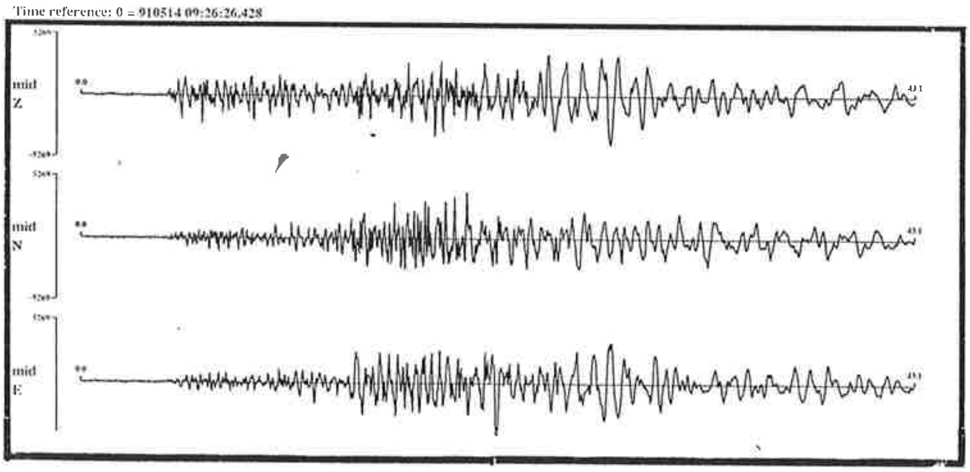
Veðurstofa Íslands
Icelandic Meteorological Office

22nd Nordic Seminar on Detection Seismology



Hotel Örk, Hveragerði, Iceland

June 9-11, 1991

Veðurstofa Íslands

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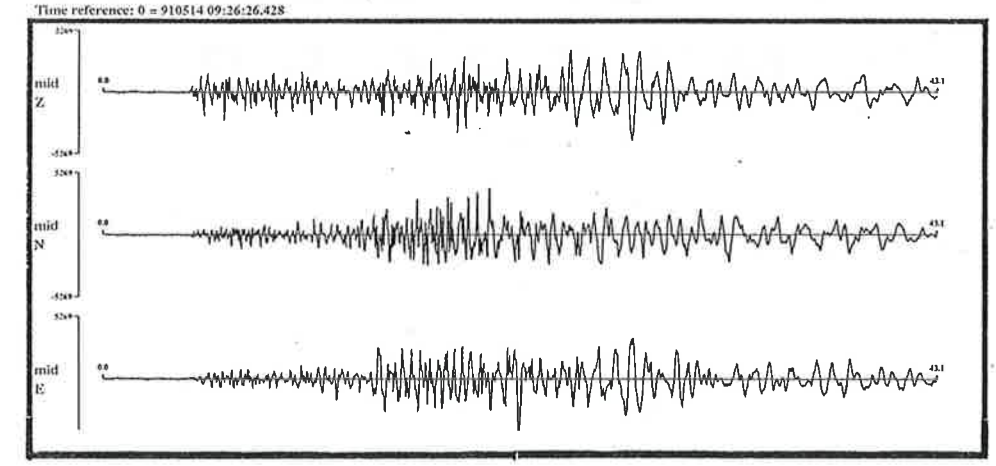

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PROGRAM

Sunday June 9

08:30 **Breakfast**

10:00-19:30 Excursion

20:30 **Dinner**

22:00 Keeping an eye on volcanoes: A new Icelandic videotape concerning prediction of volcanic eruptions and earthquakes

Monday June 10

07:15 **Breakfast**

08:15 Opening address: Ragnar Stefánsson

08:25-10:20 *Session I: Detection seismology*

Chairman: Jørgen Hjelme

H. Korhonen, H. Soosalu & P. Teikari: Seismic safety of underground nuclear testing

J. Yliniemi & M. Grad: Seismic records in Finland from JVE nuclear explosion in USSR

R.G. Roberts & A. Christoffersson: Seismic signal detection - a better mousetrap?

E. Hjortenberg: Noise studies in Northeast Greenland

S. Hestholm, E.S. Husebye, B.O. Ruud & B. Rosland: A 2-dimensional finite difference approach to modelling seismic wave propagation in the crust

D.E. Lokshtanov, B.O. Ruud & E.S. Husebye: The crustal transfer function in seismic 3-component slowness estimation

10:20 **Coffee break**

10:50-12:30 *Session II: Seismic networks, data processing*

Chairman: Páll Einarsson

J. Havskov & H. Bungum: National seismic network in Norway

H. Korhonen, M. Tarvainen & T. Tiira: First results of the Finnish participation into the full scale GSETT-2 data exchange 22. April - 2. June 1991

T. Kværna & F. Ringdal: Integrated array and 3-component processing using a seismic "microarray" (presented by J. Fyen)

C.D. Lindholm, B.O. Ruud & E.S. Husebye: Automatic location procedure with analysis of 3-component data

M. Gustavsson: The modernization of the Hagfors Array Station

12:30	**Lunch**
14:00-15:45	*Session III: The SIL project*

Chairman: Hilmar Bungum

P. Einarsson: Earthquakes and tectonic movements in S-Iceland

R. Stefánsson & R. Slunga: The objective of earthquake prediction in the SIL area

R. Böðvarsson: The SIL system, a new tool for earthquake acquisition

S. Ólafsson: Operation of the SIL system

S.S. Jakobsdóttir: The SIL system: Phase detector - parameter data

15:45 **Coffee break**

16:10-17:30 *Session III, continued*

R. Slunga: The SIL center automatic selection and event analysis

R. Böðvarsson: Possible future development of the SIL system

R. Slunga: Experiences of the earthquake analysis implemented at the SIL (South Iceland Lowland) seismic network

G. Petersen: The integrated earthquake disaster plan for South Iceland

17:30 **Coffee break**

17:40-18:20 *Session III, continued*

I.Þ. Bjarnason, W. Menke & Ó.G. Flóvenz: Wide-angle reflection/ refraction survey of the South-Iceland rift and transform zone

R. Stefánsson & K. Ágústsson: The Hekla eruption of 1991 and release of stress in the South Iceland seismic zone

18:20-18:50 Discussion: SIL research in near future

19:20 ***Reception by Ministry of Environment***

20:30 ***Dinner invited by Icelandic Meteorological Office, hosted by director Páll Bergþórsson***

Tuesday June 11

07:15 **Breakfast**

08:15 *Session IV: Seismicity*

Chairman: Heikki Korhonen

K. Meyer: Temporal variations of seismic energy release in the Baltic Shield (presented by L. Persson)

C.D. Lindholm: Some results from an Ocean Bottom Seismometer experiment in the northern North Sea

P. Einarsson: Seismicity of Icelandic volcanoes

R. Arvidsson, R. Wahlström & O. Kulhanek: The deep-crustal earthquakes in the southern Baltic Shield in 1986

J. Saari: Recent observations of microearthquakes in SE Finland

10:00 **Coffee break**

10:25-12:50 *Session V: Seismic hazard assessment*

Chairman: Ragnar Slunga

P. Mäntyniemi, R. Wahlström, C. Lindholm & A. Kijko: An estimate of seismic hazard for Fennoscandia

K. Atakan: Perspectives in earthquake hazard assessments: Importance of geological data in areas of low seismicity (a case study from Sunnhordland, Norway)

H. Bungum: Ground motion attenuation functions for Norway based on a stochastic ω-square model approach

A. Dahle: New empirical ground motion attenuation functions for the Norwegian continental shelf

B. Bessason: Site-specific earthquake load assessment

R. Sigbjörnsson: Strong motion measurements in Iceland and seismic risk

12:50 **Lunch**

14:20-16:05 ***Session VI: Seismic investigation, crustal structure, tectonics***

Chairman: Steinunn S. Jakobsdóttir

H. Gjøystdal: Research activities in the NORSAR seismic prospecting group

E.S. Husebye, B.O. Ruud & S. Hestholm: Crustal thickness in Fennoscandia - an overview

S. Gregersen, H. Thybo & E. Perchuc: Interpretation from explosion seismograms of crustal inhomogeneities in STATU NASCENDI

S. Gregersen: Crustal stress regime in Fennoscandia from focal mechanisms

O.A. Sandvin, E.S. Husebye & J.E. Lie: The transparent upper crust - a seismic profiling artefact

16:05 Coffee break

16:30-17:50 Session VI, continued

J.E. Lie & E.S. Husebye: Deep crust and mantle structures related to rifting and basin formation in Skagerrak

L. Persson: Coda Q estimations and bispectrum analysis of the coda from local earthquakes and mine explosions

B. Brandsdóttir & A.B. Lassen: The Askja central volcano, NE-Iceland. Earthquake activity during July and August 1989

S.Th. Rögnvaldsson & R. Slunga: Fault plane solutions using amplitude observations - a test with synthetic seismograms

17:50 Coffee break

18:00-18:40 Session VI, continued

K. Åstebøl: Improvement of surface representation by the introduction of surfaces with discontinuities

S. Gregersen & F. Vaccari: Lg waves absorbed in North Sea grabens

18:40-19:00 Discussion: Nordic exchange of data from seismic stations

19:00 Closing remarks

19:30 Bus transport to Reykjavík

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Ingi Þ. Bjarnason
William Menke

A B S T R A C T S

Seismic safety of underground nuclear testing

H. Korhonen, H. Soosalu and P. Teikari

Due to favorable geological conditions the Finnish seismic network can detect nearly all underground nuclear detonations above magnitude 4.5 at the Semipalatinsk, Lop Nor and Nevada test sites and above 3 at Novaya Zemlya.

