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Seismology in Finland in the Twentieth Century

U. Luosto and T. Hyvönen

Institute of Seismology, University of Helsinki, P.O. Box 26, FIN-00014,
University of Helsinki, Finland

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Abstract

In this paper we discuss the development of the seismological instrumentation, the facilities for seismological research and the most important or the pioneering studies in the different branches of the seismology in the 20th century Finland. The systematic collection of local earthquake data with macroseismic methods started in the 19th century. It was independent from the instrumental data collection and it continued actively in the 20th century. Renqvist (1930) published the first comprehensive catalogue of the earthquakes in Finland. Since then the catalogue has been updated several times. The last updated version from 1992 comprises the earthquakes in northern Europe, and the catalogue is maintained continuously by the Institute of Seismology, at University of Helsinki. Several studies on seismicity and seismic hazards in Finland and in Fennoscandia have been carried out based on the catalogues of local earthquakes.

The endeavours to establish seismograph networks in Finland at the beginning of the century were partly accomplished, when the first seismograph station was founded at the University of Helsinki in 1924. The low-magnification Mainka seismographs of the station were able to record only large distant earthquakes; however, they made possible our participation in global co-operation in collecting earthquake data. The next milestone in the instrumentation was obtained at the end of 1950's, when several short period seismograph stations were founded in Finland. These sensitive seismographs recorded both minor local and teleseismic earthquakes. The long period seismographs installed in the 1960's enabled new branches of research e.g. surface waves. The digitally recording seismographs since the 1970's made it possible to apply new mathematical methods to the recorded data. The foundation of the small aperture seismic array FINESA, later on updated to FINESS, made it possible to develop detectors and automatic location procedures especially for the detection of nuclear tests.

In Finland the first crustal studies were done using the permanent seismograph network as early as the late 1950's and in the 1960's. Proper reversed DSS profiles with a reasonable small spacing of recording stations were, however, not carried out until the 1980's. The most important and surprising result of the international deep sounding surveys e.g. SVEKA'81, BALTIC, SVEKA'91 and FENNIA profiles was the discovery of the exceptionally thick crust in the central part of the Fennoscandian Shield. These refraction experiments were followed by the large-scale marine deep seismic reflection experiment BABEL in 1989 in the Gulf of Bothnia. The BABEL field campaign proved to be a great success providing high-quality data. These deep seismic surveys have greatly influenced upon the understanding of deep geology and crustal evolution of the Fennoscandian crust.

The successful deep seismic experiments in Finland have also opened new possibilities for international co-operation in this field. Finnish seismologists have participated especially in the refraction experiments of the large EGT and EUROPROBE projects supported by the European Science Foundation. The realisation of the EUROPROBE's SVEKALAPKO tomographic array project in Finland is also based on trust in Finnish geophysicists' expertise in carrying out large international experiments.

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1. Introduction

At the beginning of the 20th century seismological research in the world was mainly concentrated on studies of local seismicity with macroseismic methods. After the first identified recording of a distant Japanese earthquake was made at Potsdam observatory in 1889 scientists were enthusiastic to construct seismographs and to establish seismograph stations for recording teleseismic earthquakes. The facilities to record distant earthquakes enabled international co-operation in seismology, and for instance, it led to the foundation of the International Seismological Association in Strasbourg in 1905 (*Rothe*, 1981).

In Finland earthquake research at the beginning of the 20th century was mainly undertaken by the Geographical Society of Finland and the Finnish Science Society, who organised the systematic collection of macroseismic data already started in the 19th century. A widely felt earthquake on April 10, 1902 in northern Finland and the foundation of the International Seismological Association gave impulse to improve seismological research also in Finland and to participate in the international co-operation in seismology. In addition to macroseismic observations, preparations for foundation of seismograph stations in Finland were started by the Geographical Society of Finland (*Donner*, 1912; *Simojoki*, 1958). Despite of a carefully prepared application, the Senate rejected the first proposal in 1911. The First World War postponed plans to establish seismological stations for several years. In the 1920's preparations were started to establish a privately financed seismograph station in Helsinki. In 1921, Sohlberg's Delegation of the Finnish Science Society accepted to purchase two horizontal Mainka seismographs (*Witting and Renqvist*, 1925). The Finnish Science Society donated the seismographs to the University of Helsinki. The Helsinki station started operation with Henrik Renqvist as its station manager (Fig. 1; *Kahma*, 1928; *Simojoki*, 1958; *Korhonen*, 1987). Risto Jurva (1937–1945) and Eijo Vesanen followed Renqvist as the station managers (*Vesanen*, 1952).

The maintenance of the station, construction of new seismographs in the 1950's and seismological research continued at the Department of Physics until 1961. At the beginning of the 1950's construction work for seismographs to record local earthquakes was started at the workshop of the Helsinki station (*Vesanen*, 1952). This work continued successfully when a group of young physicists designed and constructed sensitive seismological recorders under the leadership of Matti Nurmia for several stations in Finland (*Nurmia*, 1960). The staff of the seismological station was increased by appointment of two seismologists in 1957 and 1959 (*Vesanen*, 1957).

The most notable developments of seismology in Finland at this time was without doubt influenced by the huge nuclear explosion tests in Novaya Zemlya, by the increased activities in connection with the International Geophysical Year 1957–58 and with the XII General Assembly of U.G.G.I held in Helsinki in 1960 and, of course, by Vesanen's organisational talent. At the beginning of 1961 the Institute of Seismology was founded as an independent unit at the University of Helsinki, and Vesanen was appointed as the first director of the Institute. Because there was no longer adequate space for the growing activity of the Institute of Seismology in the Department of Physics, the institute was partly and temporarily located in a block of flats at Sinebrychoff Street. The University bought a building at Et. Hesperiankatu Street in 1962, and next year the Institute moved to this building together with two other institutes of the University. After this time the development of the Institute has been steady. Esko Penttilä succeeded Vesanen as acting director in 1975.

Fig. 1. The portrait of Professor Henrik Renqvist, Founder and first Director of Seismograph Station of the University of Helsinki. Adopted from *Vesanen* (1964).

he Finnish Research Project on Seismological Verification of Nuclear Tests has been developing and studying effective seismic verification methods with funds from the Ministry of Foreign Affairs since 1976 at the Institute of Seismology. The activities of participating in the work of the Group of Scientific Experts (GSE) under the auspices of the Conference on Disarmament in Geneva were greatly emphasised during the time of the next director Heikki Korhonen between 1977–1991. During this period the deep seismic surveys, microseismic and local seismicity research was also developed at the Institute. The study of the lithosphere structure by deep seismic refraction and reflection methods, studies on detection seismology and local seismicity were established in the main research programs of the Institute during the periods of the next directors, Urmas Luosto (1992–1998) and Pekka Heikkinen (since 1998). In 1995, the Institute moved at Teollisuuskatu Street. In the turn of the 21st century the staff of the Institute comprised of 11 positions of academic level, and of 15 posts for technical and laboratory personnel. In addition, there are a few scientists or postgraduate students employed by special research projects.

When new seismograph stations were founded in Finland since late 1950's, the maintenance of the stations was taken care by the Institute of Seismology of the University of Helsinki with the exception of the Sodankylä and Oulu stations. During the 1950's the seismographs at Sodankylä Geophysical observatory were under the maintenance of the observatory staff. In 1959, the Finnish Academy of Sciences and Letters founded a position of seismologist at the observatory. Airi Kataja was appointed to the position. She was responsible for the maintenance of the seismographs and also for investigations of the seismicity in northern Finland. After her retirement in 1991 the position was given to a physicist studying atmospheric phenomena. The registration of the Oulu station started in 1959, and the station was operated by the staff of the Department of Physics of the University of Oulu. In 1968, the position of seismologist was founded at the University of Oulu together with the foundation of the Department of Geophysics. Heikki Korhonen was appointed to the first seismologist at Oulu in 1968 and Jukka Yliniemi followed him in 1977. The position was moved to the Geophysical Observatory founded in 1985 at Oulu University. The Sodankylä Geophysical Observatory was united to the Oulu University in 1997 and the Geophysical Observatory was merged with it in the following year. At first studies of microseisms and local seismicity were the main research branches of seismology in the Oulu University. Since 1980's the geophysicists of the University have participated actively in deep seismic surveys in Finland and abroad.

The Department of Geophysics of the University of Helsinki has been responsible for the teaching of seismology. The scientists of the Institute of Seismology have mainly given the lectures on this subject. The Institute has provided also laboratory facilities for the undergraduate and postgraduate students. The Department of Geophysics of the University of Oulu has given permanent courses in basic aspects of seismology, too.

Simojoki (1958) has written a history of the collection of earthquake data until 1924 and of the establishment of the first seismological station in Finland. The instrumentation of the Finnish seismograph stations has been thoroughly described by *Korhonen* (1987) and *Pirhonen* (1994). This paper will not present a complete history of seismological research and instrumentation in Finland in the 20th century. The institutes and administration of the seismology in Finland were briefly discussed above. The most relevant scientific investigations and the developments in seismological instrumentation will be discussed in the following chapters in some details, without forgetting the pioneering works in the different fields of the seismology in Finland. During the 20th century the seismology in Finland has been developed from descriptions of earthquake phenomena to mathematical-physical science including studies of the Earth structure, and research on earthquakes and on detection seismology.

2. *Macroseismic and other local earthquake research*

At the beginning of the 20th century, before the seismograph recordings were widely available, seismology concentrated on studies of local earthquakes. A systematic collection of macroseismic data had been started in Finland during the previous century by H. Gylling (*Renqvist*, 1930), and was continued at the beginning of the 20th century by *J. E. Rosberg* (1903–1904, 1912).

Information about effects of earthquake shaking on people, buildings and their surroundings were collected from newspaper articles, by questionnaires, interviews and observations in situ. This type of data and studies are called macroseismic in contrast to instrumental observations and studies. An intensity value is determined for each observation point according to the strength of the shaking. A 10-grade (e.g. Rossi-Forel) and later on a 12-grade (e.g. Modified Mercalli) intensity scale are used for the classification of intensity values. The maximum intensity for an earthquake is observed at the centre of the earthquake i.e. at the epicentre. The isoseismals are defined as curves contouring areas of equal intensity values on the map. The observed maximum intensity gives an estimate for the strength of the earthquake on the intensity scale. Several physical parameters, e.g. the focal depth of the quake and attenuation coefficient, can be estimated from the decay of intensity with increasing epicentral distance. The direction of tectonic fault or geological structure can be estimated from the elongated shapes of the isoseisms. As an example, the map of isoseisms and macroseismic observations of the Kuopio earthquake, which occurred on 1st August 1963 in Central Finland, is shown in Fig. 2. It is easily understood that this kind of data collection and study of earthquakes was very laborious. However, macroseismic data were the main data source of the local Finnish earthquakes until end of the 1950's.

Rosberg (1903–1904) published the first earthquake seismology paper of the 20th century concerning the Paltamo earthquake of 10th April 1902 in Finland. He wrote detailed descriptions on the observations of the earthquake. This earthquake was one of the largest in Finland during the 20th century. According to Rosberg it was felt in an area covering an area of about 150 000 km^2. In the revised Finnish earthquake catalogue *Mäntyniemi and Ahjos* (1990) gave a value of 4.7 for the macroseismic magnitude M_I of the earthquake. In his next earthquake paper *Rosberg* (1912) reported the earthquakes felt in Finland during 1904–1911. The largest of the quakes reported occurred in the Bothnian region on 9th March 1909 with $M_I = 4.6$.

The work of *Renqvist* (1930) is without any doubt the most comprehensive macroseismic study of the local earthquakes in Finland. He gave a chronological list of 235 earthquakes during 1610–1929 with comments on observations of the quakes. The maximum intensity on the 12-grade Modified Mercalli -scale was estimated for each earthquake. He calculated the earthquake frequency as a function of intensity, of felt area, and of diurnal and seasonal variation. Renqvist showed that the majority of earthquakes occurred between 20–24 hours of local time. There was also about 5–10 percent increase in earthquake frequency during wintertime in Finland, Sweden and Norway. This can be due to the fact that inhabitants indoors are more sensitive to observe weak shaking and also ice shocks in wintertime (see also *Ahjos and Uski*, 1992). Renqvist suggested that land uplift accumulated the stresses released in Finnish earthquakes. Further on, he described the seismicity of Finland by plotting the felt areas of the earthquakes on four separate maps and on a combination map illustrating the overall seismicity of Finland, as seen in Fig. 3. One can easily estimate from this map, how often on the average a common person has been able to perceive an earthquake in a century at different sites in Finland. This map shows very well the overall seismic activity in Finland. It is valid even today even though the magnitudes of earthquakes were not incorporated.

