1917-1953, a Wiechert seismograph similar to that in Uppsala was in operation in *Lund* in southern Sweden. From 1917, there were thus three seismograph stations operating in Sweden, covering the country relatively well in the north-south direction. However, in contrast to Uppsala Wiechert records, seismograms from Vassijaure/Abisko were not analysed in a regular way and the available record collection, stored in Uppsala, is far from complete. The Lund records were analysed and stored in Copenhagen, from where they were transferred to the Uppsala archive in the 1980s. This series of records is also incomplete. Details of the operation of historical (first half of this century) Swedish seismograph stations are given in Table 1 and station locations are shown in Figure 2.

3 Uppsala University operated stations

3.1 1950s and 1960s: Formation of a national network

A vast instrumental modernization and station densification took place in Sweden in the 1950s and 1960s on the iniative of M. Båth (professor in seismology 1967-1981). Altogether, six

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[*)] A calibration in December 1996 showed that no significant change has taken place.

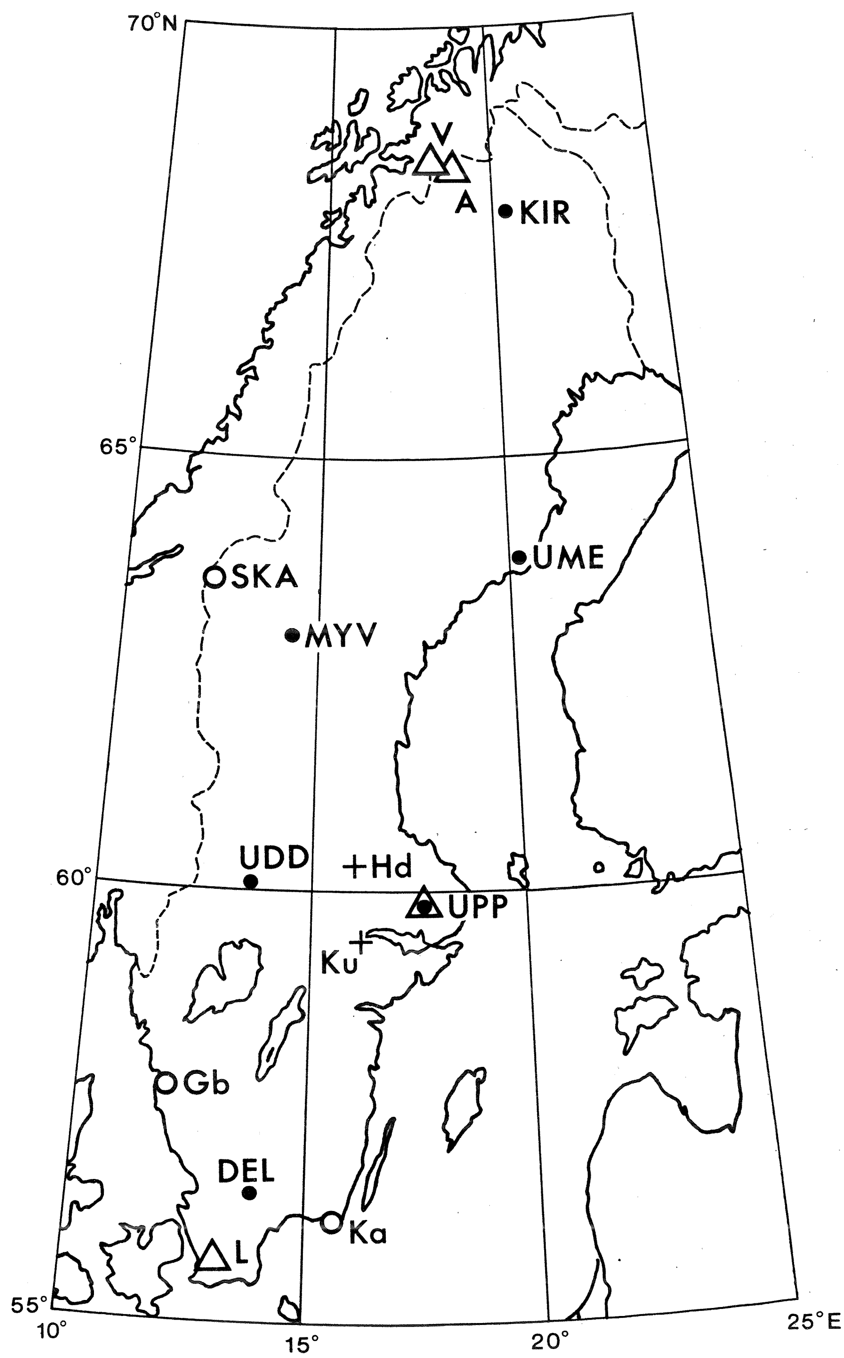

Figure 2
Sites of seismograph stations in Sweden not operated by FOA.
Open triangles: Stations operated before 1950. A=Abisko, V=Vassijaure, UPP=Uppsala, L=Lund.
Open circles: Swedish Seismograph Station Network (SSSN); closed stations.
Solid circles: SSSN; current stations (1996).
Crosses: Auxiliary stations of the telemetric array operated 1969-1970 with Uppsala as main station.
Cf Tables 1, 2 and 3.

permanent seismograph stations, all with recording on photographic paper, were operated by the late 1960s. Detailed information about all Uppsala University operated stations after 1950 is summarized in Tables 2 and 3 and the station locations are plotted in Figure 2. This network is named the Swedish Seismograph Station Network, in short SSSN.

In *Uppsala*, in 1950-1951, a new room with three large concrete piers was added to the old seismograph house and photographic recording rooms were arranged. A Grenet-Coulomb vertical-component seismograph was installed in 1951 and Benioff three-component instruments in 1955. In collaboration with Lamont-Doherty Geological Observatory, Columbia University, New York, three Press-Ewing instruments were installed and started operating in 1957.