The detection limit for regional events is below magnitude 2.5 (ML). Thus nuclear explosions of fractions of Kiloton can be detected if carried out in northern Europe.

A special study of environmental safety of underground nuclear testing has been recently started in Finland.

Seismic records in Finland from JVE nuclear explosion in USSR

Jukka Yliniemi[1)] and Marek Grad[2)]

Soviet nuclear explosion conducted on 14 September 1988 at Semipalatinsk Test Site in USSR as an outcome of the Joint Verification Experiment (JVE) Agreement was recorded very well along deep seismic sounding profile Kemi-Kostamus in epicentral distance interval 3286-3481 km and in all permanent seismic stations in Finland. Seismic waves recorded on the Baltic Shield in Finland penetrated through the upper mantle of the southern part of the West Siberian platform, Ural mountains and East European platform. Characteristic for all records are very strong first arrivals of P-waves and no distinct waves in further pulses. The apparent velocity of the first arrivals of P-waves in about 12.5 km/s. The travel times of JVE explosion are very close to travel times calculated for the East European platform models KCA (King, Calcagnile, 1976) and MUMEP (Grad, 1987, 1988). The JVE travel times are about 1-2 s early compared to the travel times to the Baltic Shield and Western Russian (Enayatollah, 1972; England, Worthington, 1977) and 2-3 s early compared to Jeffreys-Bullen travel times (Jeffreys, Bullen, 1940). Scattering of times of P-waves from JVE explosion is of the order 0.4 s. Because the locations of stations and arrival times were determined with very high accuracy, the deviations from a smooth line must result from inhomogeneities of the structure. All differences had been fully explained by Moho depth and mean crustal velocity differentiation.

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1) Geophysical observatory, University of Oulu, Finland
2) Institute of Geophysics, University of Warsaw, Poland

Seismic signal detection - a better mousetrap?

Roland G. Roberts and Anders Christoffersson

Departments of Geophysics and Statistics, Box 556, 751 22 Uppsala, Sweden.

The first stage of the analysis of any seismological (earthquake, explosion) data is detection of the presence and onset time of a seismic signal. Traditionally this has been achieved by visual inspection of data records or by the use of a short-term average/long-term average (STA/LTA) detector. Here we present a new algorithm for the detection of seismic signals. Using single (vertical) component data working in one or several frequency bands, the algorithm detects seismic signals based on signal power within each frequency band. By limiting the class of filter functions which we use, the algorithm can be made very computationally efficient, outperforming comparable techniques. If three-component data are available, in parallel with the signal power detector we can apply a model-based polarization analysis procedure giving an estimate of predicted coherence. Examples of available models are P and Rayleigh waves. These also provide estimates of the direction of propagation of the signal, and for P waves the apparent surface velocity. These estimates are instantaneously available at very little additional computational cost.

The technique can be readily extended to work with array data where the computational advantages become even more significant.

Noise Studies in Northeast Greenland

Erik Hjortenberg

Seismic noise in the 0.1 - 0.3 Hz frequency range at station Scoresbysund was studied by Inge Lehmann (1952), at Scoresbysund and Nord by Henry Jensen (1957 - 1967), and at Danmarkshavn and Kap Tobin by Erik Hjortenberg and Jørgen Hjelme (1980).

Seismic noise in the range 0.2 - 30 Hz was studied by short reconnaissance visits to Danmarkshavn and Nord in July - August 1989. Results were presented by Philip Harben, LLNL in Barcelona, 1990 and will appear in the proceedings of the ESC General Assembly. We concentrated on determining the background noise levels measured during calm weather and minimal site activity to determine a minimum average noise level that can be expected during that season. Between 1 Hz and 10 Hz the Danmarkshavn low-noise-period spectrum has a significantly higher magnitude than the Nord low-noise-period spectrum. This is probably caused by numerous flowing streams in the Danmarkshavn area. The Nord spectrums resemble that of a continental low noise period spectrum.

Further studies of this noise in northeast Greenland are planned by setting up digital recording stations for one year at Nord, Daneborg and Scoresbysund.

A 2-DIMENSIONAL FINITE DIFFERENCE APPROACH TO MODELLING SEISMIC WAVE PROPAGATION IN THE CRUST

S. Hestholm[1], E.S. Husebye[2], B.O. Ruud[3] and B. Rosland[1]

[1] IBM Bergen Science Centre, Bergen, Norway
[2] NORSAR, Kjeller, Norway
[3] Dept. of Geology, Oslo Univ., Norway

It is well known that the direct, discrete solution of the elastic wave equation constitutes an excellent platform for synthetic seismogram analysis as *all* propagation effects are included in the solution. A practical realization of this approach has been problematic until recently due to limitations imposed by currently available computers. This being said, we will in this talk report on 2-dimensional (2D) finite difference (FD) seismogram synthetic experiments aimed at a better understanding of seismic wave propagation in the crust. Firstly, to ensure that the synthetics are realistic, a linear sensor geometry with Z and R (radial) instrumentation is used. This allows us to process the synthetics in a conventional manner in order to verify that phase velocities and polarization characteristics comply with model expectations (ray tracing, etc.). The first experiment undertaken was to model scattering contributions from a bumpy Moho southwest of NORESS. The outcome here was (as expected) that an anomalous structure of several wavelengths contributes little to seismogram complexity. We have also experimented with various source depths and crustal velocity gradients, which have a marked effect on the synthetics. In the talk, we will give details on computational methodology, present experimental results and also outline on-going efforts on structural modelling in order to also produce realistic coda waves.

THE CRUSTAL TRANSFER FUNCTION IN SEISMIC 3-COMPONENT SLOWNESS ESTIMATION

D.E. Lokshtanov[1], B.O. Ruud[2] and E.S. Husebye[3]

[1] Dept. of Solid Earth Physics, Bergen Univ., Norway
[2] Dept. of Geology, Oslo Univ., Norway
[3] NORSAR, PB 51, Kjeller, Norway

Here we present a new approach for estimating the slowness vector of incident P-waves from records of a single or an array of 3-component (3C) seismometers. The slowness vector is extracted by using an ML inversion scheme where the signal model incorporates the transfer function of the layered crust beneath the receivers. The unknown time function of the incident plane wave is excluded from the inversion. In the case of array observations both polarization and kinematic properties of the wavefield are utilized. The scheme was tested on records of NORESS 3-component stations from teleseismic and local events, and the obtained slowness estimates are in general closer to the expected values than estimates derived by conventional methods.

National Seismic Network in Norway

J. Havskov, University of Bergen

H. Bungum, NORSAR

In Norway, almost all seismic stations are operated with funds from private sponsors. This funding will to a large extent expire at the end of 1992. In order to assure continued operation, a long term plan for a national seismic network has therefore been agreed upon between NORSAR and the University of Bergen (UiB). The 'new' network will to a large extent consist of a modernized subset of the current network (8 stations), with the addition of a station on Bear Island and a miniarray on Svalbard. The total national network will thus consist of 9 three-component stations and 3 miniarrays (Svalbard, NORESS and ARCESS). The 3 component stations will use Ranger seismometers, Nanometrics RD3 digitizers, VME68020 computers (OS9 operating system) and 9600 baud modems for communication. All single stations will be operated by UiB and the miniarrays by NORSAR. The routine data processing, including the regional bulletin, will take place in Bergen as today. NORSAR will make real time analysis of the miniarrays making it possible for both UiB and NORSAR to give information about earthquakes a few minutes after their occurrence. Financing for the modernization is mostly covered by existing projects. UiB and NORSAR have together made application to all oil companies in Norway through the Norwegian Petroleum Directorate for long term financing of the operation of the new national seismic network in Norway.