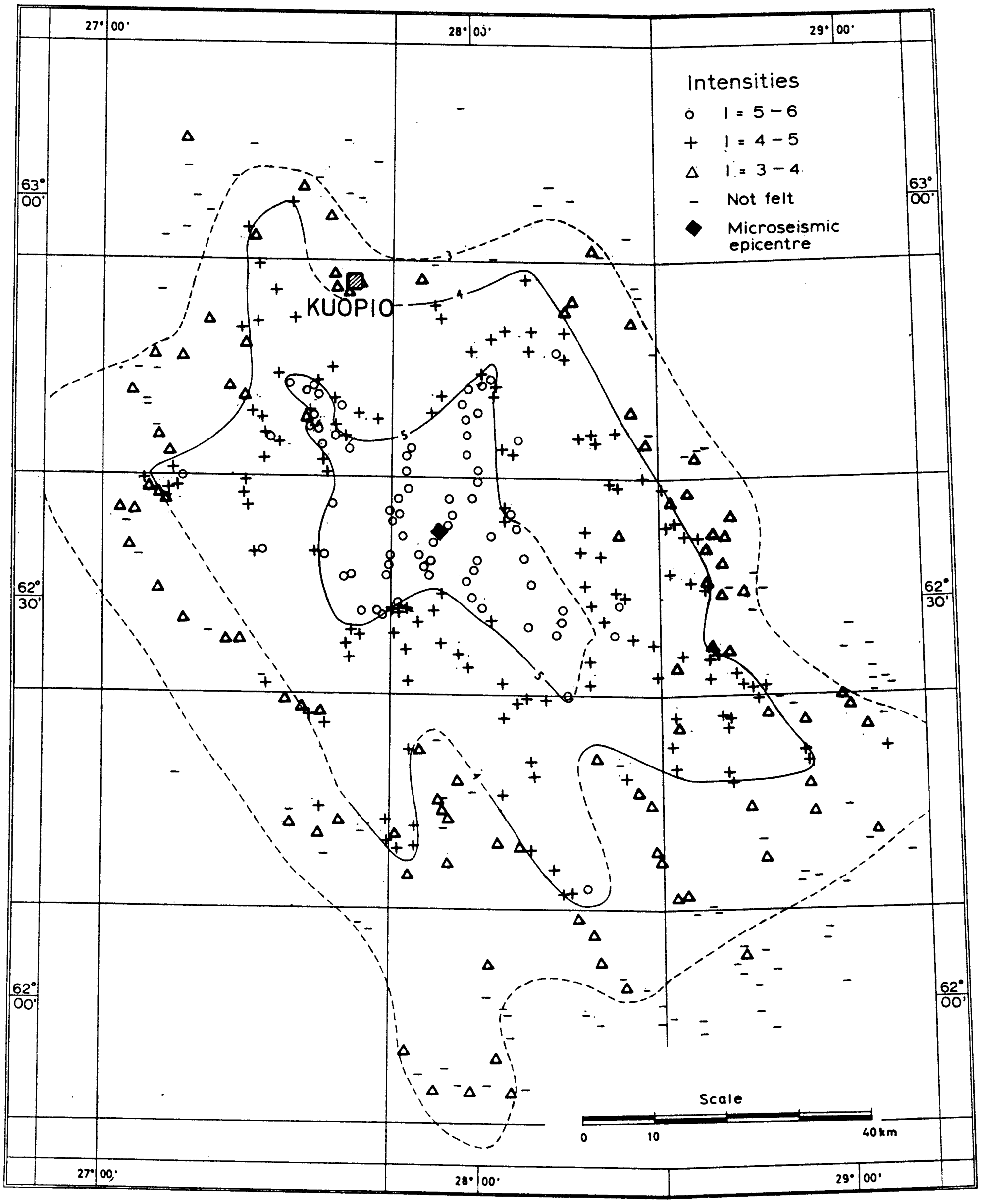


Fig. 2. Isoseismal map of the Kuopio earthquake of 1st August 1963 after *Talvitie* (1971).

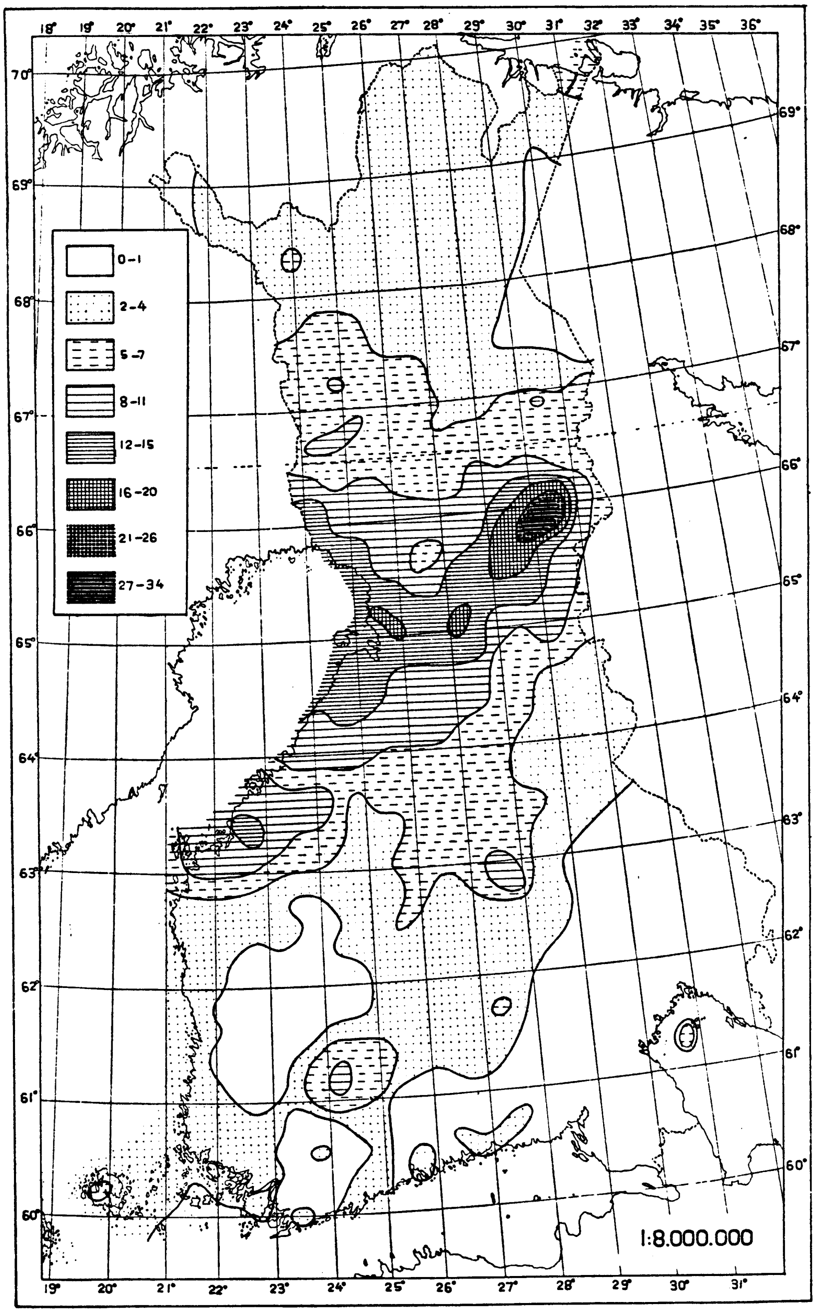


Fig. 3. Seismicity map of Finland (adopted from *Renqvist*, 1930). Numbers of felt earthquakes per century with different shadings are given in the insert.

Penttilä (1978) collected the second, updated catalogue of Finnish earthquakes, which occurred during the years 1610–1976. He also estimated the magnitudes of the earthquakes, and reported instrumentally determined co-ordinates of the earthquake epicentres from the beginning of the 1960's if available. *Korhonen and Ahjos* (1979) combined and studied the macroseimic investigations of the largest earthquakes felt in Finland, and compiled an earthquake catalogue for Fennoscandia (*Ahjos and Korhonen*, 1984). They discussed different methods for the determination of earthquake magnitudes and focal depths both from macroseismic and instrumental data. The sizes of the historical earthquakes were revised on the basis of more recent magnitude studies (*Wahlström and Ahjos*, 1984).

In the 1980's, the earthquake catalogue of Fennoscandian earthquakes was upgraded to a computer database at the University of Helsinki. *Ahjos and Uski* (1992) presented an updated version of the catalogue, and discussed the earthquakes in northern Europe on the basis of the catalogue. It comprised events inside a window of 55–80°N and 10°W–45°E, and a time window of 1375–1989. The earthquakes were divided into historical (1375–1964) and instrumental (1965–1989) data sets. The data were collected from all available historical catalogues and newest publications concerning the Fennoscandian region, but since 1984 also partly from the regional seismic parameter database maintained by the Institute of Seismology. An interesting result in the study by *Ahjos and Uski* (1992) was about the reported focal depths of earthquakes in Fennoscandia. The peak in the depth distribution of the historical events was observed to be at depths of 9–12 km, and that of the instrumental events in depths of 14–15 km. It was suggested that the difference could be caused by uncertainties in the historical data or that some focal depths might have been mixed with default values (i.e. of 15 km in Norway) used in the location procedure and not reported as such in bulletins. Earlier, *Ahjos* (1990) observed a depth peak at 10 km for selected historical and well-located instrumental earthquakes. The present catalogues of Finland and northern Europe can be found on the web pages of the Institute of Seismology (www.seismo.helsinki.fi).

In his dissertation, *Talvitie* (1971) dealt with the source of the seismicity in Finland focused in an area of 10 000 km^2 surrounding the city of Kuopio (Fig. 2). He found that in the bedrock the linear trenches and sharps show four preferred orientations. The earthquakes were situated in zones, where lineaments of similar orientation were concentrated. *Saari* (1998) presented both regional and local seismotectonic character of the area surrounding the Loviisa Nuclear Power Plant in SE Finland in his dissertation. He considered micro-earthquake analysis to be a good method for locating active faults when the stability of the bedrock is long-term.

In 1970's when the planning of nuclear power plants and nuclear waste storage sites began, the estimation of even minor risks of natural disasters on sites of the nuclear power plants became of current interest. *Ahjos et al.* (1984) estimated earthquake hazard in Finland on the basis of the earthquake data during the years 1880–1980. In Fig. 4, the calculated return periods of magnitudes, estimated by Gumbel's method, are

displayed. *Mäntyniemi et al.* (1993) divided the Fennoscandian area into several sub-regions according to seismic activity obtained by studying seismic hazard in Fennoscandia based on the earthquake catalogue. They found that the maximum expected magnitude is 4.66 ± 0.64 for southern Finland and 5.87 ± 1.65 for northern Finland. The most recent seismic hazard estimation for Central, North and Northwest Europe was done as a part of the Global Seismic Hazard Assessment Program (GSHAP) by *Grünthal and the Region 3 Working Group* (incl. *P. Mäntyniemi*, 1999). The calculated hazard for northern Europe is shown in Fig. 5.

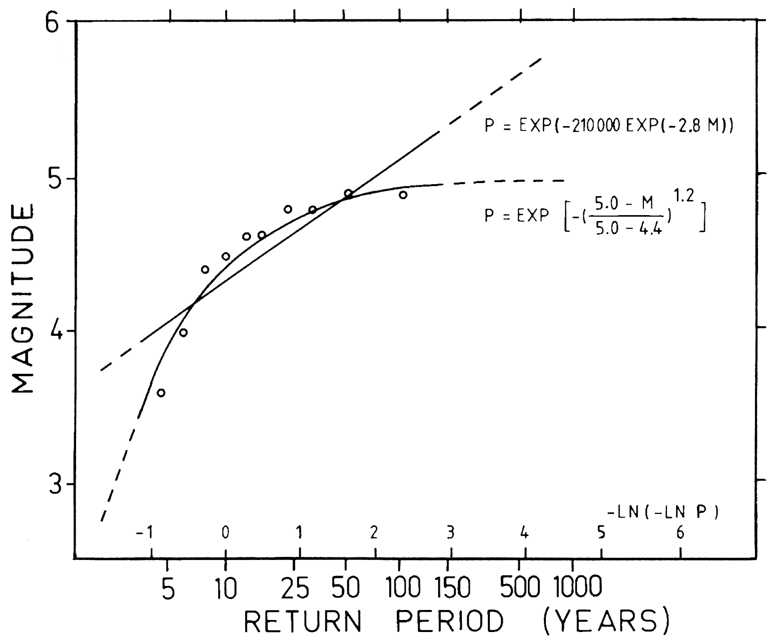


Fig. 4. Return periods for various magnitudes determined by Gumbel's methods I (straight line) and III (curved line) for Finnish earthquakes during the period 1880–1980 (*Ahjos et al.*, 1984). Estimation of magnitude extreme by Gumbel's III method yields the value 5.0 for the upper limit of earthquake magnitude in Finland.