In *Kiruna* in Swedish Lapland, a seismograph building was erected in 1951 on the premises of the Geophysical Observatory of the Royal Swedish Academy of Sciences. A Grenet-Coulomb instrument, similar to that in Uppsala, was installed in 1951. Three Golitzin instruments from the old station at Abisko were at the same time repaired and re-installed at Kiruna. In 1963, a vertical-component Press-Ewing instrument was also deployed.

After a thorough search for a suitable location in the province of Jämtland, a seismograph house was built in 1955 on the property belonging to the farm of *Skalstugan*. The instrumental installation (Grenet-Coulomb vertical-component) was finished by the end of 1955 and the continuous operation started in January 1956.

First plans for a seismograph station in *Göteborg* were made already in 1954. After searching for a suitable recording site, the station was installed in the basement room of the Physics Department of Chalmers Institute of Technology. Following a period of test recordings, continuous operation started in January 1958. The instrument was the same vertical-component Grenet-Coulomb previously operated in Uppsala. The operation of the Göteborg station was discontinued in 1968.

The *Umeå* station, located near the coast of the Gulf of Bothnia, operated a vertical-component Grenet-Coulomb seismograph from 1960 to 1962. In 1962, the world-wide standardized equipment of the U.S. Coast and Geodetic Survey was installed. Umeå was a complete WWSSN station with three-component, short-period (Benioff) and long-period (Press-Ewing) instruments.

The station *Karlskrona* on the south coast of Sweden was also provided with a vertical-component Grenet-Coulomb instrument, similar to that in Uppsala. This station was opened in 1961 and closed down in 1968.

The most sensitive station in the Swedish network is *Uddeholm* in the province of Värmland. During the period 1966-1967, Uddeholm operated a vertical-component Grenet-Coulomb instrument. In 1967, this was replaced by a Benioff vertical-component seismograph.

As mentioned above, the stations at Göteborg and Karlskrona ceased their operations in 1968. The reason was that a more sensitive site had been found in south Sweden, near *Delary* in the province of Småland. Delary operates a vertical-component Grenet-Coulomb seismograph since 1967.