First Results of the Finnish Participation into the Full Scale GSETT-2 Data Exchange 22. April - 2. June 1991

Heikki Korhonen, Matti Tarvainen and Timo Tiira

Finnish national data centre took part into the full scale data exchange experiment of GSETT-2 by sending Level-1 and Level-2 data from stations KAF and VAF of FINSA network and from FINESA small-aperture array. KAF was used as the reference station for parameters data of FINSA network.

After the 'warm-up' period in November-December 1990 some improvements in the operating procedures and programs were done. The number of filtering bands in automatic processing was increased from 3 to 7. The waveform transmission was changed into automatic mode. This automation was tested before the beginning of the test and it was found to work well during the GSETT-2.

Parameter messages and additional waveform detections were all sent within 11 hours after the data day.

Daily amount of the data received by the Washington "HUB" averaged near 2 MB.

This paper is based on preliminary results obtained in Finland during the test.

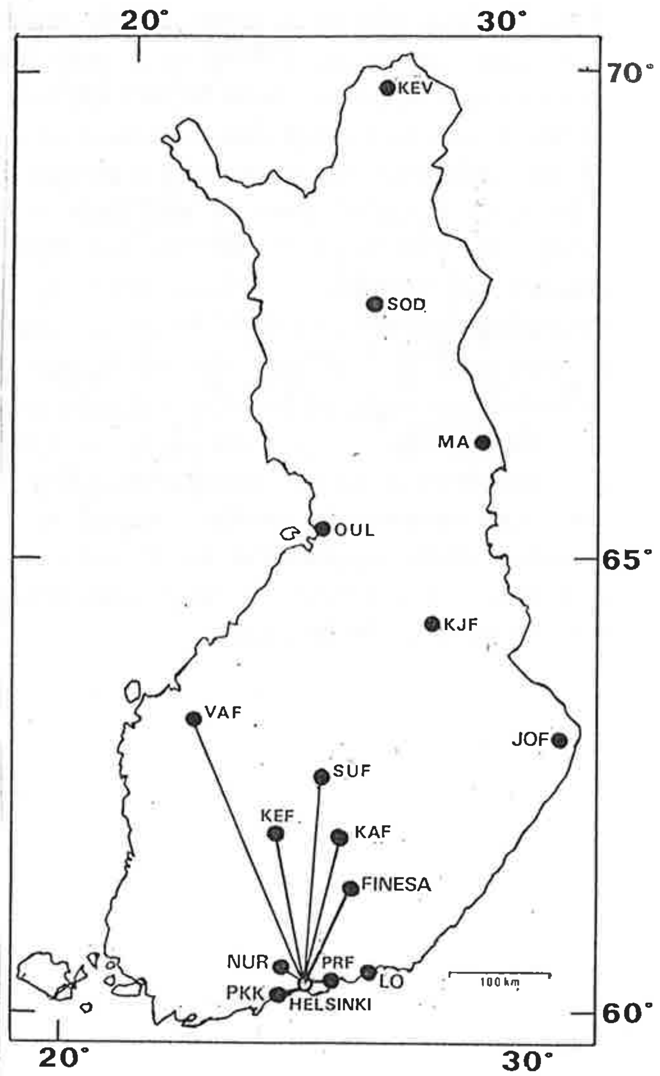

Fig. 1. Seismograph stations in Finland

INTEGRATED ARRAY AND 3-COMPONENT PROCESSING USING A SEISMIC "MICROARRAY"

Tormod Kværna and Frode Ringdal
NORSAR, 2007 Kjeller, Norway

A "microarray" as defined in this study is modeled on a subgeometry of the NORESS array, and comprises a 3-component center seismometer surrounded by 3 closely spaced vertical-component sensors deployed over a typical aperture of 0.3 km. Analysis of five days of continuous data has shown that such a system combines the benefits of array and 3-component processing in providing reliable automatic detection, phase identification and location of weak seismic events at local and regional distances. The data processing has comprised a) multiple-band filtering, b) coherent and incoherent beamforming, c) STA/LTA threshold detection, d) broadband f-k analysis and e) automatic phase association and event location. Using vertical components only, broadband f-k array analysis enables correct phase identification (P-type or S-type phase) in 95 per cent of the cases, and gives S-wave azimuths with an RMS deviation of 13.9 degrees from the estimates of the full NORESS array. It is particularly significant that the small array eliminates the need for introducing particle motion models, which creates ambiguities in 3-component analysis of secondary phases when interfering SH and SV phases occur. P-phase azimuths are estimated using integrated array and 3-component f-k analysis, and have an RMS deviation relative to NORESS of only 9.6 degrees. Compared to the full NORESS array, the P-wave detection capability is good for events with epicenters within 500 km of the station, but for greater distances the performance is significantly reduced. The S-phase detection capability is enhanced by incoherent beamforming of the horizontal channels, and approaches that of NORESS at all distances. A considerable reduction in the detector false alarm rate is achieved by imposing constraints on the estimates of apparent velocity obtained from the f-k analysis before accepting a detected phase.

In conclusion, we have found that the large problems encountered when using a single three-component instrument in an automatic processing environment appear to be effectively alleviated when the station is expanded by a very small 3-element array.

Automatic Location Procedure with Analysis of 3-Component data.

C. D. Lindholm[1], B. O. Ruud[2] and E. S. Husebye[3]

As a consequence of an increasing number of seismic stations beeing deployed, the amount of data to process routinely increases. However, economical recources often put severe contraints on the manual processing of these data, thus providing a strong incentive for automated processing. This situation also applies to the Institute of Solid Earth Physics, Univ. of Bergen, which operates 14 seismic sites in Norway of which 4 are 3-component stations, (it is planned to make all stations 3-component). As an approach to meet the new challenges that this dataflow presents, an automatic processing sheme has been implemented.

All data is automatically processed when it is registered in the database as an event, and the processing involves the following steps: i) All data is processed for P and S phase arrivals, and 3-component stations are in addition subject to polarization analysis where the P slowness vector is extracted whenever possible. ii) The event parameters (P, S, azimuth, apparent velocity and signal duration) are written to a pickfile in the database. iii) A location of the event is performed with a newly developed location program. Here weight is given to the azimuth parameter, which has proved to be a very useful piece of information in addition to phase arrival times. iv) An event classification discriminant program is then activated in order to flag probable explosions. v) Finally a plot of the data with phase arrivals is plotted, and a file with the location and explosion filtering results is printed. The automatic processing procedure is not entirely fool proof. The plotted and printed output is therefore presented to the analyst for evaluation and eventually continued manual processing

The process has been implemented on a Vax, and is based on the Standard Nordic data formats. Future plans include implementing the more sensitive 3-component detector on the field stations. In addition to lower detection threshold, part of the data processing (polarization analysis) can be performed without loading on the central computer.

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The modernization of the Hagfors Array Station

Matts Gustavsson
The National Defence Research Establishment, Stockholm

The modernization of the Hagfors Array Station which started in 1988 has now reached the end phase. The new data acquisition system has been installed at three of the four stations and parts of the NDC has been modified.

The paper describes the design and performance of the system and the experience of operating the system.

EARTHQUAKES AND TECTONIC MOVEMENTS IN S-ICELAND

PÁLL EINARSSON
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The structure of the mid-Atlantic plate boundary in the Iceland area is strongly influenced by the Iceland hot spot. The relative motion of the Mid-Atlantic Ridge with respect to the hot spot leads to ridge jumps, propagating rifts, oblique spreading and complex transform zone. To the south of Iceland the Reykjanes Ridge becomes progressively more oblique as it approaches the hot spot and the ridge obtains some of the characteristics of a fast spreading ridge. Seismicity decreases and the central graben is replaced by a central high. On shore the plate boundary becomes even more oblique. Here, on the Reykjanes Peninsula, the boundary is marked by a narrow zone of seismicity that trends 70°. Volcanic systems are arranged in an en echelon pattern along the peninsula, the volcanic and tectonoc structures thus occupy a much wider zone than the current seismicity.