3. *Milestones of the seismological instrumentation*

The first seismographs were constructed in the 1880's fifty years after Poisson's theoretical proof that longitudinal and transversal seismic waves propagate in elastic media. Therefore, Finnish scientists were among the pioneers when planning the establishment of seismograph stations in Finland in the first decades of the 20th century (*Donner*, 1912; *Simojoki*, 1958). The two horizontal Mainka seismographs donated by the Finnish Science Society were installed in 1924 in the building of the Department of the Physics on Siltavuori hill in Helsinki. In 1925 a vertical Mainka seismograph was also installed at the seismograph station (*Kahma*, 1928; *Simojoki*, 1958; *Korhonen*, 1987).

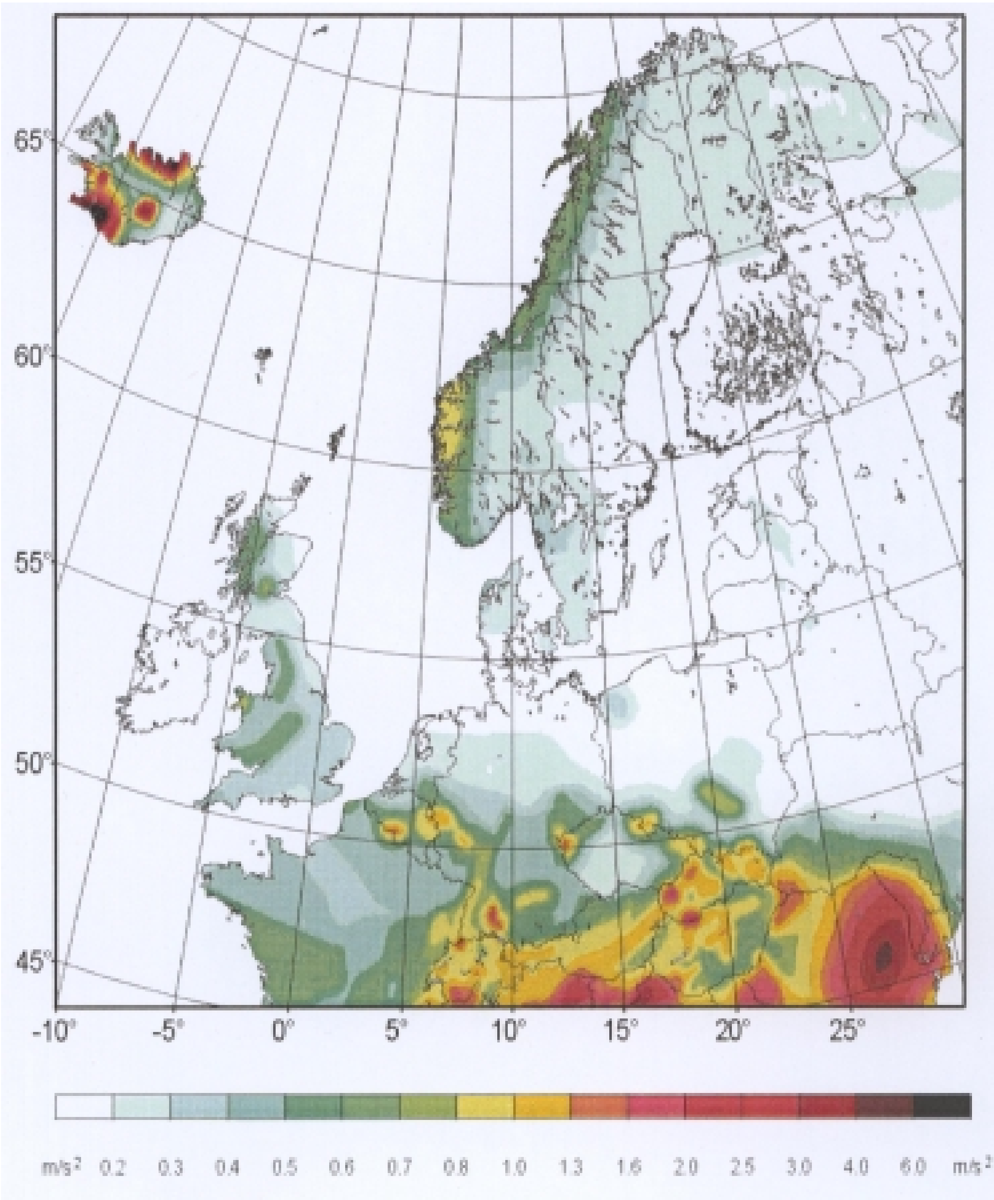


Fig. 5. Hazard map for Northern Europe (After *Grünthal and GSHAP WG 3*, 1999). The hazard is expressed in horizontal peak ground acceleration for occurrence rate of 10 % within 50 years.

The mechanical Mainka seismographs are massive constructions consisting of a framework, a heavy pendulum mass (730 kg in horizontal and 300 kg in vertical seismographs) and a complicated combination of levers in order to detect and amplify ground vibrations. In this installation, the stationary amplitude magnification was 140 with a maximum of 250 at period of 12 s with a damping ratio of 3.5 (*Vesanen*, 1952). The recordings were made on smoked paper. A recording of the Mainka seismograph of the earthquake on 30th June 1936 on the Kuril Islands (United States Coast and Geological Survey, USCGS, reported epicenter: 51.5°N, 160°E) is shown in Fig. 6 (*Vesanen*, 1942). Although the mechanical seismograph with low

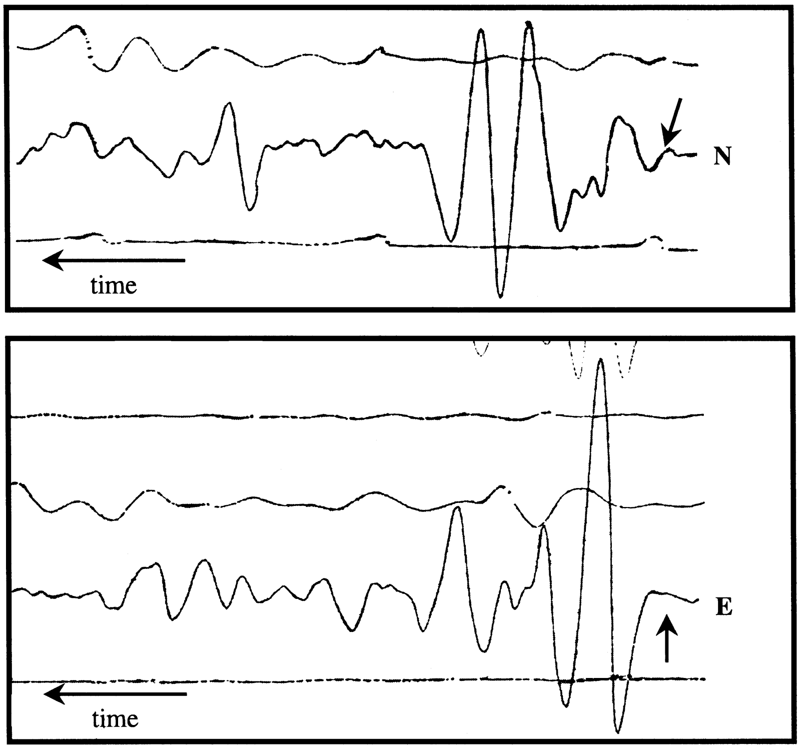


Fig. 6. Seismograms for the Kuril earthquake of 23rd December 1936 recorded by the horizontal North-South (N) and East-West (E) components of Mainka seismographs (adapted from *Vesanen*, 1952, Fig. 56). The arrows show the first arrivals of the P-wave.

magnification could not detect small, local earthquakes in Finland, they recorded seismic waves from large, distant earthquakes. *Vesanen*'s (1942) dissertation with analysis of P- and S-wave characteristics on seismograms was a notable scientific work based on Mainka recordings. In addition to scientific studies, the Mainka seismographs were used at the Department of the Physics for training and diploma studies of the students. These seismographs operated until 1964 (*Korhonen*, 1987).

In order to record local earthquakes, Galitzin and Wood-Anderson torsion type seismometers were constructed at the Department of the Physics (*Vesanen*, 1952) at the beginning of 1950's. However, even these seismographs with magnifications of a few thousands were not sensitive enough to record weak local earthquakes. A remarkable milestone in the seismological recording was achieved, when a short period vertical Benioff seismometer was purchased in 1956. By coupling the seismometer to a galvanometer with free period of 0.2 s, a maximum amplitude response of 50 000 was gained on photo paper recording. Helsinki was, however, a too noisy site for such a sensitive recorder. Thus, the Benioff seismometer was installed at the Sodankylä Observatory, where it recorded local earthquakes of northern Finland as well as distant earthquakes from all around the world.

In the last years of 1950's several short period, high sensitive seismometers were built in the Department of Physics under Nurmia's leadership (*Nurmia*, 1960). Seismograph stations were installed at Nurmijärvi, Kotka, Oulu and Kajaani (Fig. 7) and

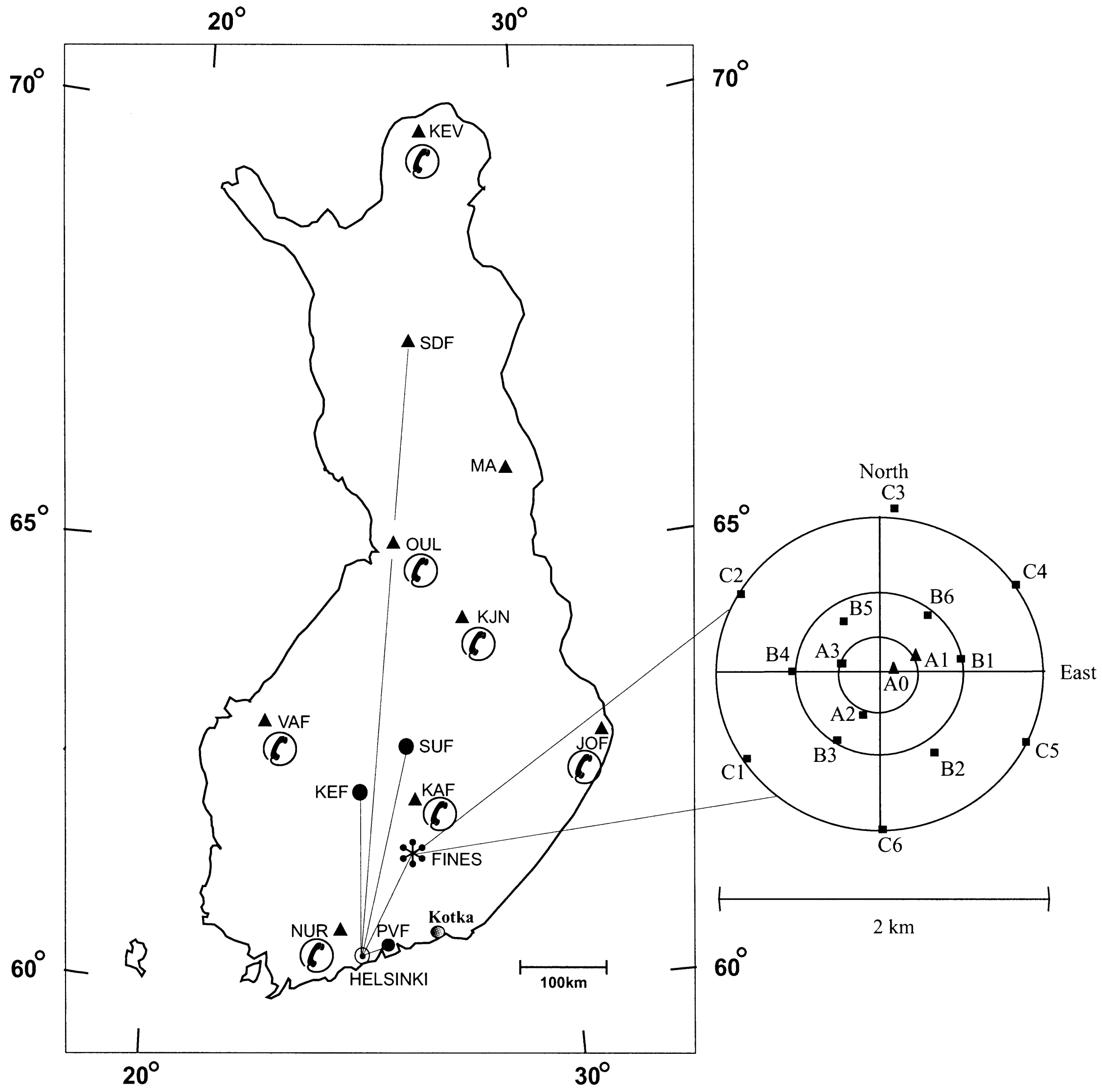
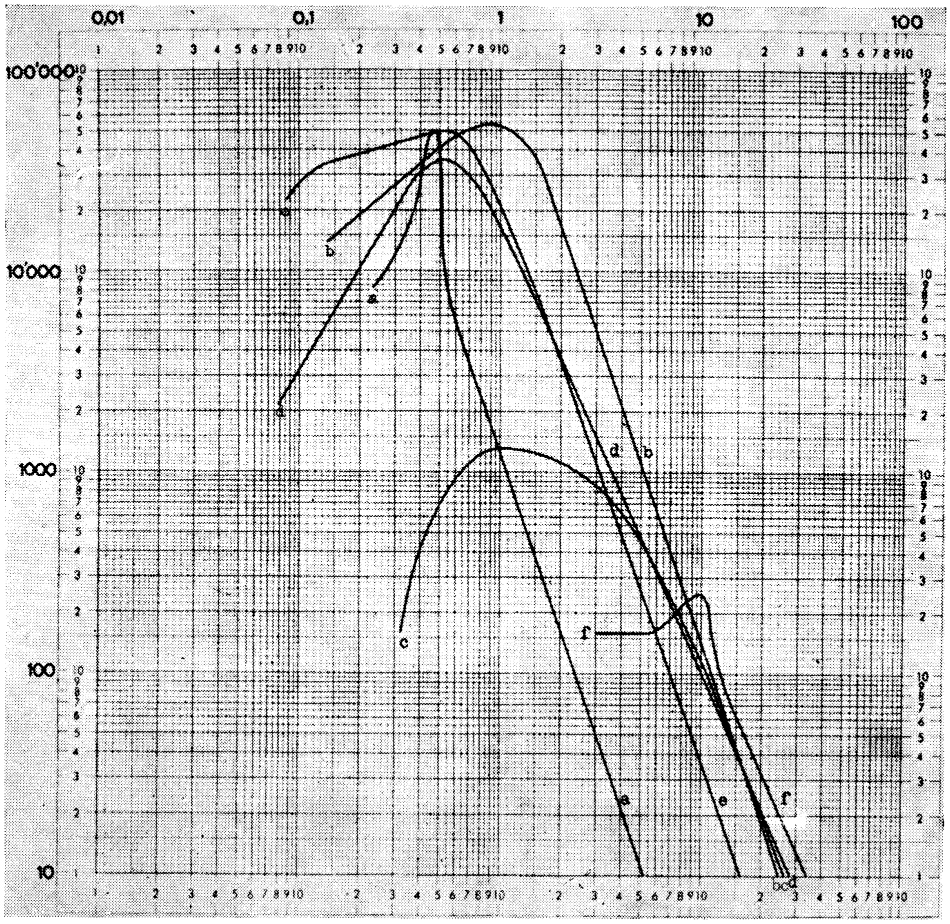