Beside these stations, sensitivity tests were made at several other sites in the years 1964-1966, using Grenet-Coulomb seismographs. Temporary station sites were located at Askersund (province of Närke), Bollnäs (Hälsingland), Haparanda (Norrbotten), Hermanstorp (Småland), Lycksele (Lappland), Mora (Dalarna), Strömsund (Jämtland), Suppovaare (Lappland), Sveg (Härjedalen) and Uggelheden (Värmland).

3.2 The Uppsala triangular array

During a one-year period, from August 1969 to August 1970, the Seismological Institute, Uppsala operated a simple triangular array. The triangle was almost equilateral with an aperture of around 100 km and the sensors at the permanent station in Uppsala, *Hedemora* and *Kungsör* (Tables 2 and 3; Figure 2). All three stations were equipped with Grenet-Coulomb vertical-component seismographs. The signals were continuously transmitted over commercial telephone lines to the central recording unit in Uppsala (Borg and Båth, 1971). Extremely favourable geological conditions and consequently high signal coherence across the array (Kulhánek, 1973) prove that the area around Uppsala very well serves the purpose of array-station recording.

3.3 1980s: Modernization at Uppsala

Further modernization of SSSN took place in the 1980s, mainly at the central station in Uppsala. In 1983, a three-component, short-period system equipped with Teledyne-Geotech S-13 sensors and hot-stylus recording was installed. In 1989, a three-component broadband system equipped with leaf-spring Wielandt-Streckeisen seismometers was deployed together with a data acquisition system with 16 bits resolution and 20 Hz sampling, employing an IBM/AT personal computer.

3.4 Current SSSN

The current SSSN consists of six permanent stations, Uppsala (UPP), Kiruna (KIR), Umeå (UME), Uddeholm (UDD), Delary (DEL) and Myrviken (MYV), a configuration that almost equally covers the whole territory of Sweden (Figure 2). The stations operate a varying number of seismographs and altogether 24 channels are now in operation (Table 3).

The station at *Myrviken* in the province of Jämtland started its operation in December 1981 as a substitute for Skalstugan, which was discontinued in September 1981 due to logistic difficulties. Myrviken is equipped with an S-500 Teledyne-Geotech seismometer and a Portacorder with ink recording.

In Kiruna, the two medium-period, horizonal-component Golitzin seismographs and the ultra-long period, vertical-component Press-Ewing seismograph were closed down in 1982. In Umeå, the operation of the long-period instruments was discontinued between December 1990 and May 1994, but today the station is running just like in the WWSSN time.

A quartz clock is used for the timing at each of the six stations. Daily comparison with the time signal issued by the Swedish radio was used (except for MYV) until December 1993. Since December 1993, stations UPP, UME, UDD and DEL are making use of the DCF Mainflingen, Germany, transmitter. MYV is using the DCF signal since the time of installation in 1981 and KIR employed a GPS system from December 1993 to October 1994 and an OMEGA system after this period. The UPP S-13 recording is equipped with a standard Teledyne-Geotech timing system, model TG-120, with a 1.536 MHz temperature-controlled crystal oscillator.

Seismogram readings from the UPP, KIR and UME records are done regularly. For regional earthquakes, also records from the other stations are analysed. Larger events are reported immediately to the news media. Seismogram readings are sent regularly to international seismological centres and, as weekly (UPP only) and monthly bulletins, to observatories all over the world.

Considerable efforts have been made to establish a convenient seismogram storage system in Uppsala. After decades of improvisation, all records are now deposited in an archive at the Seismological Department. They are easily accessible for inspection and/or further analysis or processing. Upon request, we provide microfilm copies of photographic records and photographic copies of smoked-paper Wiechert seismograms.