Spreading in South Iceland occurs along two sub-parallel rift zones, the Western and the Eastern Volcanic Zones. The western zone is the older of the two and appears to be dying in response to increased activity of the eastern zone. The two rift zones are connected by a transform zone near 64° N, the South Iceland Seismic Zone, where many of the most damaging earthquakes in Icelandic history have occurred. It is marked by a 10-15 km wide, easterly trending epicentral belt. The large earthquakes occur by faulting on N-S striking right-lateral faults. The left-lateral transform motion along the zone thus appears to be taken up by slip on numerous parallel faults and counterclockwise rotation of the blocks between them (bookshelf tectonics). It is argued that the South Iceland Seismic Zone is a transient feature, migrating sideways in response to propagation of the Eastern Volcanic Zone. The Eastern Volcanic Zone is thus seen as a propagating rift that began propagating away from the central area of the Iceland hot spot 1-3 million years ago.

The tectonic picture presented here remains to be confirmed by direct measurements of crustal movements. Preliminary results of GPS-measurements in the period 1986-1989 are marginally significant, but appear to be in general agreement with this picture.

The objective of earthquake prediction in the SIL area

Ragnar Stefánsson,

Geophysical Division, Icelandic Meteorological Office.

Ragnar Slunga

Uppsala University

Historically the earthquakes in the SIL area reach the magnitude of 7.1. The earthquake genetic zone is 70 km long and 15 km broad. The thickness is also about 15 km. This limits the magnitude of possible largest earthquake in the region to 7.2 or 7.3.

What favours the objective of earthquake prediction is the heterogeneity of the region, the proximity to the rift zone and the proximity of partially molten material at the base of the seismogenetic crust. This is expressed in clustering of earthquakes during hours or days, frequent swarmlike activity inside the zone and outside. There are examples of foreshocks of moderate earthquakes and various expressions of slow strain changes connected with earthquakes.

Earthquake occurrence is a stick slip motion in discrete parts of a region of strainbuild-up. The slip is forrun by accelerated stable or unstable motion in the adjacent material. This redistribution of stress towards the large earthquake asperite is the main object for those who work towards earthquake prediction. This redistribution can be monitored by observing and evaluating the very small earthquakes which occur frequently in the parts where creep motion is dominating and also reflect heterogeneity of the block where stress is building up towards a large earthquake. It can also be recorded by strainmeters or tiltmeters and other instruments fit for monitoring of slow stable motion.

The design criteria for the SIL system were based on the above consideration, those are high dynamic range, 3 component system, automatic near realtime evaluation, flexibility towards the introduction of various types of sensors to be introduced in the system.

THE SIL SYSTEM, A NEW TOOL FOR EARTHQUAKE ACQUISITION

Reynir Böđvarsson

Section of solid earth physics
University of Uppsala

Several possible architectural models for the SIL acquisition system where considered before the start of the development. The conclusion reached was that fully centralized and fully decentralized systems were not satisfactory. A hybrid system, involving both central facility and distributed capabilities has been constructed. A **low-noise** channel between the sensors and a directory in the central computer has been established.

Utilizing powerful computers at each station allows for extensive analysis of all incoming data in "real-time". Short messages describing detected **phases** are then transmitted to the center for analysis. The analysis, of the detected phases, performed at the center, include: estimation of time interval consistency, localization of possible events derived from the detected phases and calculation of theoretical travel times to all stations for each event. The final selection of data to be transferred to the center is based on the results of these calculations.

The software at the stations and the center is fully independent of the utility used for communication in the network. The SIL software at the sites produce files in a *date-directory-structure* holding the phase-logs and later the selected signals. The selection programs at the center produces one file at a time for each station defining the time interval to be fetched. The way these files are transferred between the computers can be chosen depending on how close to real-time the network is to be operated. In the SIL network this is done directly through the X.25 channel for the phase-logs but the waveform data is transferred by the UNIX utility *uucp* after compression.

Earthquakes, within the SIL area, down to $\mathbf{M_L=-0.5}$ are selected and located automatically by the network. Fault plane solutions and estimate of various dynamic source parameters can be automatically calculated for earthquakes down to $\mathbf{M_L=0}$.

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Operation of the SIL system

Sveinn Ólafsson
Geophysical Division, Icelandic Meteorlogical Office

The seismic signal goes through many stages on its way through the SIL system. The earth movement is changed into analog signal which is digitized and stored temporary in a 25 hours ring buffer. A phase detection software analyzes the data in the ring buffer and produces the so-called phase logs which are transmitted to SIL center. Waveform data which is saved (automatically or manually) is formatted into SIL format, compressed and sent to the SIL center. Data exchange between the center and a site can be divided into three types.

1) Phase logs (128 bytes) sent from site to center.
2) Save requests from fetcher software or users, sent from center to site (22 bytes per event).
3) Waveform data files sent from sites to center.

Phase detection logs are received in the SIL center and made available to the selector and fetcher software which analyzes them and sends save requests to the sites.

The SIL center receives the waveform data in SIL format, translates it to AH format and stores it both in SIL and AH format.

Because of the amount of phase detections sent to the center, a specialized x25 software was written to transmit the logs with minimal overhead. Currently all other transmissions are done with UNIX uucp software.

While implementing the SIL system we have experienced many things which have interrupted the performance of the network. In the beginning the dominating errors where related to the build-up phase we were in, i.e. hardware and software problems which showed up during the period of installation. Today the operation is mostly interrupted by environmental causes, such as lightnings, electricity power down and broken telephone lines. Spikes have been eliminated from the electronic equipment, so data is free of them. Concerning electricity the down-time can be reduced by increasing the power-backup time at the sites either with el-generators or batteries. Currently we have up to 40 minutes backup, which is to short. In cooperation with the National Telephone Company we are improving the lightning protection at the modem end of the lines.

The SIL system: Phase detector - parameter data

Steinunn S. Jakobsdóttir

Geophysical Division, Icelandic Meteorological Office

The phase detector is a tool specially designed to supply the selector with information about the seismic signals. This includes information about onset time, duration, signal and noise averages, 3-component analysis and frequency analysis.

The data is high-pass filtered with a simple derivate filter. The vector length at each time of the derivated signal is calculated and signal and noise averages found for the vectors.

The detection state is found by comparing these averages. When detection state is declared on the signal window is scanned to find the onset time more precisely. The signal and noise averages are calculated for each channel and the DC-levels and the corner frequencies are found using unfiltered data.

The azimuth and the coherency of the 3 components is calculated on band-pass filtered data, where the band-pass interval is dependent on the corner frequency of the Z-component.

The duration of the phase is observed and if more than one phase is found within the same detection state, the time in seconds to previous and past phases is calculated.

All this information is packed into the phase-log and sent to the central computer at the SIL-center in Reykjavík.

The SIL center automatic selection and event analysis

Prof. Ragnar Slunga

Uppsala University

The central SIL computer receives the phase detections from the site computers. The analysis of these is at present divided into two steps. In the first step a set of voting criteria are applied. These voting criteria are of the form "at least a number of n(k) phase detections of quality k within a time window T". A number of 5 different quality classes are allowed and must be specified for each station. These criteria are formulated both for 3-component (time and azimuth) and 1-component (time) detections. Simple checks on the consistency of the azimuth observations are also made. When one of the criteria is fulfilled place in the file system for the possible event is prepared by creating a subdirectory. The name of this subdirectory together with all phase detections for the actual timeinterval (-T,2T) are written into a temporary file which is the input to the following automatic event location. This automatic location algorithm searches for combinations of phase detections that can define (locate) a seismic event. This algorithm is very similar to what I developed for the IDC:s. Information about all accepted events is saved in event-files in the subdirectory. The key information about each accepted event is also appended to the preliminary event file of the day. Once the location and origin time of each event are known it is straightforward to apply algorithms for signal analysis, for fault plane solutions, and for dynamic source parameters inversion etc. As the net is not only a research net but also in practical use as a monitoring and warning tool the analysis has been designed in such a way that one can starf the analysis of an interval before the phase detections from all sites are available. When late phase detections arrive the events are automaticly improved. New events may also be created at later stages. These problems are solved by making use of a memory file showing the present stage of the analysis.

POSSIBLE FUTURE DEVELOPMENT OF THE SIL SYSTEM

Reynir Böðvarsson

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The SIL acquisition system provides possibilities of different operational configurations. Some aspects on possible configurations will be discussed. Two examples are given below.

A **pure research station** with **no warning duties** can be linked to the center via a *dial-up* line two times per night. First the center gets the phase logs for the last 24 hours. These are then processed by the selector software and the second call is made to deliver information to the station on what time intervals are to be saved from the *ring-buffer.* Waveform data is then sent on cartridge tapes every month from each station. Full detectability is achieved as if the stations where more closely connected as in the SIL network. The operational cost of such configuration is at minimum.