Fig. 7. The seismograph stations in Finland in 1999 (added with the old station Kotka). The insert shows configuration of the FINESS array station.

equipped with the Nurmia seismographs. Galvanometer recording on photosensitive paper (at Nurmijärvi) or recording on smoked paper was used (Fig. 8). In the latter case, the signals from the seismometers were amplified with modern transistor based on amplifiers constructed by *Siivola* (1960). These seismographs were sensitive enough for also recording local earthquakes (Fig. 9). The Nurmia seismographs were important also for recording nuclear tests from Novaya Zemlya in the early 1960's. These instruments were, however, not stable enough for dynamic studies, and during the next decades industrial seismometers such as Willmore, Press-Ewing and Geotech S13 replaced them.

Fig. 8. First seismologists Esko Penttilä and Mauno Porkka watching at research assistant Antti Siivola (later on professor in Physics) presenting his transistor based amplifier of the smoked paper recorder at Helsinki seismological laboratory in 1960. (Photo: PressPhoto)

The World Wide Standard Seismograph Network (WWSSN) was founded and funded by the United States of America at the beginning of the 1960's. Two seismograph stations in Finland were equipped with the WWSSN instruments, one at Kevo in 1962 and the other at Nurmijärvi in 1963. The stations comprised vertical and horizontal seismographs with short period Benioff and long period Press-Ewing seismometers. A combination of seismometer and galvanometer was applied. Crystal clocks for time signals, radio receivers for time control and necessary electronics for maintenance were added to the instruments. Several studies were performed on properties and calibration of the electromagnetic seismographs (*Tobyas and Teikari*, 1980, 1982; *Teikari and Tobyas*, 1986). The magnification i.e. the amplitude response curves of WWSSN seismographs are plotted in Fig. 10. The WWSSN network produced valuable first-rate data for the international seismological community e.g. the seismic evidence for plate tectonics and for the structure of the Earth's interior. The Kajaani seismograph station in Finland was also equipped with seismographs with similar seismometer and galvanometer constants as the WWSSN instruments. In 1963, a second long period vertical Press-Ewing seismograph was installed at Oulu seismograph station. The long period recording enabled the studies of surface waves and of microseisms in Finland.



a—a	Nurmia	Z		10 kg
a--b	ditto	Z		96 kg
c—c	ditto	Horiz.		10 kg
d—d	ditto	»	short-per.	12 kg
e—e	Benioff	Z		100 kg
f—f	Mainka	Horiz.		730 kg

Fig. 9. Amplitude response curves of the Nurmia, Benioff and Mainka seismographs versus period in seconds (adopted from *Karras and Nurmia*, 1960). The seismometer masses are expressed in kilograms.

Various efforts were made to receive telemetric recordings in Helsinki from distant seismic stations since the year 1959, when the first tests were performed to transmit analogue signals via telephone cables from Porkkala and from Kotka to the Helsinki seismological station. The amplifiers, frequency modulators (FM) and other necessary electronics for transmission were designed and constructed at the Institute. In 1963, a continuous FM based telemetric recording was started from three seismograph stations in southern Finland to the Institute of Seismology (*Riihimaa,* 1962).

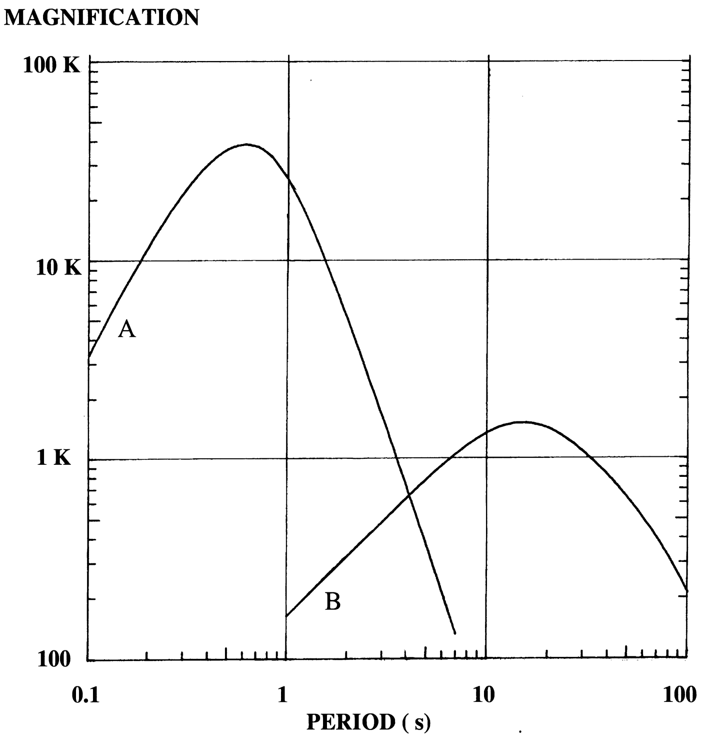


Fig. 10. Amplitude response curves of short and long period WWSSN seismographs: A) – Benioff Z, N, E and B) – Press-Ewing Z, N, E. (*Teikari and Suvilinna*, 1985).

In the 1970's, engineer Seppo Nurminen started to design digital recorders and transmission systems utilizing C-MOS microcircuit technique of RCA at the Institute of Seismology (*Nurminen*, 1974, 1976). The first digital system was completed in 1972 and installed at the Kajaani seismograph station. In 1975, a tripartite seismometer station was founded in central Finland, and equipped with digital recorders and a transmitter system. Also the tripartite station of southern Finland was upgraded to a similar digital configuration.

The same technique was applied in 1980's when constructing three- or five-channel PCM field recorders later on called PCM-1218-80 recorders (*Nurminen and Hannula*, 1981; see Fig. 11), which were first digital field recorders in Europe. Altogether fifteen recorders were constructed at the Institute. During the next twenty years these instruments were used to record seismic signals from explosive shots of six international deep seismic sounding (DSS) profiles in Finland. The recorders were also in great demand for use in several DSS experiments carried out in many European countries (see Chapter 5 for more details). Just at the end of the 20th century Nurminen designed a completely new digital seismic recorder, model DAS-98, which runs under the Linux operating system. These recorders are used both in the permanent stations and in field experiments. Until the end of the century almost the entire seismic network in Finland was operating using digital telemetric or dial-up method.

Fig. 11. Designer of the PCM-80 field recorder Seppo Nurminen records FENNOLORA shots with the prototype of the instrument in Finnish Lapland in 1979. (Photo: Institute of Seismology)

After recording on photo paper for over 20 years, the WWSSN stations maintained by the U.S.A. were started to be modified to digital stations. The Kevo station was updated in 1981 to a digital DWWSSN station and in 1993 to USGS/IRIS2 dial-up station, consisting of three Streckeisen broad-band and one short-period seismometer (*Korhonen*, 1987; *Pirhonen* 1994). In 1990's, also other Finnish seismograph stations were started to be equipped with digital broad band seismometers. The seismogram of an earthquake in Pakistan is shown in Fig. 12 as an example of a broad band recording.

An experimental small aperture array station, FINESA (FINnish Experimental Seismic Array), was installed at Sysmä in co-operation with NORSAR (NORwegian Seismic Array) to detect seismic signals from underground nuclear explosions (*Korhonen et al.*, 1987). The data was transmitted via telephone lines to the Institute of Seismology in Helsinki. The array was upgraded and renamed the FINESS array in 1993. DARPA (the US Defense Advanced Research Project Agency) donated the modern instrumentation, and the University of Helsinki paid expenses for the construction of the buildings and the local telephone network. The array with a diameter of 2 km consists of 15 substations and a central station. The digital data is transmitted continuously to the Helsinki and NORSAR data centers. Small array data are optimal for automatic signal detection and for instant location of seismic events.

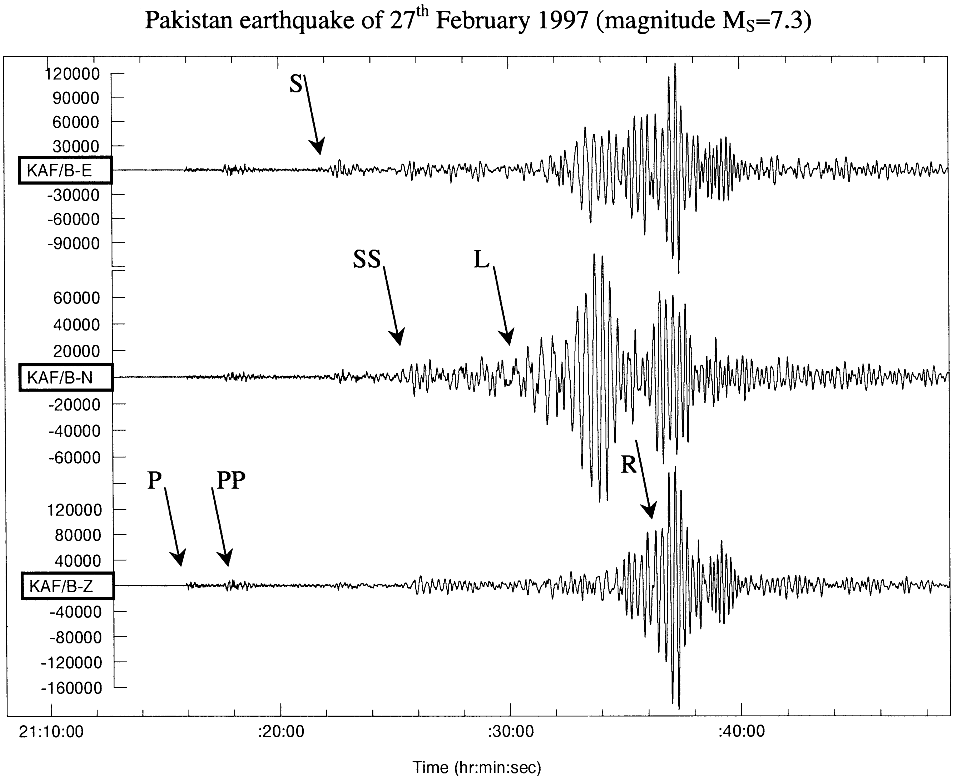


Fig. 12. The broad band seismograms of the Pakistan earthquake on 27th February 1997 at Kangasniemi seismic station (KAF). The arrows mark arrivals of different seismic phases: body waves P, PP, S, SS, and Love (L) and Rayleigh (R) surface waves on horizontal (B-N, B-E) and vertical components (B-Z).