4 Seismological monitoring by the National Defence Research Institute, Stockholm

Besides Uppsala University, seismological monitoring and research in Sweden have been performed by The National Defence Research Institute (FOA) in Stockholm. The main task for FOA in seismology has been to record and analyse underground nuclear explosions to provide seismological criteria for discrimination between this type of events and earthquakes. Monitoring of regional seismicity has been another task, specially in the early 1980s. Today, the activities in both detection and especially regional seismology are low.

4.1 The Hagfors Observatory and other stations monitoring nuclear explosions

Field measurements by FOA in preparation for the establishment of a seismic array for detection of underground nuclear explosions started in 1966 and the following year a place, Gunnerudssätern, near *Hagfors* in the province of Värmland was selected as the main station. The array, including a subarray at Hagfors and single substations at *Äppelbo* and *Stöllet*, opened in 1969. Radio link transmitted signals from the substations were recorded, together with signals from the main station, in both analog and digital forms at Hagfors. By 1973, subarrays were installed at all three sites. The station *Torsby* was added in 1975. The locations of these and other FOA operated stations are shown in Figure 3. More detail is given in Table 4.

Originally, record analysis was performed both in Hagfors and Stockholm. In the early 1980s, all analysis was moved to Stockholm. The Hagfors Observatory was later modernized to serve as a potential prototype station for monitoring underground nuclear explosions (for technical details, see Seismology 1989-1992, 1993). Since 1994, the basic data analysis is performed at NORSAR, Kjeller, Norway and readings are included in their bulletin.

In 1989, after more than a year of testing, a mini-array started operating in *Näsudden* in northern Sweden. The site was chosen to be close to the centre of the existing Fennoscandian arrays - ARCESS, NORESS, FINESA and Hagfors (see the Norwegian and Finnish contributions of these Proceedings).