A configuration using X.25 (as in the SIL network) can be operated **without any transfer of waveform data.** A protocol is defined for *function calls* from the center to the stations. The analysis is based on the *phase-logs* and whenever some computational operation is to be performed on the waveform data a function call is made to the station and a corresponding operation is performed remotely. The value(s) are then returned to the calling program at the center through the *function protocol.* By this the amount of data transferred will be very small without reducing the quality of the analysis.

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Experiences of the earthquake analysis implemented at the SIL (South Iceland Lowland) seismic network

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The extended SIL network consists at present of nine three component short-period instruments covering an area with a diameter of some 120 km. Algorithms developed in the analysis of the Swedish earthquakes during the last ten years have now been implemented.

The algorithms are:

1) scanning of the phase detections from the stations, and grouping them to define and locate events

2) signal analysis for extracting spectral amplitudes, corner frequencies, first motion directions etc

3) source mechanism determination (fault plane solution, seismic moment, fault radius, static stress drop, and peak fault slip etc)

These algorithms are designed for completely automatic analysis. In this presentation examples of the results from these algorithms will be given. During the last year a number of swarms (up to hundreds of automatically located events per day) have occurred. The largest event so far within the area covered by the net has ML 4.6. The access to three component data turns out to be very valuable (compared to only vertical seismometers). The formal (conservative) estimates of the location uncertainty (including depth) are often of the order of 500m. Together with the access to three component data, and together with the high signal quality (no electric spikes etc) this means that very good results from the fault plane solution algorithm (making use of both first motion directions and spectral amplitudes) are expected. This is verified by the results so far achieved. In comparison with the experiences of the analysis of the shield area earthquakes (Fennoscandia) the earthquake sources and wave propagation seem very similar. The noise free signal data, the dense network and the high seismic activity will make it possible to go much further into a detailed analysis of the source mechanisms and fault movements than was possible with the Swedish local digital networks operated during the eighties.

The intergrated earthquake disaster plan for South Iceland

Guðjón Petersen

The paper includes the general outlines of the Disaster plan prepared in Iceland to meet the consequences of large or damaging earthquake in South Iceland. It does not include other fields of the earthquake problem such as public education, investigation and strengthening of critical sites and building requirements or policies.

The disaster management system in Iceland consists of the National Disaster Management Agency (Civil Defence) and Disaster Committees in districts.

An advisory counsel of four senior scientists from geological institutions in Iceland serves the National Disaster Management Agency in its preparedness activities, and under crisis situation.

The South Iceland Area, suffering from potential earthquake hazard is divided into two jurisdictions which are then divided to seven 'Disaster' districts. Each district has Disaster Committee seated by the chief of police (or his deputy), the mayor (or chairman of the District Council), the fire chief, the district physician, the district engineer (or building inspector) and two memers appointed by the District Council.

The responsibility of the Disaster Committee by law is to organize and implement Disaster relief services arising from natural or man-made disaster. The Committees are thus charged with the organization and implementation of the following measures within their areas:

1. Organization of auxilary Rescue and Relief teams and their training and outfitting.
2. Supervision of and instructions concerning private disaster protection measures in apartment houses, business concerns and institutions.
3. Selection and organization of Mass Care Shelter for evacuees.
4. Command Centers.
5. Telecommunication systems for emergency purposes.
6. Collection of supplies and management of supply centers.

National Disaster Management Agency

The National Disaster Management Agency undertakes the general organization of Disaster Preparedness and Management throughout the country. It arranges for the implementation of matters falling under the jurisdiction of the State Authorities; including

1. Telecommunication between districts.
2. Information and data collection regarding hazards.
3. Warnings and warning systems.
4. Instructions and informations to the public.
5. Training of officers and instructors.
6. Collection of supplies and their safekeeping.
7. Organization and direction of evacuation from hazard zones.
8. Direction of assistance rendered between districts and by State institutions.
9. Supervision of district disaster committees.

The Disaster Management Agency does also monitor and support studies on the danger from ice layers, volcanic eruptions, earthquakes, floods, avalanches, landslides and other hazards in cooperation with the scientific counsel.

It furthermore supports, monitors and co-ordinates measures aimed to reduce the likelihood of bodily injury or property damage from natural disasters or other hazards, including such measures as construction of protective earthworks or other provisions for public protection.

The paper discusses the implementation of abovementioned tasks into the Earthquake Plan of South Iceland.

Wide-Angle Reflection/Refraction Survey of the South Iceland Rift and Transform Zone

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During July-September 1990 a cooperative seismic wide-angle reflection/refraction experiment between Lamont-Doherty Geological Observatory and the Icelandic National Energy Authority, was conducted in Iceland. The main objective of this experiment was to collect data for construction of relatively high resolution velocity images of crustal structures in South Iceland, including a cross-section of the mid-Atlantic rift and a transform zone down to the crust-mantle boundary. The profile is 150 km long and runs from the west, across the Western Rift Zone and continues obliquelly through the South Iceland Transform Zone toward the Eastern Rift Zone. We used a total of 11 shot points and 200 receiver stations, which were spaced at 500 m in the center of the profile and 1-2 km at the ends. The data were recorded digitally with 3 component geophones. A high degree of lateral velocity variation is observed along the profile from east to west and a number of extinct central volcanos produce fast velocity anomalies. As expected the data show that Icelandic crust is significantly thicker than typical oceanic crust. A number of multiple arrivals are observed in the data, including a prominent phase that can be interpreted as a wide-angle reflection of an interface at considerably greater depth than the currently assumed crust-mantle boundary.

The Hekla eruption of 1991 and release of stress in the South Iceland seismic zone.

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The volcano Hekla is situated at the eastern end of the South Iceland seismic zone. The eruption of Hekla starting January 17, 1991 is the third eruption of Hekla since 1970 compared to 55 years average repose period since 1104.

The first earthquakes associated with the eruption occurred only 28 minutes before the start of the eruption and borehole strainmeters in the South Iceland area showed a beginning of a strain pulse at the same time. Prior to the eruption and in its first phase the borehole strainmeters reflect release of horizontal deviatoric stresses, comparable to those which are dominating in the seismic area of the South Iceland Lowland. As the eruption continued the stress release was isotropic.

The eruption was followed by increased microseismic activity over most of the seismic zone. This experience is compared to earlier Hekla eruptions.

Temporal variations of seismic energy release in the Baltic Shield

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Recent results of quantitative analysis of seismic energy release along parts of the North Atlantic Ridge (NAR) and in Scandinavia suggest that the interplate seismicity along the NAR is causally connected with the Scandinavian intraplate seismicity. In the present work, we have chosen the Iceland region and major parts of the Baltic Shield, i.e. Sweden and Finland (SWE+FIN), to test the interconnection of seismicities for smaller selected interplate and intraplate areas. In the investigated time period from 1967 to 1990 we find a close relationship between seismic energy release around Iceland and in SWE+FIN, with a zero or slightly positive time lag, i.e. the energy release in SWE+FIN precedes that on Iceland. The ratio of smaller to larger earthquakes is manifested in the b-value. Thus, larger b-values correspond to smaller energy release, and small b-value to large energy release, which is also obvious from the present work.

Extrapolating the rather periodical temporal energy variation in SWE+FIN we suggest that we are in a period of low seismicity. Higher seismicity in SWE+FIN may be expected again in the middle of this decade.

Some results from an Ocean Bottom Seismometer experiment in the northern North Sea.

Conrad D. Lindholm

In the summer 1989, 17 Ocean Bottom Seismometer's (OBS's) and 3 equivalent onshore stations acquired seismic data in the Northern North Sea for 24 days. From the data acquired 60 micro earthquakes ($M_c \leq 2.6$) could be located. Nine offshore events were studied in terms of focal mechanism solutions. Three of these events provided enough first motions to calculate individual focal mechanism solutions. The scarcity of data prevented robust solutions, but all 3 events yielded oblique reverse faulting in a NNE - SSW compressional regime.

The RMS of the traveltime residuals were used to test for likely focal depths. From the 9 events studied there is some evidence of 2 seismogenic zones: One in the upper crust, and one (possibly 2) in the lower crust or upper mantel.