4. Surface wave and related studies

Porkka (1960a, 1961) was the first in Finland to study the surface wave dispersion along some Eurasian paths. It is amazing, how he was able to determine surface wave velocities up to long periods of 50–60 seconds from short period instruments. The Rayleigh wave dispersion for ray paths from Finland to Japan and to Kamchatka showed e.g. that the Arctic continental shelf has a continental structure instead of an oceanic one. A new era started in studies of surface waves when long period seismographs were installed at Nurmijärvi, Kevo and Kajaani stations in the 1960’s (see Chapter 3). At the same time the computer facilities at the University of Helsinki were improved, now it was also possible to calculate synthetic dispersion curves for the Earth’s models as well as the phase and group velocities from observed surface waves using modern digital methods for analysis of histograms. The system only lacked digital recorders. Digital data was created by reflecting seismograms with an episcope to scale paper, from which an ocular measurement was done. *Noponen* (1966) and *Noponen et al.* (1967) published the most important results of these studies, see Fig. 13. *Porkka* (1969) defended his dissertation on surface wave studies in Finland and *Noponen* (1974) his dissertation on a comparison of crust and mantle structures between shield and island arc areas.

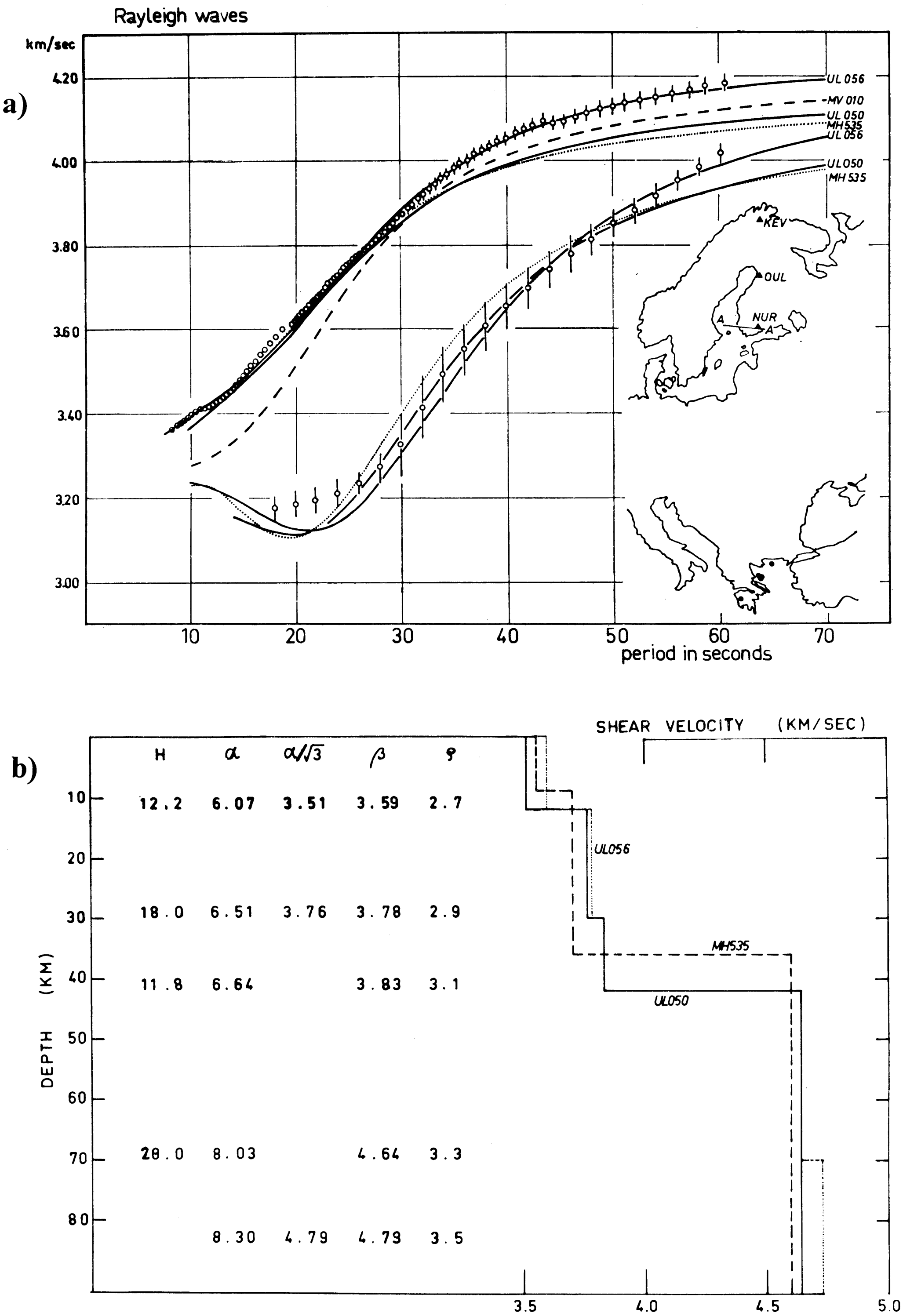


Fig. 13. Structure of crust and mantle according to surface wave studies in Finland after *Noponen et al.* (1967). (a) The circles mark the observed Rayleigh wave velocities with mean standard deviations. The curves show dispersions of the layer models seen in (b), and of the two-layer model MV010 of 33-km thick crust with a P-wave velocity of 6.1 km, underlain mantle with velocity of 8.1 km. The measurements were made from seismograms at the stations shown in the insert. The black dots in Greece show epicentres of earthquakes used. (b) Properties of the best-fit model UL056, model UL050 from the refraction study of Sylen-Porvoo line (*Luosto*, 1967), and the three-layer model MH535 after *Noponen et al.* (1967).

Special kind of surface waves, called microseisms, are generated by sea waves in oceans. The microseisms recorded with the Finnish seismograph network are generated within the deep air depressions over the North Atlantic Ocean. These were investigated mainly by Korhonen at the University of Oulu. He has been especially interested in the spectral peaks of microseisms and where the source areas of the peak waves are located. *Korhonen*'s (1971) dissertation summarises most of these studies.

Saastamoinen (1969a, 1969b, 1972 and 1994) published several theoretical papers on methods for calculating theoretical dispersion of the surface waves or on wave propagation in the Earth. His dissertation dealt with oscillations of a thermoviscoelastic, selfgravitating, spherically symmetric and rotating Earth model (*Saastamoinen*, 1970).

5. Structural studies

The seismology nowadays consists of two main branches: earthquake seismology and structural seismology. Soon after seismographs were invented, attempts were made to construct travel time curves of the seismic waves for the localisation of the earthquakes. By inverting travel times into structures, the large-scale Earth structure was determined surprisingly early. For instance, in 1912 Beno Gutenberg found 2900 km to be the depth of the outer boundary of the Earth's core. This value is within few kilometres of today's estimate (2889 km).

After construction of sensitive seismographs, seismic methods have been commonly used in determining crustal structure and also structures of the uppermost layers of the crystalline crust or sedimentary cover in oil prospecting. In Finland, where earthquakes are rather weak, the structural seismology grew in importance after sensitive seismographs were available. The first investigations of crustal structure using seismic waves of local earthquakes (e.g. *Porkka*, 1960b) or of explosive sources (*Penttilä et al.*, 1960) were carried out in the late 1950's.

Esko Penttilä was a pioneer of the refraction studies in our country without any doubt. In 1965 and 1966 he was responsible for large-scale marine seismic refraction studies carried out in the Gulf of Bothnia. The financing partner of the project was interested in possibility of finding oil resources. The shots were also recorded on land stations and used for investigating the crustal structure (e.g. *Penttilä*, 1969; *Luosto*, 1967). Unfortunately, most of the recording stations were permanent seismograph stations with too small time resolution for deep seismic surveying purpose. The station spacing was also too large, sometimes hundreds of kilometres. Therefore, most of the results should be considered as preliminary findings of the crustal structure in Finland. The most comprehensive refraction experiment in the 1960's was the Trans-Scandinavian Seismic Profile of 1969 (*Vogel* 1971; *Penttilä*, 1971). *Penttilä*'s (1972) doctoral dissertation summaries his studies of the crustal structure in Finland and combines them with gravimetric observations.

After the early refraction investigations it took about ten years until the first proper deep refraction surveys: SVEKA’81 and BALTIC profiles were carried out in 1981 and 1982 in Finland (*Luosto et al.,* 1984, 1990; *Grad and Luosto,* 1987). The field surveys and interpretation of the collected data were performed as international co-operation with Polish, Russian, Swedish and German scientists. The most important and most surprising result (see Figs. 14, 15 and 16) of these deep soundings was the discovery of very thick crust, up to 65 km, in the central part of the Fennoscandian Shield. *Luosto*’s (1987) doctoral thesis summarizes the deep refraction investigations in Finland during 1980–1986.

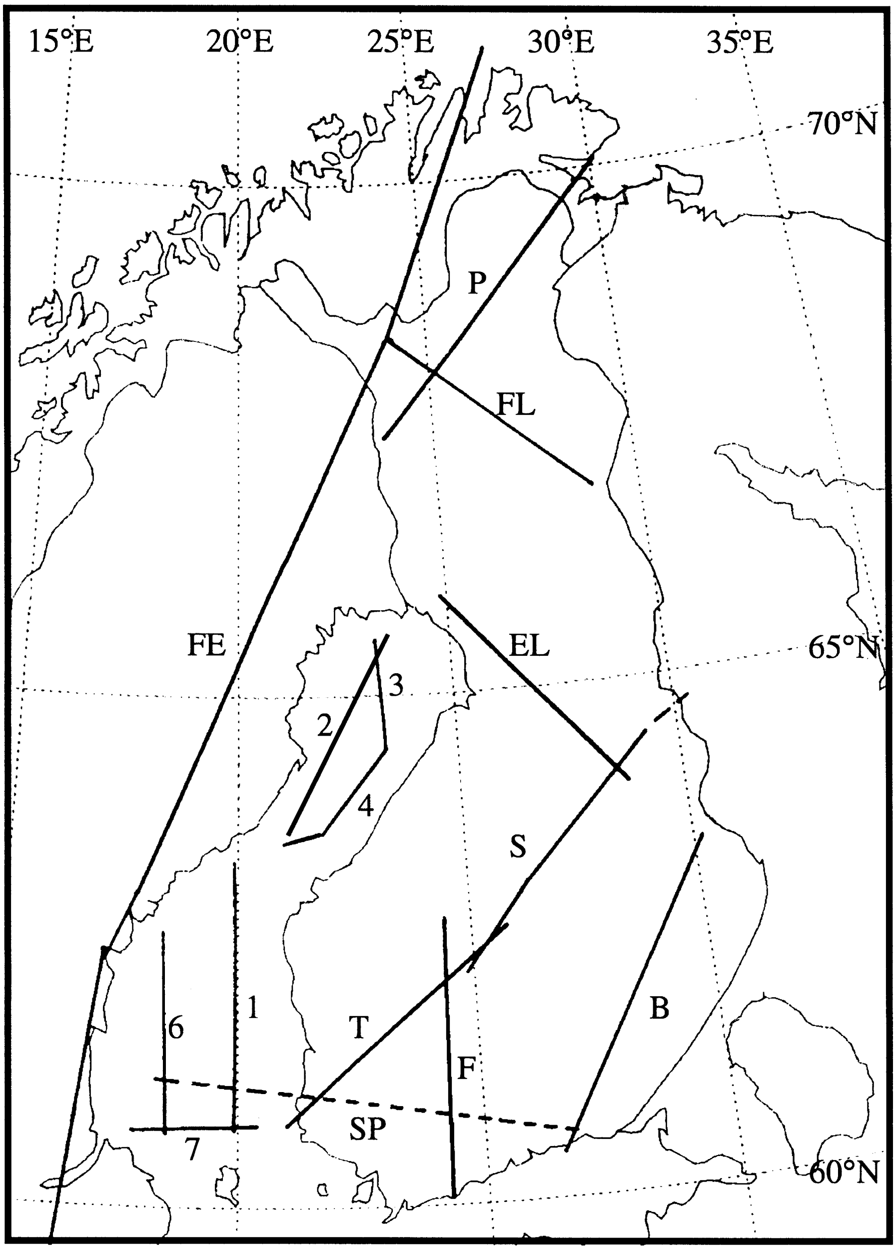


Fig. 14. The deep seismic refraction profiles and the BABEL reflection lines. S=SVEKA’81, T=SVEKA’91, FE=FENNOLORA, FL=FINLAP, P=POLAR, F=FENNIA, B=BALTIC, SP=SYLEN-PORVOO, EL=ELIMÄKI. The numbers 1, 2, 3, 4, 6 and 7 mark the corresponding BABEL line.