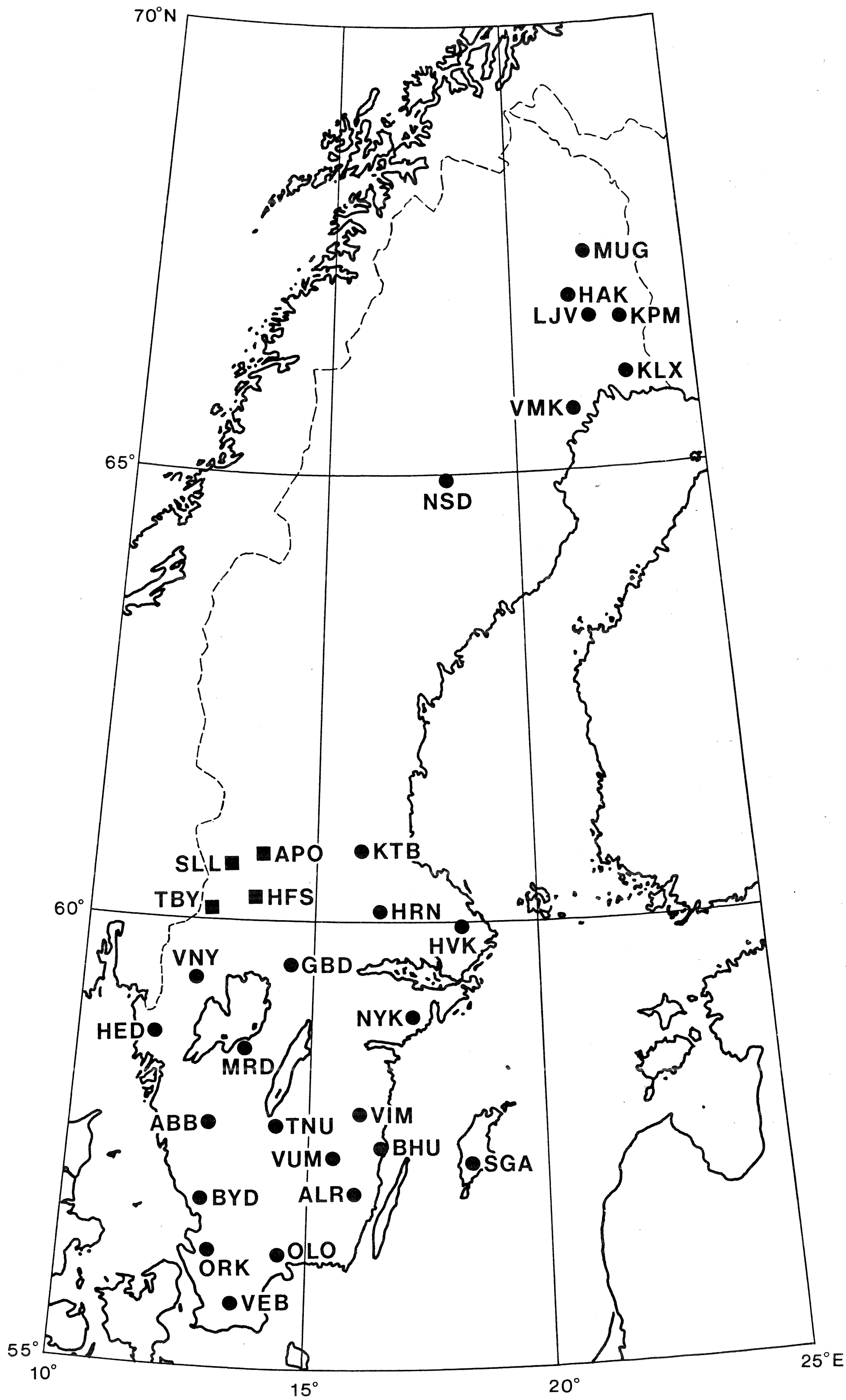

Figure 3
Sites of FOA operated seismograph stations. Squares denote the Hagfors array. Cf Table 4.

4.2 Networks for monitoring regional and local seismicity

Starting in 1979 (15 stations) and 1980 (two stations), a dense regional network of short-period seismographs was installed in the southern part of Sweden, up to approximately lat. 61°N (Figure 3). Together with the Hagfors array and three similar stations in Denmark, the result was a significant improvement in event detection and other signal analysis. Three of the Swedish and one of the Danish stations had three-component sensors and the remaining stations had a vertical-component sensor. The digital signals were transmitted on permanent telephone lines to a computer centre at FOA.

The Swedish part of the project was financed by the Swedish Nuclear Power Inspectorate (SKI) with the purpose to get a detailed picture of rock movements and stress patterns in the bedrock connected to earthquake activity, information of use for the seismic safety of nuclear power plants and potential storage of the radioactive waste in the bedrock. The project terminated in 1984/1985 and stations started closing down from 1985. The longest operating stations remained open until late 1994 (see Table 4).

Connected to projects funded by the Swedish Nuclear Fuel and Waste Management Co (SKB), two six-station, short-period, vertical-component local networks were operated from the autumn of 1987 (Figure 3). One was located in northern Sweden and closed down in the spring of 1989. The other was located in southeastern Sweden, with three stations closing in the late 1988 and the remaining three in 1993/94. Four of the stations of the southern network are on sites identical to SKI station locations. Again, records were transmitted on permanent telephone lines to the computer centre at FOA in Stockholm.

Acknowledgements

To build up, maintain and operate the SSSN would not have been possible without the essential economic contributions from the Swedish Natural Science Research Council, Ministry of Education, Uppsala University, Swedish Nuclear Fuel and Waste Management Co, National Board for Spent Nuclear Fuel, Knut and Alice Wallenberg Foundation, Royal Swedish Academy of Sciences, City of Kiruna and Skalstugan Foundation. Hopefully, future extended funding will facilitate a much needed upgrade of the SSSN (more broadband stations, digital recording, telemetric data transmission, etc.). L. Nordgren contributed material to the section on FOA's activities.