Ocean Bottom Seismometer noise was also studied as function of frequency, component and deployment depth, and in summary the results were:

- The vertical OBS component is relatively more noisy at 0.5 Hz than the horizontal component. This feature is depth dependant, and decreases with deployment depth. This low freqency noise is particularily dominating on vertical components of OBS's deployed at water depths less than 400 meters.
- Offshore sites are more noisy than onshore sites. This feature is frequency dependant: At 0.5 Hz there is a difference between the sites that may exceed a factor of 10, whereas no systematic difference is found at 10 Hz.
- For both onshore and offshore deployment, the ambient noise levels of different stations are highly site dependant. Site dependant noise variation up to a factor of 10 is indicated by the data.
- Simple Signal to Noise Ratio is higher when calculated from the horizontal component than when calculated from the vertical component.

SEISMICITY OF ICELANDIC VOLCANOES

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Magma movements in the crust are accompanied by strain and stress changes that can cause brittle failure and earthquakes. Inflation and deflation of magma chambers may lead to normal and reverse faulting, respectively, in the chamber roofs. A dyke propagating in the crust may be traced by the earthquakes generated around the dyke tip. Furthermore, magma flow and eruptive processes are accompanied by continuous tremor. Seismographs therefore provide a wealth of information about the activity, processes and structure of volcanoes.

The seismicity of the volcanic zones in Iceland is characterized by spatial clustering of epicenters. Most clusters coincide with central volcanoes. Rifting structures such as fissure swarms and normal faults are mostly aseismic except during episodes of rifting and magmatism like the present events in Krafla. Seismic recording has been used very successfully at Krafla to monitor the activity of the volcano. Earthquakes in the caldera region correlate well with the level of inflation of the volcano. During deflation of the volcano earthquakes trace the path and speed of lateral magmatic intrusions from the central magma chamber into the associated fissure swarm. Two types of volcanic tremor have been identified, one associated with intrusion activity, the other with eruptions.

Seismic activity at the Bárðarbunga volcano in Central Iceland increased markedly in 1974. Several earthquakes of magnitude exceeding 5 have occurred there since then. Fault plane solutions show reverse faulting, interpreted to be due to magma chamber deflation. The activity at Bárðarbunga correlates in time with the Krafla events, and it seems as if inflation of Krafla is followed by deflation of Bárðarbunga. It is postulated that the pressure drop in the partially molten mantle beneath Krafla is transmitted to neighbouring volcanoes, leading to magma withdrawal from their shallow reservoirs. Bursts of seismicity of the Katla volcano in South Iceland in 1967 and 1977 may similarly be the result of magma withdrawal in response to the 1964-67 Surtsey and 1973 Heimaey eruptions. Annual periodicity seen in the Katla seismicity is explained as the result of the triggering effect of pore pressure in the crust beneath the glacier covering Katla. Several volcanoes exhibit persistent, low-magnitude seismicity. In the Hengill volcano in SW-Iceland a good part of the events have a non-double-couple mechanism. The seismicity is interpreted as the result of extensional failure and heat extraction from a cooling magma chamber.

THE DEEP-CRUSTAL EARTHQUAKES IN THE SOUTHERN BALTIC SHIELD IN 1986

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On July 14, 1986, one of the largest earthquakes in the Baltic Shield during this century occurred near Skövde in the province of Västergötland, Sweden, with a magnitude of M_L(UPP)=4.5. It was followed by the so far largest number of recorded aftershocks, more than 20, from a Swedish earthquake. The largest aftershock occurred about one hour after the main shock and had a magnitude of M_L(UPP)=3.4. A few months later, on November 2, a M_L(UPP)=3.6 event took place some 30 km NW of the Skövde series, near Mariestad. All earthquakes were located in the lower crust with foci at depths between 20 km and 30 km, thus adding information on active movements in the shield at these depths, for which mainly ductile deformation has been assumed. Focal mechanism determinations for the three mentioned events have been obtained from polarities and/or synthetic seismogram modeling. The synthetics show good agreement with short-period seismograph records for at least frequencies up to 2 Hz and distances up to 200 km. A comparison of the mechanisms indicates that the faulting of the area is complex, with styles ranging from strike-slip to normal. One explanation is that more local factors than the push from the North Atlantic Ridge contribute to the lithospheric stress pattern. This is in concordance with findings from nearby southern Norway. The calculated seismic moment and stress drop for the Skövde main shock are 5.9×10^{14} Nm and 2.8 MPa, respectively, and for the Mariestad earthquake 2.3×10^{14} Nm and 12 MPa, respectively.

Recent observations of microearthquakes in SE Finland

Jouni Saari

The local seismicity of the Loviisa region, SE Finland, has been studied. The results are compared with the presented seismotectonic interpretation. The study area locates around a nuclear power plant.

The data set comprises recordings of a triangular seismic network (1984-1988) and recordings of a single three-component seismic station (since 1989). During the instrumentations, there have been 82 microearthquakes in the magnitude range of ML = -1.0 - 1.3. The events occurred in 8 source areas, mostly in earthquake sequences.

Source parameters of the events were calculated for simple circular source model. The observed corner frequencies were higher (generally from 25 to 60 Hz) than in near field studies made elsewere in the Baltic Shield. The obtained values of seismic moment are in the range $8*10^7$ - $5*10^{10}$ Nm, source radius between 20 and 50 m, stress drop between $2*10^3$ and $6*10^5$ N/m^2 and peak slip less than 0.6 mm.

An estimate of seismic hazard for Fennoscandia

P. Mäntyniemi[1], R. Wahlström[2], C. Lindholm[3] and A. Kijko[4]

A seismic hazard evaluation has been conducted for Fennoscandia including Denmark, the Kola peninsula and adjacent sea areas. Several subregions were considered. The data used were taken from FENCAT which comprises both macroseismic and instrumental national data.

The analysis was based on a maximum likelihood approach which permits the use of mixed catalogs with incomplete historical and complete instrumental parts, the consideration of different detection thresholds, and the incorporation of earthquake magnitude uncertainty. The output consists of the seismic hazard parameters maximum regional magnitude, the Gutenberg-Richter b parameter and the activity rate, and their standard deviations. Also return periods and probabilities that a given magnitude will not be exceeded in a given period of time were calculated.

The main features of the input data, the applied data treatment techniques, and the obtained seismic hazard estimates are presented.

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Perspectives in earthquake hazard assessment: Importance of geological data in areas of low seismicity (a case study from Sunnhordland, Norway)

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Neotectonic studies in intraplate areas have lately focused on tectonic interpretations of seismicity data obtained from regional seismic networks which provide details of the seismicity patterns. This preliminary study intends to emphasize the importance of the seismic risk analysis in areas with relatively low seismic activity in a global scale. In these regions, where direct correlation of surface rupture data for historic earthquakes are lacking, using geological data as a tool to identify significant fault zones, is considered important. Possible correlation of these fault zones with the seismicity would help locating the active faults.

Detailed lineament studies conducted on satellite images, have revealed the identification of possible fault zones in Sunnhordland District and one fault zone (Etne Fault Zone) proved to be the possible candidate for neotectonic activities. Linear drainage anomalies at the northwestern extension of the Etne Fault Zone (EFZ), are partly controlled by the structural characteristics of metagabbros of the Precambrian basement to east of Etne. The parallelism between a NW-SE trending aeromagnetic lineament and the EFZ, implies that the fault zone may be related to a regional deep-seated fracture zone which can be followed through the Precambrian basement and allochthonous units. This relation suggests the extence of the EFZ, as a component of a regional fault zone that may have a long and complex history.

Preliminary seismic hazard map of the Sunnhordland District shows peak ground accelerations exceeding 1.77, 9.46 and 50.52 gals for the 10^{-2}, 10^{-3} and 10^{-4} years recurrence periods, respectively. These relatively high values coincide with the Etne Region, in which the EFZ runs through. This correlation suggests that the use of geological data in identifying the major fault zones, is an essential part of the seismic hazard assessments in areas of low seismicity. In such areas, possible secondary effects of earthquakes, such as landslides, are considered important in estimating the damaging potential of future events.

GROUND MOTION ATTENUATION FUNCTIONS FOR NORWAY BASED ON A STOCHASTIC ω-SQUARE MODEL APPROACH

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The stochastic ω-square model of ground motions uses simple models of energy release, source scaling and wave propagation to predict ground-motion amplitudes and seismograph responses over a wide range of magnitudes and distances. This model is very attractive for application to low-seismicity regions with few strong-motion records. The model parameters are calibrated using more abundant seismograph data from small earthquakes recorded at regional distances, and extrapolation to larger magnitudes and shorter distance is done with more confidence because it is guided by physical principles. In this study we used over 500 high-quality digital ground-motion records to calibrate a stochastic ω-square model for the Norwegian Continental Shelf. These records were obtained from 140 earthquakes of magnitudes 2 to 5, at distances of 60 to 1200 km. Most of the records have good signal/noise ratios in the 1-15 Hz range, and a few records extend to frequencies as low as 0.2 Hz.