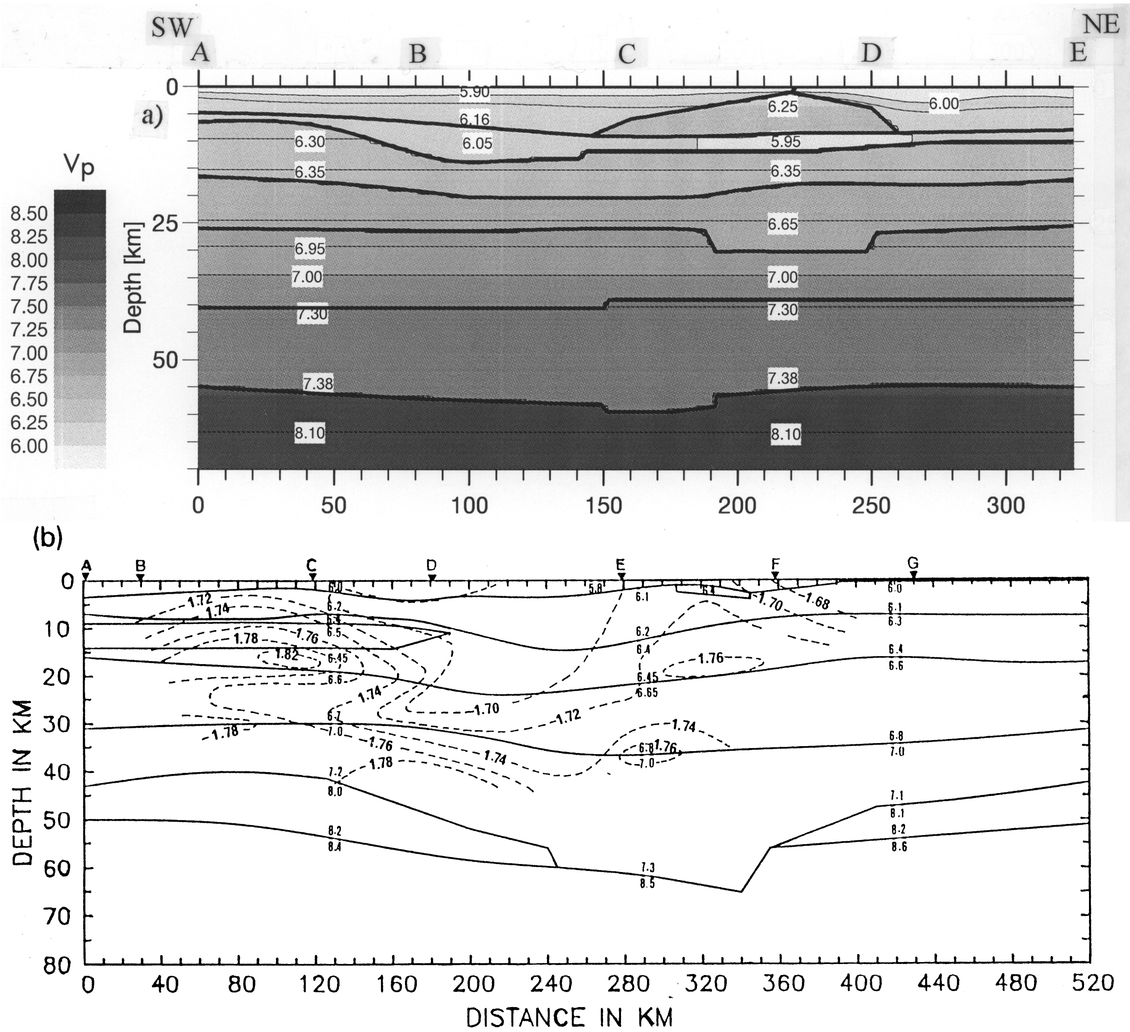


Fig. 15. P-velocity models of the crust along the SVEKA’81 (a) and BALTIC (b) profiles adapted from *Grad and Luosto* (1987), and *Luosto et al.* (1990), respectively. Velocities are expressed in km/s. Isolines of the V_P / V_S –ratio (dashed lines) are plotted on (b).

After the successful refraction profiles BALTIC and SVEKA’81 the crustal structure in Finland has been studied using both deep refraction and reflection measurements. The POLAR profile experiment in northern Finland was done as part of the EGT (European GeoTraverse) project in 1986 (*Luosto et al.*, 1989). The fieldwork along the SVEKA’91 profile, southwest continuation of the SVEKA’81, was carried out in 1991 (*Luosto et al.*, 1994) as part of the GGT (Global Geoscience Transects) program and along the FENNIA profile in South Finland in 1994 (FENNIA Working Group, 1998). These profiles verify the deep depression of the crust in Central Finland, whereas the crust is thinner (45–50 km) in other parts of Finland (see also Fig. 18). *Yliniemi* (1991) carried out additional studies of the crustal structure using quarry blasts in the middle part of Finland. *Kozlovskaya and Yliniemi* (1999) made a combined seismic and gravimetric interpretation along the SVEKA line.

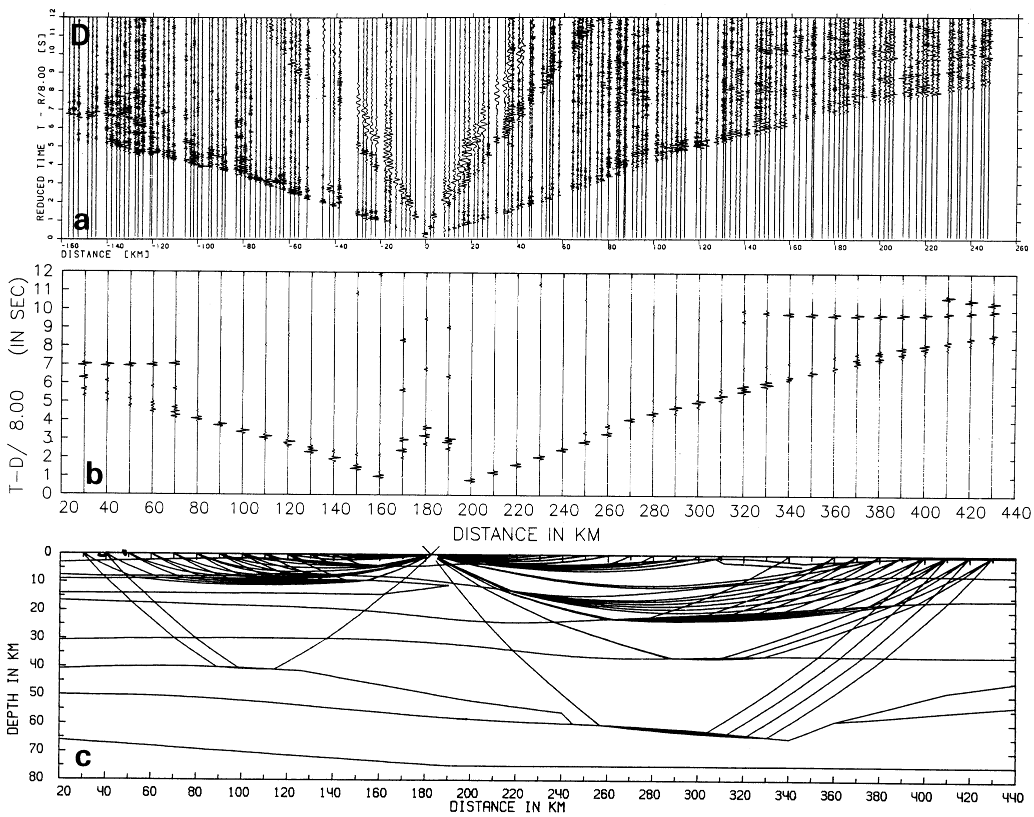


Fig. 16. Example of the documentation of the modelling of DSS profile BALTIC: (a) amplitude normalised observed P-wave record section for shot point B; (b) amplitude normalised synthetic record section; (c) ray paths of the refracted waves in the model (after *Luosto et al.*, 1990).

The BABEL (Baltic And Bothnian Echoes from the Lithosphere) project, co-ordinated by BIRPS (British Institutions Reflection Profiling Syndicate), was a large-scale marine deep seismic reflection experiment carried out in collaboration with British, Danish, Finnish, German and Swedish institutions and geoscientists. More than 2000 km of profiles was collected in 1989 on ship S/V Mintrop in the Baltic Sea and the Gulf of Bothnia. The air gun shots were also recorded at 64 landstations, of which 13 were situated in Finland. The BABEL field campaign was a great success and high quality vertical and wide-angle reflection data were obtained. The most surprising first result was the finding of traces of early Proterozoic plate tectonics in north of the Quork in the Gulf of Bothnia (see Fig. 17; BABEL Working Group, 1990).

The near vertical reflections show large variations of reflectivity in different tectonic units of the Proterozoic crust. In the southern Gulf of Bothnia the crust was most reflective and the Moho (bottom of the crust) can be seen as a base of reflectivity, which coincides with results determined from the wide-angle measurements. In the middle of the BABEL line 1, the reflectivity is diffuse and no clear base can be determined. The wide-angle results in the Bothnian Sea area confirmed the earlier observations of the very thick crust in the central Fennoscandian Shield (*Heikkinen and Luosto*, 1992).

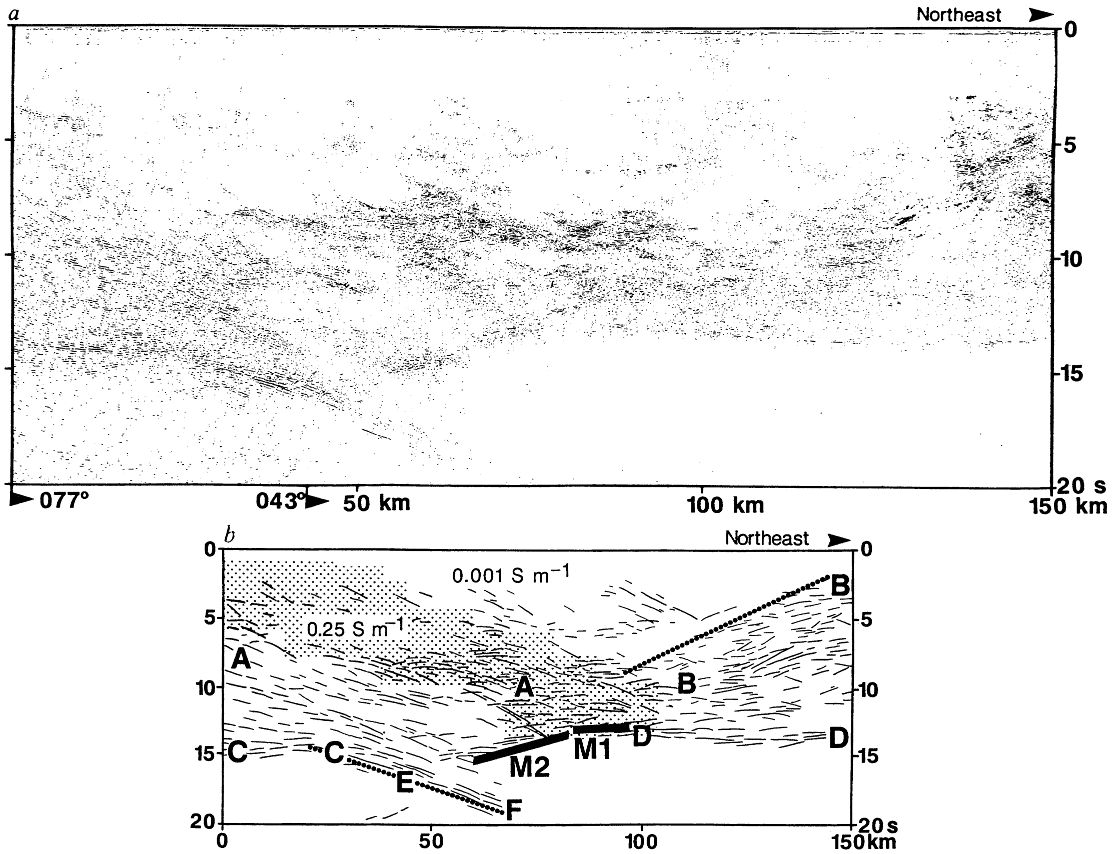


Fig. 17. (a) The reflection profile along the southern part of BABEL line 3, (b) Line drawing of (a). M1 and M2, Moho as located by wide-angle data. Dotted lines, reflection boundaries. The figure is adapted from the *Babel Working Group* (1990).