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TABLE 1. List of Historical Seismograph Stations in Sweden

Station	Lat. (°N)	Long. (°E)	Seismograph type, comp.	Record paper	Time of operation
Uppsala	59.86	17.63	Wiechert E,N	smoked	1904-
Vassijaure	68.42	18.18	Wiechert Z	smoked	1906-1915
Abisko	68.34	18.82	Wiechert Z	smoked	1915-1951
			Golitzin E,N,Z	photo	1919-1943
Lund	55.70	13.19	Wiechert E,N	smoked	1917-1953

TABLE 2. Site Information of the Swedish Seismograph Station Network and the Auxiliary Array Stations at Hedemora and Kungsör

Station	Code 1)	Lat. (°N)	Long. (°E)	Altitude (m)	Geology
Uppsala	UPP	59.858	17.627	14	granite
Kiruna	KIR	67.840	20.417	390	porphyry
Skalstugan	SKA	63.580	12.280	580	gneiss
Göteborg	Gb	57.698	11.978	66	gneiss
Umeå	UME	63.815	20.237	16	mica gneiss and pegmatite
Karlskrona	Ka	56.165	15.592	11	granite
Uddeholm	UDD	60.090	13.607	240	granite
Delary	DEL	56.470	13.870	150	gneiss
Myrviken	MYV	62.942	14.347	345	granite
Hedemora	Hd	60.288	15.948	124	gneiss-granite
Kungsör	Ku	59.402	16.133	63	gneiss

1) Two-letter codes are unofficial.

TABLE 3. Instrumentation of the Swedish Seismograph Station Network and the Auxiliary Array Stations at Hedemora and Kungsör; Full Stations Names are given in Table 2

Code	Seismometer type, component	To (s)	Tg (s)	Max. magnif.	Recording type, paper	Time of operation
UPP	Wiechert E	11		240	smoked	1904-
	Wiechert N	10		230	smoked	1904-
	Grenet-Coulomb Z	1.4	0.7	13,510	photo	1951-1957 & 1965 & 1969-1981
	Benioff E	0.9	0.7	80,000	photo	1955-1983
	Benioff N	0.8	0.7	80,000	photo	1955-1983
	Benioff Z	1.0	0.7	40,000	photo	1955-
	Benioff E	0.9	83	3,030	photo	1955-1982
	Benioff N	0.8	92	3,290	photo	1955-1982
	Benioff Z	1.0	88	3,670	photo	1955-
	Press-Ewing E	15	103	2,270	photo	1957-
	Press-Ewing N	15	98	2,250	photo	1957-
	Press-Ewing Z	15	100	1,770	photo	1957-
	Press-Ewing Z	15	100	1,200	ink	1963-1983
	Geotech-Teledyne S-13 E,N	1.0		110,000	hot stylus	1983-
	Geotech-Teledyne S-13 Z	1.0		92,000	hot stylus	1983-
	Wielandt-Streckeisen E,N,Z	20			digital & hot stylus	1989-
KIR	Grenet-Coulomb Z	1.4	0.7	13,310	photo	1951-
	Golitzin E	12	12	770	photo	1951-1982
	Golitzin N	12	12	800	photo	1951-1982
	Golitzin Z	10	10	860	photo	1951-
	Press-Ewing Z	15	100	1,200	ink	1963-1971
	Press-Ewing Z	15	100	3,800	photo	1971-1982
SKA	Grenet-Coulomb Z	1.3	0.8	10,530	photo	1956-1981
Gb	Grenet-Coulomb Z	1.4	0.5	12,040	photo	1958-1968
UME	Grenet-Coulomb Z				photo	1960-1962
	Benioff E,N,Z	1.0	0.7	75,000	photo	1962-
	Press-Ewing E,N,Z	15	100	5,500	photo	1962-1990 & 1994-
Ka	Grenet-Coulomb Z	1.5	0.7	11,590	photo	1961-1968
UDD	Grenet-Coulomb Z	1.4	0.7	(12,990)	photo	1966-1967
	Benioff Z	1.0	0.7	75,000	photo	1967-

TABLE 3. (cont).