The Fourier spectra of these records were inverted for a regional anelastic attenuation model and for seismic moments and corner frequencies, and these results were then used to investigate source scaling. The duration of strong ground motion was found to be distance dependent due to the dispersive character of the Lg waves that dominate high-frequency ground motions at regional distances. The resulting stochastic ω-square model reproduces the observed spectral velocities in the 0.2 to 10 Hz range, as well as the relationship between seismic moment and M_L. The model has also successfully predicted amplitudes from a selection of larger (up to magnitude 6) and older (back to 1904) earthquakes recorded only on analog seismographs. The most significant source of uncertainty was found to be source scaling, and two candidate source scaling hypotheses were consequently identified. Attenuation functions generated for each of these hypothesis have been used for seismic hazard analyses at several test sites on the Norwegian Continental Shelf.

NEW EMPIRICAL GROUND MOTION ATTENUATION FUNCTIONS FOR THE NORWEGIAN CONTINENTAL SHELF

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The intraplate Norwegian Continental Shelf (NCS) in a region with a relatively low seismic activity. Seismic hazard assessments and zonations are still important there, however, because of the large number of sensitive industrial installations. While earlier work has been concentrated on source zone regionalization and earthquake geology, the present work focuses on obtaining more reliable ground-motion predictions. The approach taken in this respect is one with multiple attenuation relations, including relations based on calibrated-theoretical stochastic omega-square models for NCS as well as empirical models.

These empirical models have been derived for frequencies between 1 and 10 Hz, using about 400 seismograph records from NCS combined with about 30 accelerograph records from other intraplate areas, notably eastern North America, northern Europe and Australia. These two data sets are complementary in that the latter cover larger magnitudes and smaller distances. The resulting empirical relations are consistent with stochastic omega-square relations (which cover a wider frequency range), within the uncertainties in both models. Predictions for high magnitudes in the empirical model are controlled by the canadian Nahanni (1985) and Saguenay (1988) earthquakes. The Nahanni earthquake is more consistent with the NCS data than the Saguenay earthquake, which generally yields high ground motion levels.

The new multiple attenuation relations for NCS differ from those used earlier in that they have stronger magnitude scaling, mostly because we now have better data for the smaller earthquakes. As a result, the hazard levels obtained in probabilistic earthquake hazard computations now exhibits a greater separation between the 10^{-2}/year and the 10^{-4}/year exceedance probabilities.

Site-specific earthquake load assessment

Bjarni Bessason

An elaborate knowledge of earthquake load at a site is necessary to do reliability analysis of existing structures and/or to achieve a desired risk level in structural design.

The paper describes and discusses various methods for site-specific earthquake load assessment.

First, there is a discussion of what representation forms of earthquake load are desirable for engineering purposes. This is followed with an overview of available methods for prediction of ground motions from earthquakes. A stochastic model for prediction of earthquakes is presented. The model uses the Monte Carlo technique to simulate seismicity in a specified region. The seismicity model can be expanded to cover evaluation of seismic hazard maps, site-dependent unit hazard response spectra, and site-dependent time series. The method is quite flexible and uncertainness in magnitude, location of epicentres, attenuation laws, etc., can be accounted for in the model.

The earthquake loading in Southwest Iceland is studied in a numerical example. Seismic hazard maps for the region and some site dependent unit hazard response spectra are presented and discussed.

Strong motion measurements in Iceland and seismic risk

Ragnar Sigbjörnsson

This paper deals with a recently installed strong motion network for Iceland. The network, which consists of approximately 150 sensors, includes both standard triaxial instruments and sensors systems installed in important facilities and buildings. Recordings obtained by the network are discussed. Emphasis is put on response spectra and strong motion attenuation. The presentation concludes with a discussion on seismic risk assessment using the available data.

RESEARCH ACTIVITIES IN THE NORSAR SEISMIC PROSPECTING GROUP

Håvar Gjøystdal
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This presentation is intended to give a summary of the various research activities at NORSAR within the field of seismic prospecting. The present areas of interest are:

- representation of complex geological structures
- 2D and 3D seismic modelling
- wavefield computation techniques
- wavefield animation techniques
- velocity inversion/tomography
- standardized software tools

CRUSTAL THICKNESS IN FENNOSCANDIA --- AN OVERVIEW

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Crustal studies became popular among seismologists in the Fennoscandinavian countries some three decades ago, and still remain so. The numerous seismic surveys conducted within this region are aimed at mapping crustal structures in ever-increasing detail. We have reviewed the knowledge accumulated from these studies and made a new crustal thickness map with contour intervals of 2 km for Fennoscandinavia. In some areas the sediment thicknesses exceed 10 km, so we have also produced maps of crystalline crustal thicknesses, notably for Denmark and adjacent areas where sufficient data are available. The observed crustal thickness variations have a counterpart in the geological ages of the tectonic units constituting Fennoscandinavia. The same applies to the seismicity patterns, namely, that the largest occurring earthquakes and the highest seismicity take place in areas where the thinnest crust is found.

The many published Moho depth estimates are reasonably consistent (seldom exceeding $\pm$ 2 km) at profile intersections, while the corresponding P-velocity - depth relations often vary considerably. We are systematically investigating the observational consequences of specific velocity models in terms of 2D finite differences (FD) synthetic seismograms. In particular, the class of Pg-phase appears to be sensitive to whether the crust is modelled as an aggregate of constant velocity layers, linear velocity gradients or a combination hereof. The synthetic results will be compared to observational data at hand. One conclusion of this study is that 2D FD synthetics are essential for a better understanding of seismic wave propagation at local and regional distances.

Interpretation from explosion seismograms of crustal inhomogeneities in STATU NASCENDI

Søren Gregersen, Hans Thybo and Edward Perchuc

In areal investigations of differences in crustal structure from one seismic profile to the next it should be possible to distinguish the important differences already in the seismograms. Common practice is to invert the seismic data of each profile into a crustal structure and then note differences and similarities of structures of the various profiles. We make an attempt to go back to the 'state of birth', STATU NASCENDI of the differences and similarities, and look in the original data material. This is especially important, when the interpretation of the seismograms has a component of subjectivism, as is the case in trial and error interpretation of seismograms from explosion profiles.

The EUGENOS-S areal coverage of the Fennoscandian Border Zone is well suited for this STATU NASCENDI approach. The results substantiate, that the Ringkøbing-Fyn ridge has significant similarities to the Fennoscandian Shield, while there are large differences to the Norwegian-Danish Basin. This emphasizes the historical development of the Norwegian-Danish Basin as crustal spreading, pulling a piece of the Fennoscandian Shield, namely the Ringkøbing-Fyn ridge, away from its original position as part of the Fennoscandian Shield.

Crustal stress regime in Fennoscandia from focal mechanisms

S. Gregersen

An extensive data set of earthquake focal mechanisms is now available for all of northern Europe, and especially for Fennoscandia. These mechanisms are considered to provide representative coverage of the stress field. The maximum, horizontal compressional stress orientations are internally very consistent over the area of northern Europe. The dominating NW-SE compressional stresses appear tied to relative plate motion, with mid-Atlantic ridge spreading and European-African collision in southern Europe. For Fennoscandia some exceptions to the regional stress pattern exist. The causes of these local anomalies have been investigated. No correlations with geological provinces or province boundaries were found. In addition, there does not appear to be any clear correlation between anomalous stress directions and postglacial uplift, in the present earthquake activity. This lack of correlation is in sharp contrast to geological evidence in the form of large faults indicative of large postglacial earthquakes occurring right after the end of the latest Ice Age, 10.000 years ago. Taken together this evidence suggests a tremendous change of stress field in Holocene time, from one dominated by the postglacial unloading right after the Ice Age, to one dominated by the present plate motion today.