A combined interpretation of near vertical and wide-angle data (BABEL lines 3 and 4) was made by *Komminaho and Yliniemi* (1992) showing e.g. similar features in the southern Bothnian Bay as the first findings of the *Babel Working Group* (1990). *A. Korja and Heikkinen* (1995) have carried out a three dimensional structural interpretation of the seismic data (BABEL lines 1, 6 and 7) in the Bothnian Sea and concluded that the crustal structure was formed by extensional tectonics. With a combined interpretation of seismic, geoelectric and geological data *A. Korja et al.* (1993) have found evidence for collisional and extensional events in the Fennoscandian Shield implicating Precambrian crustal evolution. *A. Korja* (1995) in her doctoral dissertation has discussed the tectonic implications of the Moho depth map and thickness of the lowermost high velocity crustal layer. *Heikkinen's* (1998) doctoral thesis on the crustal structure of the Fennoscandian Shield summarizes the results of the deep reflection and refraction surveys in Finland during 1986–1994.

Moho depth maps have been calculated (*Luosto*, 1991, 1997; *BABEL Working Group*, 1993; *A. Korja et al.*, 1993) to get a general overview of the thickness of the crust behaviour in Fennoscandia. Depth values were collected from recent refraction and wide-angle reflection profiles. Luosto's Moho map from 1997 is displayed in Figure 18. It can be seen that in Central Finland and central Sweden the crust is unusually thick being 55–65 km with an abrupt thinning to the east approximately along the Archaean–Proterozoic border. In Lapland there is an almost E–W trending 46–50 km deep trough. Elsewhere in Finland the crust is 42–46 km thick which can be considered to be normal for shield areas.

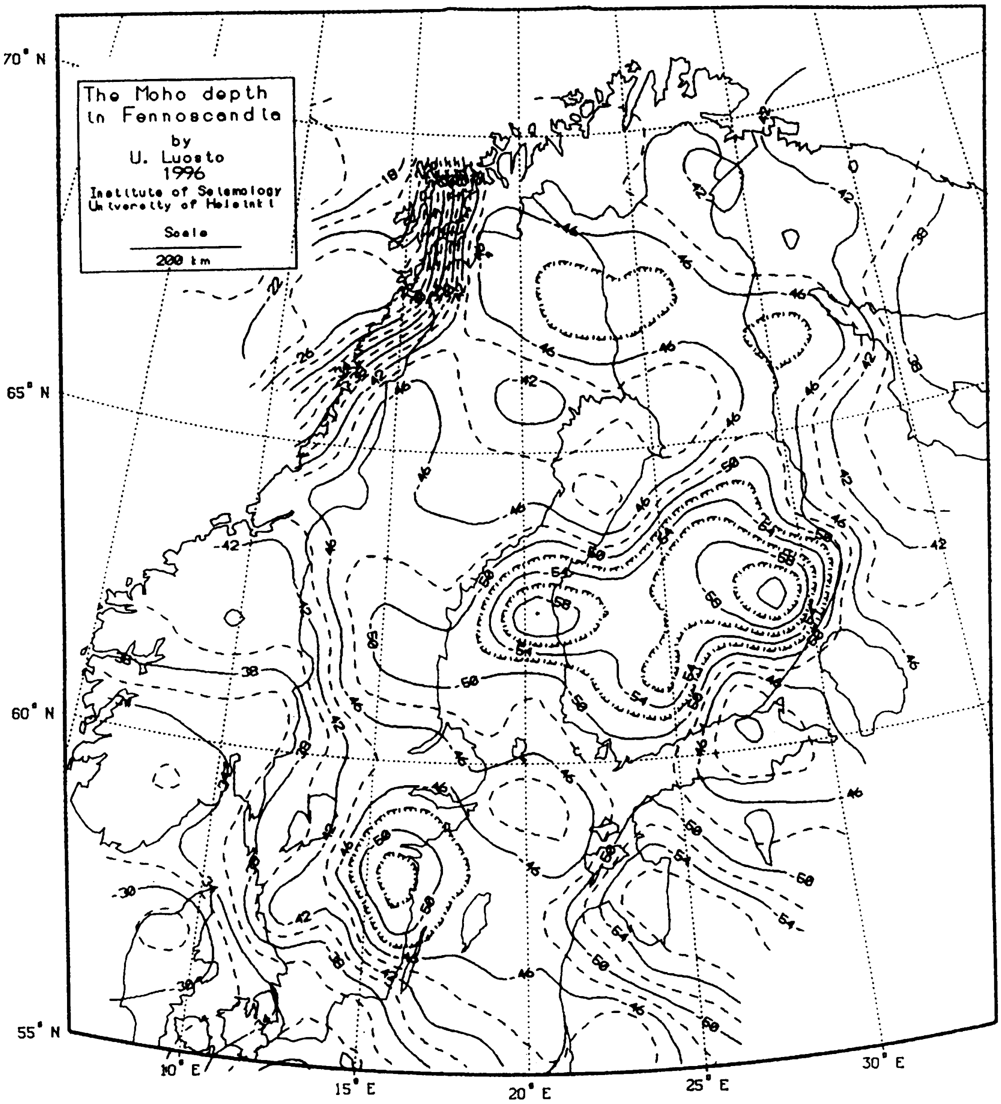


Fig. 18. Moho depth map based on the refraction and wide-angle reflection profiles in the region (adopted from *Luosto*, 1997). Depths are given in km as negative values from the Earth's surface. The contour interval is 2 km. The tick marks in closing the contour lines give the direction of the increasing Moho depth.

As part of the multidisciplinary GGT program, the SVEKA'81, SVEKA'91 profiles and BABEL line 7 were combined to a 840 km long cross-section called the GGT/SVEKA -transect (*Korsman et al.* 1999). By combining geophysical and geological data Korsman and others focused on solving the temporal and causal relationship between deformation, metamorphism, and magmatism and on investigating the crustal thickness and density variations and high metamorphic temperatures during the Svecofennian Orogeny, and the significance of crustal conductors. The results of the GGT/SVEKA are considered to be of a very high international standard.

Finnish seismologists have participated in several international deep seismic refraction measurements abroad in return for the participation of foreign seismic groups in seismic experiments in Finland. In the EGT (European GeoTraverse) project they have participated in recordings of shots in southern Scandinavia, in Central and Southern Europe and in several EGT workshops (e.g. *Ahjos*, 1984, 1990; *Luosto*, 1990). The co-operation with the Polish scientists has been continuing in larger scale. The Finnish seismologists participated in experiments of the Trans European Suture Zone (TESZ) project (*Grad et al.*, 1994, 1999) and of the profiles of the large POLONAISE project (*POLONAISE'97 Working Group*, 1998; *Guterch et al.*, 1999). Measurements along the long EUROBRIDGE / EUROPROBE profile running from the Baltic Sea via Lithuania and Belorussia until Ukraine was made during 1995–98 in a co-operation between Finnish, Belorussian, Danish, German, Lithuanian, Polish and Swedish scientists (The EUROBRIDGE Seismic Working Group, 1999). Joint investigations with Russian scientists have also continued (e.g. *Pilipenko et al*., 1999).

The deep seismic experiment of the subproject Deep Seismics of EUROPROBE's SVEKALAPKO-project was performed in Fennoscandia in 1998–1999. The seismic antenna of 90 short period and 50 broad band stations in a regular 50 x 50 km^2 grid over an area of 600 x 400 km^2 was designed to record seismic body and surface waves (Fig. 19). The equipment was provided by scientific institutions from Finland, France, Germany, Poland, the Netherlands, Sweden, Switzerland and Russia. The SVEKALAPKO event list includes 1356 seismic events: 701 selected distant earthquakes, 75 regional earthquakes, 580 local events (explosions) and 120 strong quarry blasts. All event data have been transformed to MiniSEED format to provide convenient data access for all members of the subproject. There are tomographic, surface wave and anisotropy studies in the study program (*Hjelt and Daly*, 1996).

Applied seismology has been widely used in environmental studies (e.g. nuclear waste disposal site studies and ground water prospecting) and in construction industry. Methods of applied seismology have been investigated at the Technical Research Centre of Finland in Espoo. *Okko*'s (1998) doctoral dissertation was concerning the development in digital engineering-seismic studies in Finland.

6. Detection seismology

The research focused on detection of nuclear tests and other large explosion has concentrated on developing methods for precise location, discrimination and size determination of the seismic events. From the early studies one should mention *Talvitie*'s (1962) investigation on nuclear explosions based on the recordings of the Finnish seismograph network. Methods were developed for determining the sizes of the Novaya

Zemlya atmospheric nuclear tests from recordings of the seismographs and microbarographs in Finland.

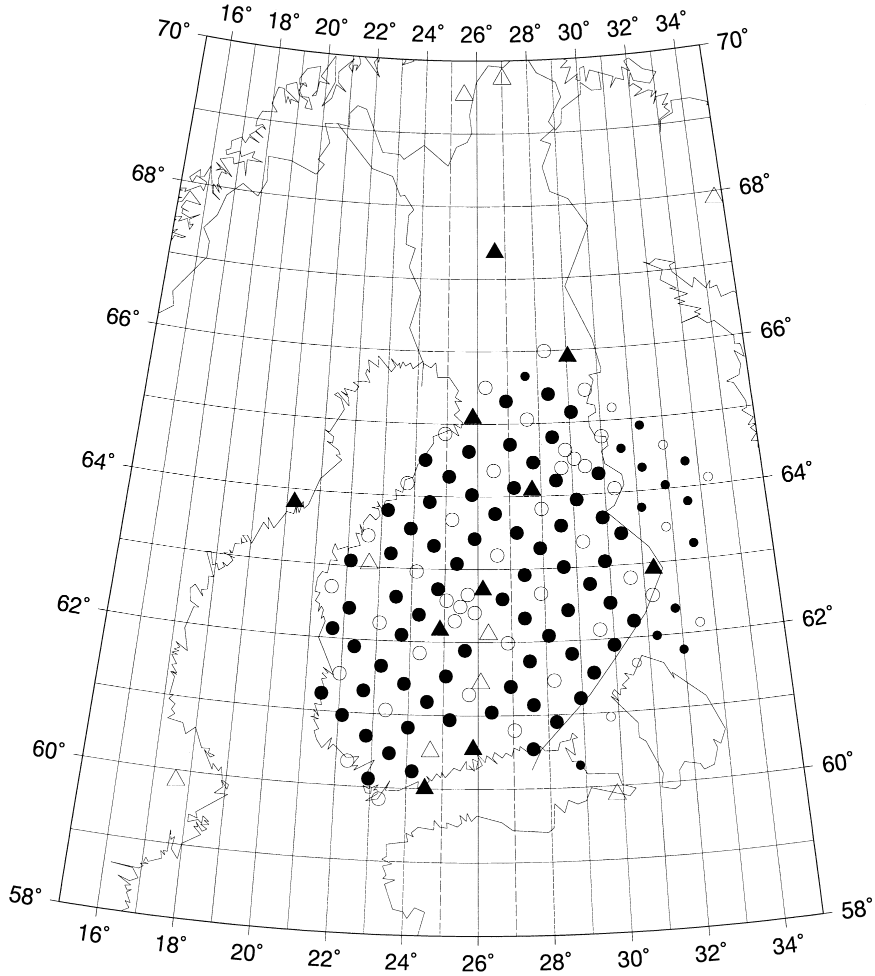


Fig. 19. Station network of the EUROPROBE / SVEKALAPKO seismic tomography experiment in 1998–99. Black circles mark short period and open broad band field stations; black triangles short period and open broad band permanent seismograph stations.

In 1963, the nuclear weapon countries agreed on the partial test ban treaty, which bans nuclear tests in the atmosphere, in outer space and under water. Afterwards the studies have been concentrated on underground tests. In the beginning of 1970's, *Noponen* (1972) calculated event location errors using NORSAR, Hagfors and HEL arrays. He published also scientific reports concerning the power spectra of compressional waves from different types of seismic sources (e.g. *Noponen*, 1976), and publications on event identification using NORSAR data (e.g. *Noponen et al.*, 1972; *Noponen*, 1975).