Code	Seismometer type, component	To (s)	Tg (s)	Max. magnif.	Recording type, paper	Time of operation
DEL	Grenet-Coulomb Z	1.4	0.7	12,990	photo	1967-
MYV	Geotech-Teledyne S-500 Z	1.0		varying	ink	1981-
Hd	Grenet-Coulomb Z	1.4	0.7	(15,000)	photo	1969-1970
Ku	Grenet-Coulomb Z	1.4	0.7	(15,000)	photo	1969-1970

TABLE 4. List of FOA Operated Seismograph Stations in Sweden

Name	Code	Lat. (°N)	Long. (°E)	Time of operation	Network(s)/ Instrument(s)
Abborråsen	ABB	57.845	12.786	1979-1985	SKI/SPZ
Alsterbro	ALR	56.995	15.918	1979-1993	SKI,SO/SPZ
Äppelbo	APO	60.593	13.928	1969-	HFS/SP3,LPZ,4sS
Basthult	BHU	57.428	16.559	1987-1988	SO/SPZ
Broaryd	BYD	57.058	13.164	1980-1985	SKI/SP3
Granbergsdal	GBD	59.485	14.553	1979-1988	SKI/SPZ
Hagfors	HFS	60.134	13.697	1969-	HFS/USPZ,SP3, LP3,BBZ,3moreSPZ,4sS
Hakkasbyn	HAK	66.925	21.560	1987-1989	NO/SPZ
Hallstavik	HVK	60.009	18.567	1979-1986	SKI/SPZ
Hedekas	HED	58.680	11.788	1979-1985	SKI/SPZ
Horndal	HRN	60.250	16.489	1979-1993	SKI/SPZ
Kalix	KLX	66.067	23.031	1987-1989	NO/SPZ
Katrineberg	KTB	61.067	16.283	1979-1994	SKI/SPZ
Korpilombolo	KPM	66.755	22.905	1987-1989	NO/SPZ
Lansjärv	LJV	66.655	22.182	1987-1989	NO/SPZ
Mariestad	MRD	58.617	13.747	1980-1985	SKI/SP3
Masugnsbyn	MUG	67.462	22.045	1987-1989	NO/SPZ
Näsudden	NSD	65.196	18.823	1989-	M-AR/SP3,4sS
Nyköping	NYK	58.925	17.092	1979-1994	SKI,SO/SPZ
Olofström	OLO	56.308	14.470	1979-1986	SKI/SPZ
Örkelljunga	ORK	56.268	13.262	1979-1986	SKI/SPZ
Stånga	SGA	57.303	18.472	1979-1988	SKI,SO/SPZ

TABLE 4. (cont).

Name	Code	Lat. (°N)	Long. (°E)	Time of operation	Network(s)/ Instrument(s)
Stöllet	SLL	60.475	13.319	1969-	HFS/SP3,LPZ,4sS
Tenhult	TNU	57.639	14.269	1979-1985	SKI/SP3
Torsby	TBY	60.083	12.833	1975-1992	HFS/SPZ
Värmlands Ny-säter	VNY	59.403	12.483	1979-1988	SKI/SPZ
Västmark	VMK	65.680	21.587	1987-1989	NO/SPZ
Veberöd	VEB	55.599	13.516	1979-1986	SKI/SPZ
Vimmerby	VIM	57.788	12.483	1979-1994	SKI,SO/SPZ
Virserum	VUM	57.328	15.488	1987-1988	SO/SPZ

Networks

HFS	Hagfors array or subarray within Hagfors array /samling rates USP 120 Hz, SP 40 Hz, LP 1 Hz/
M-AR	Mini-array
NO	Northern Sweden local network /sampling rate 60 Hz/
SKI	SKI network /sampling rate 60 Hz/
SO	Southeastern Sweden local network /sampling rate 60 Hz/

Instruments

SP3	short-period, 3 components
SPZ	short-period, vertical component
USPZ	ultra-short-period, 3 components
LP3	long-period, 3 components
LPZ	long-period, vertical component
BBZ	broadband, vertical component
4sS	4 substations

Instrumentation of mini-array and subarrays are given at the peak of operation in the early 1990s.