THE TRANSPARENT UPPER CRUST -- A SEISMIC PROFILING ARTEFACT

O.A. Sandvin[1], E.S. Husebye[2] and J.E. Lie[3]

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A common observational feature in deep seismic profiling surveys is that the upper 10-15 km of the crystalline crust appears seismically transparent, that is, almost void of reflectors. This contrasts sharply with the strong reflectivity of the lower crust, particularly just above Moho. These apparent contradictory observations are difficult to reconcile on geological grounds as in several areas the present-day upper crust once constituted a major structural element of the lower crust. For example, the Bamble Zone exposed in the western coastal areas of the Skagerrak Sea once must have been at depths around 20 km. With a basis in our marine seismic observations, we have been able to trace the Bamble block throughout the entire crust, although its upper part "remains" seismically transparent. We have tried to resolve the transparency puzzle by seismic means, that is, by using 2D finite difference synthetics (acoustical wave equation) as the principal tool of investigation. The structurally anomalous features are given a sinusoidal shape, and at crustal depths ranging from 4 to 30 km. Occasionally, diffraction layering is intervened between the corrugated layers of wavelengths 0.25 to 5.0 km and amplitudes from 0.25 to 1 km. The synthetic records are generated for typical marine air-gun-streamer geometries and thus can be processed in a manner identical to real surveys. The main outcome of the study is that rugged structural bodies appearing as flat, clear reflectors in the lower crust are seldom seismically visible when located at 5-10 km depths.

DEEP CRUST AND MANTLE STRUCTURES RELATED TO RIFTING AND BASIN FORMATION IN SKAGERRAK

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In the past decade the complex continental crust and underlaying mantle has been studied by using reflection seismology. In 1987 the R/V Mobil Search made a grid survey of 1740 km covering the entire Skagerrak area. During the last six months the entire deep seismic survey has been reprocessed using the computer facilities at BIRPS, University of Cambridge, UK. Careful post-stack processing, including FK-migration, has greatly improved the resolution of the data enabling detailed study of both crust and upper mantle structural features. This survey is quite unique because of the grid, high data quality and that it here is possible to relate deep crustal features with geological structures and dated events on the exposed surface onshore.

Interpretation of the profiling sections indicates that the dominant structure in the crust and mantle beneath Skagerrak is the Bamble Sveconorwegian collision tectonics. The Telemark block is observed to be underthrusted into the mantle beneath the Skagerrak block. This "Telemark suture" can be mapped beneath the entire northern Skagerrak dipping SE. The Skagerrak graben, which is the offshore continuation of the Oslo rift, runs parallel to the main strike of the older Bamble tectonics. Beneath the graben a prominent feature can be followed cutting the entire crust, offsetting Moho 3-4 km and continuing into the upper mantle. In the mantle this feature appears to be a very sharp boundary; extrapolated onshore this feature coincides with the Porsgrunn-Kristiansand Fault.

In the southern Skagerrak the Fjerrislev Fault (FF) clearly appears on the profiles as a deep structural divide between the Fennoscandian shield and the mobile belts of western Europe. Along the most northern part of FF flectural response to loading seems to have happened without thinning of the crystalline crust beneath the basin, giving an offset in Moho. Finally, the tectonic prominence of the Tornquist zone or the FF in southern Skagerrak has been a subject of controversy in the past. The seismic sections indicate that the Fjerrislev fault cuts through the entire crust almost vertically in contrast to the more fashionable concept of listric lower crustal detachments constraining the assumed rheological properties of the crust and upper mantle.

Coda Q estimations and bispectrum analysis of the coda from local earthquakes and mine explosions

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High frequency coda-Q, in the range from 10 to 80 Hz, has been estimated in central and northern Sweden. In the central Sweden mine explosions have been used for the analysis and in the northern part local earthquakes. The coda-Q values are compared and show resemblance in the higher frequency bands. In this paper bispectrum analysis is also applied in order to detect and provide information about nonlinearities in the S-wave coda. Results show that bispectrum could be a useful complement in the coda-Q analysis.

The Askja central volcano, NE-Iceland

Earthquake activity during July and August 1989

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Seismicity in the Northern Volcanic Zone is presently mainly confined to the central volcanoes of Krafla and Askja. A major rifting episode has been in progress in this zone since 1975. The activity has been confined to the Krafla central volcano. Other rifting episodes, centered around the Askja central volcano, took place in 1874-1876 and 1921-1930. The latest eruption in Askja was in 1961.

Seismicity of Askja was the focus of a seismic survey undertaken in the summer of 1989. The purpose of this study was to collect high-quality, three-component, digital seismograms in order to improve earthquake locations in the Askja region, investigate source mechanisms, perform waveform and spectral studies, delineate prospective S-wave attenuation zones, and compare the seismic data with ground deformation measurements and geothermal activity.

More than 400 earthquakes were recorded during the field period. Hypocentral solutions were obtained for 91 earthquake. Most of the located earthquakes originated within the Askja central volcano but a few events originated in a seismic zone striking northeast from Askja.

Earthquake epicenters within the Askja central volcano are confined to the Öskjuvatn caldera and Austurfjöll. The majority of the best located earthquakes form a cluster, about 2.5 km long and 3.5 km wide at the eastern flank of the Öskjuvatn caldera. Earthquakes occurred down to a depth of 5.5 km, clustering at a depth between 2 and 3.5 km.

A focal mechanism solution was obtained for one earthquake using P-wave first motions. The focal solution shows reverse faulting which can be caused by a deflation process. This interpretation is in agreeement with recent ground deformation measurements which show subsidence in the central part of the Askja caldera.

Our explosion data indicates the existence of large lateral velocity anomalies in the upper crust of the Askja region. Attenuation variations are also clearly seen in the seismic data, especially at the higher frequencies, where the same earthquake may exhibit both A-type and B-type characteristics, depending on the raypath travelled.

FAULT PLANE SOLUTIONS USING AMPLITUDE OBSERVATIONS - A TEST WITH SYNTHETIC SEISMOGRAMS

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For regional and local networks aimed at analysis of microseismicity the classic method for fault plane solution by use of first motion directions is of limited value as often very few good first motions are observed. A number of alternative methods making use of amplitudes have been proposed. For the microseismic events recorded by the Swedish digital network in operation since 1979 the analysis routinely includes an automatic fault plane solution based on spectral amplitudes. This method has been verified by comparison with standard first motion solutions and with independent estimates of the fault planes (e.g. accurate relative locations of aftershocks).

The method makes use of the fact that the radiated far field low frequency spectral amplitudes of body waves depend only on the seismic moment and orientation of the earthquake source. The observed spectral amplitudes (PZ, PR, SVZ, SVR, SH) are corrected for the free surface effect, attenuation, instrument response and geometrical spreading. Searching over the range of possible fault plane solutions, the source orientations that give the least misfits between observed and predicted spectral amplitudes are accepted as possible focal mechanisms for the earthquake.

In the nordic project for earthquake warning in Iceland (the SIL project) this algorithm has been implemented for the automatic event analysis.

In this study the reflectivity method was used to generate synthetic seismograms for earthquake sources within the SIL-network with realistic one-dimensional crustal models. To test the algorithm, these synthetic seismograms have been fed into the automatic event analysis implemented as part of the network.

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IMPROVEMENT OF SURFACE REPRESENTATION BY THE INTRODUCTION OF SURFACES WITH DISCONTINUITIES

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During the past few years significant developments have been made within the area of surface representation. However, for the more complex cases, the solutions have been too simple and insufficient. This paper demonstrates how the surface representation has been improved through the introduction of surfaces with discontinuities.

Firstly, the motivation behind the concept of surfaces with discontinuities is presented. The theory is discussed in some detail, and the principles are illustrated through some simple examples. In particular, the improvements achieved by surfaces with discontinuities relative to traditional surface representation are emphasized.

Finally some examples of the application of surfaces with discontinuities on real data are presented.

Lg waves absorbed in North Sea grabens

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The North Sea has a continental structure. So propagation should be good of the Lg waves, which are usually the largest signals in regional earthquake seismograms in continents, but which disappear in oceanic structures. It has long been recognized that they do not propagate well, the reason being the North Sea Central and Viking grabens. These were developed with more than 10 km of sedimentary thickness in Mesozoic times, by crustal stretching, before the North Atlantic Ocean stared to open. The North Sea grabens and their counterparts in eastern Greenland developed as incipient rifts, but the lithosphere later split in another direction, along the present North Atlantic margins. The reason for the attenuated Lg waves in the faild rift could be energy pumping up or down, geometrical scattering, reflection or anelastic absorption. Recent computations, showing well-behaved as well as ill-behaved surface wave mode conversions, can explain part of the Lg wave phenomenon as energy being pumped from the surface near a source in the graben structure to deeper levels in the continental crust around the graben. Only very little geometrical scattering and reflection is seen. The energy pumping is a very important phenomenon for earthquakes occurring in the Viking Graben and Central Graben. For earthquakes on either side of the graben another effect, namely that the inhomogeneous structures spread the energy of the Lg waves over a longer time interval, is very important. Anelastic absorption in the graben structure may be of little significance.