The establishment of the FINESA array station in southern Finland in 1985 (see Chapter 3) and improved computer facilities in the 1990's began new era in studies of detection seismology in the Institute of Seismology. *Uski* (1990) investigated detection and location capabilities of the FINESA array during a two-week test period. Her results were encouraging: FINESA detected 84 per cent of the events reported in the local bulletin of the Institute of Seismology, and 99 per cent of events in the weekly teleseismic bulletin. However, the location accuracy was poor with errors up to 20 per cent of the epicentral distance. *Tarvainen and Heikkinen* (1992) found that systematic slowness anomalies up to 0.01 s/km were observed in the central Finland tripartite array, when locating 667 teleseismic events at distances more than 20°. This caused the median mislocation of 6° from the true epicentre. After applying a correction algorithm to the data the median error was 1.5°.

Remarkable progress was achieved in the automatic localisation accuracy of the detected events using new mathematical methods like genetic algorithms and interval arithmetic (*Tiira*, 1993, 1999a; *Tarvainen and Tiira*, 1995; *Tarvainen et al.*, 1999). Several automatic detectors were constructed applying modern methods like artificial neural networks on digital data of the Finnish seismological network (e.g. *Tiira and Tarvainen*, 1992; *Tiira*, 1999b). *Tiira and Tarvainen* (1994) and *Tiira* (1996) developed discrimination methods for teleseismic events with a local network of short period stations. The discrimination of an underground nuclear test in the Lop Nor test site on 7th October 1994 in China (*Tiira*, 1995) is illustrated in Figure 20. The tested event activated an artificial neural network as clearly as the known nuclear tests.

Two doctoral dissertations are based on these studies. *Tarvainen*'s (1995) thesis dealt with the monitoring capabilities of the Finnish seismological network, and *Tiira*'s (1998) dissertation was on the discrimination of seismic events using the Finnish station network.

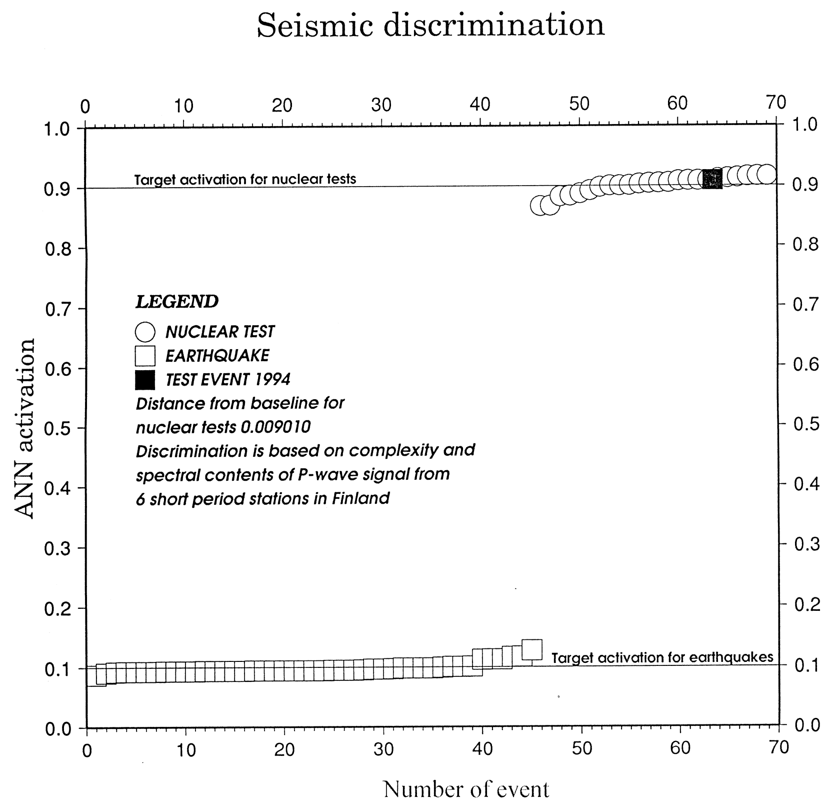


Fig. 20. Discrimination of a Lop Nor event of 7th October 1994 using activation of Artificial Neural Network (ANN) after *Tiira* (1995).

7. Observational seismology

When the first seismographs were installed at the beginning of the century, the collection of travel time data of seismic waves was started. When acoustic compressional and shear waves propagate in the Earth, they are called P- and S-waves, respectively. In addition to the principal P- and S-waves, several waves reflected and refracted once or multiple times at different velocity discontinuities inside the Earth arrive to seismograph stations. These waves are called phases and cited with different symbols e.g. PP, SS, PKP indicating their ray paths through the Earth's interior. The analysis of seismograms includes identifying phases and picking phase arrival times. The analysed earthquake data are transferred to international data centres such as ISC (International Seismological Centre) for location and source parameter determination of earthquakes to be published in seismological bulletins. The seismological stations and the products of the centres are very important part of the international co-operation in seismology. In the first quarter of the century, the seismological bulletins of different stations were used in determining the travel time curves of different phases. It is possible to determine the inner structure of the Earth by travel time inversion of these phases.

The participation in the international data collecting for seismological community was considered very important in Finland. The first seismological bulletin was prepared based on the registrations of the Helsinki seismograph station in 1927 (*Vesanen*, 1952). In Figure 21 Professor Vesanen points to the seismogram of a large earthquake recorded with Mainka seismograph. When the number of the stations increased at the turn of the 1950's and the 1960's, the analysing work increased dramatically. The seismograms recorded at Sodankylä and Oulu stations were also analysed in Helsinki. At this stage, special technicians, analysts were educated at the Institute of Seismology for the work. When communication means improved, the rapid need of earthquake readings was increased at the international centres such as USCGS (USA) and BCIS (Bureau Central International de Séismologie, France). Phase readings were sent weekly by mail and later on, daily via telex or the Internet to the centres.

Detecting and locating seismic events in one's own country is the duty of every civilised nation. Although only a few earthquakes occur annually in Finland, numerous industrial explosions in Finland and surrounding areas are recorded daily by the Finnish seismic network. In addition to the earthquake bulletin discussed previously, the Institute of Seismology has published a special bulletin of local events in order to separate earthquakes from artificial events and also for the needs of the detection seismology. The analysis has been expanded to cover the whole of Fennoscandia and near-by seas in 1987, when the institute agreed to maintain a data bank of Nordic events. Parameter data of events observed at the seismic stations in Finland, Denmark, Norway and Sweden have been collected into the data bank. Monthly data analyses are published in bulletins: "Seismic Events in Northern Europe".

Fig. 21. Professor Eijo Vesanen shows the Mainka recording of a large earthquake on smoked paper to Professor Setumi Miyamura. Other persons in the figure are reserve officer student Reino Kurki-Suonio (on back left) and seismologist Esko Penttilä (on right). (Photo: PressPhoto)

A prototype for an international data centre, IDC, within the framework of the GSE (Group of Scientific Experts) was established in Arlington (USA) for monitoring seismic events. Instead of parameter data, original digital waveform data was continuously transferred from the primary stations of the seismic monitoring network to the IDC and with dial-up protocol from the auxiliary stations for the CTBT (Comprehensive Test Ban Treaty). The FINESS array is one of the primary stations, and since January 1st 1995 FINESS data have been continuously transferred by VSAT-satellite transmission via NORSAR to Arlington.

The Institute of Seismology established a seismograph network in Zambia during the years 1982–1989 in the framework of FINNIsh Developing Aid (FINNIDA) of the Ministry of Foreign Affairs in Finland. Kari Saviaro and after his death, Seppo Pirhonen acted as project supervisors. Personnel for analysing work and maintenance of the network were trained at the Institute. During the extension of the project 1990–91, the Lusaka seismic station was upgraded to record digitally, and the analysis centre was modernised at the Geological Survey Department at the University of Lusaka.

8. Discussion

By chance, the turn from 19th to 20th century was the beginning of the instrumental era in seismology, too. The Finnish scientists were among the pioneers in planning to establish seismograph stations in Finland. Although the foundation of the stations did not succeed at once, the systematic collection of the observation of local earthquakes continued. The comprehensive catalogue of local earthquakes in Finland between 1610 and 1929 by Henrik Renqvist has been the base for later studies and for the catalogues of the Finnish earthquakes and also for the present version of the catalogue of earthquakes in northern Europe (*Penttilä*, 1978; *Ahjos and Korhonen*, 1984; *Mäntyniemi and Ahjos*, 1990; *Ahjos and Uski*, 1992). The magnitude of the earthquakes was also evaluated for the historical earthquakes according to macroseismic data. *Ahjos and Korhonen* (1984) recognized that the attenuation coefficient used in the magnitude calculation formula used in California gave too high values for magnitudes in the Fennoscandian Shield. They introduced smaller attenuation coefficients valid here, which led also to lower magnitude values. *Uski and Tuppurainen* (1996) introduced a new local magnitude scale for the Finnish seismic network. Thus we can consider that the Finnish and Fennoscandian earthquake catalogues offer excellent data for both seismological, e.g. seismic hazard (*Mäntyniemi et al.*, 1993) studies and other geophysical and geological studies.

The foundation of the seismograph station in Helsinki in 1924 was a great progressive step. The international co-operation actually started in the observational earthquake seismology, when the seismological bulletin of the station was first published in 1927 (*Vesanen*, 1952). The magnification of the Mainka seismographs were so low that they recorded only large distant earthquakes, but carefully made analyses of seismograms were certainly an important contribution to seismological research aimed at determining the travel times of seismic waves in the Earth.

State of seismology continued unchanged in Finland for over 30 years while instrumental seismology developed in the other European countries. It is understandable that it is difficult to get resources for the earthquake seismology in a country like Finland where earthquake risk is low. Manmade activities such as wars and armament can bring resources to science. The huge nuclear explosions in Novaya Zemlya 1950–1960's gave an impulse for a rapid progress in the seismology in Finland. New seismographs were constructed and several seismic stations founded. At last it was possible to locate local earthquakes using instrumentally recorded data.

Detection seismology has been an important source of the resources for the Institute of Seismology, and has also offered an interesting field for studies of detection and identification methods of the seismic events. Two doctoral dissertations were based on detection seismology as a result of these studies. In addition, the data collection and transmission facilities have greatly improved as a consequence of the detection seismology.

In addition to the detection and identification of the nuclear tests the established seismograph station network was used also for studies on local earthquakes, surface waves and the structure of the crust in Finland. For proper deep seismic surveys the seismic station network, supplemented with few temporal stations, was not adequate. However, the Pori–Kotka profile connected to the Trans-Scandinavian Seismic Profile in 1969 (*Penttilä*, 1971) was the first reversed profile in Finland with a reasonable short station spacing of 10 km.

The international co-operation in the 1980's with scientists from countries with experience in the deep seismic surveys led the Finnish deep seismic surveys into a great international fame. Already the first co-operative deep seismic sounding profile SVEKA'81 together with Polish colleagues gave the most striking result of 57 km thick crust (*Luosto et al*., 1984) in such a low altitude region, a thickness which usually is found under high mountain belts. The following international profiles, e.g. BALTIC in 1982 together with Russian and German scientists (*Luosto et al*., 1990), verified the finding of the thick crust in the Central Finland. These profiles were followed by the EGT/POLAR profile in North Finland (*Luosto et al*., 1989; Fig. 22) with international co-operation of scientists from several West European countries. The variation of the Moho boundary depth and the inner structure of the crust were studied within international projects also along SVEKA'91 and FENNIA profiles in southern Finland. In addition to the interesting study area, the old Fennoscandian Shield, the digital recorders (*Nurminen*, 1974, 1976) developed at the Institute of Seismology were a substantial qualification for including Finnish researches in international co-operation experiments. The Finnish structural seismologists have been in great demand for participation in the deep seismic experiments of the EGT and EUROPROBE projects in central and eastern Europe supported by the European Science Foundation.

The 1989 BABEL marine deep seismic reflection survey in the Baltic Sea and in the Gulf of Bothnia produced very interesting near vertical and wide-angle reflection data. Interpretation of this data and deep refraction data have given new information on plate tectonic processes during the Paleoproterozoic (*BABEL Working Group*, 1990) and on the Proterozoic extensional and collisional tectonics of the central Fennoscandian Shield (*A. Korja et al*., 1993; *A. Korja and Heikkinen*, 1995). The huge amount of data still offers many interesting study subjects for researchers and postgraduate students.

The well-defined structure of the crust by numerous deep seismic refraction and reflection surveys has stimulated the international seismological community to investigate the deeper lithosphere structures in the Fennoscandian Shield. This resulted in establishing the EUROPROBE's multidisciplinary SVEKALAPKO-project, in which the large tomographic experiment in southern and middle Finland was carried out in 1998–99.

Fig. 22. Professor Heikki Korhonen and seismologist Urmas Luosto preparing an application to the Academy of Finland for funding the field experiment of the EGT/POLAR profile. (Photo: Institute of Seismology)

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