Icelandic Meteorological Office

University of Iceland

37th Nordic Seminar on Detection Seismology

Organizing Committee:

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Jørgen Hjelme
in memoriam

State seismologist and friend Jørgen Hjelme - in memoriam

S. Gregersen, E.S. Husebye, E. Hjortenberg, H. Bungum and O. Dahlman

Jørgen Hjelme - Jørgen to all of us - was born on December 27, 1928 in Gentofte, Denmark in a family of civil servants. His father worked at the main telegraph station. Jørgen went to the University of Copenhagen from 1948 and graduated as mag. scient. in physics in 1953. At that time there were few research positions available so Jørgen started his career as a teacher in a local high school. However, after just a year he came to the Geodetic Institute in Copenhagen (later transferred into the National Survey and Cadastre - Denmark) and his main initial task was to maintain and operate the national seismograph stations in Denmark and Greenland. Jørgen obtained a supplementary mag. scient. degree in geodesy from University of Copenhagen in 1956. He studied seismology in Germany, in Clausthal-Zellerfeld, Stuttgart and Hamburg in 1960.

In the 1950es seismology was not well developed, suffering from poor instrumentation, lack of adequate computational facilities, and analog earthquake recordings. Jørgen, with his background in physics, was keenly aware of this so when the Geodetic Institute acquired its first computers he was in the forefront for using these new tools in analysis of parameterized seismological data. The few seismograph stations in the 1950es were not easily suitable for research via the computer. Instead seismic profiling surveys became popular with tens of closely spaced sensors along lines hundred to thousand kilometers long. Jørgen participated in some of the first crustal profiling studies in Denmark (1960) and later on the more ambitious multinational profiling lines in Jylland and across the Skagerrak Sea to Norway. Friends participating in these investigations still remember Jørgens exceptionally careful seismogram analyses.

In 1958 UK, USA and USSR representatives convened in Geneva for scientific discussions on technical seismological means for monitoring compliance of a future, possible UN test ban treaty prohibiting any type of nuclear weapon tests. The year 1958 was significant on two accounts; the preceding year USA had demonstrated that underground tests were adequate in the context of weapon design, and underground tests(explosions) could be monitored most efficiently by seismological means. It was equally clear that the seismological science as such was not up to the monitoring challenges, so major countries like UK and USA launched large seismological research programmes aimed at transforming seismology into a modern and theoretically advanced science. The first step was to ensure better observational data both quantitatively and qualitatively by deploying experimental small aperture arrays. And the USA funded the World Wide (WWSSN) network of 100 identical seismograph stations. Four of these WWSSN stations were deployed by Jørgen: one in Copenhagen and three in Greenland. Better data spurred theoretical advances which in turn demanded ever better seismograph stations and easy data access worldwide. This process is still going on. Jørgen was among the pioneers.

Political technical discussions on detection and discrimination of earthquakes and explosions were conducted by the 'first' nuclear powers mentioned above, under the United Nations auspices in Geneva. Later on this was extended to 18 members of the UN Conference of Disarmament. Due to a Swedish initiative the Group of Scientific Experts (GSE) for technical test ban monitoring was extended to any interested UN member state in 1976, and Jørgen was the Danish representative from the beginning to 1995. He was very popular with all the group members due to his many wise and moderating questions. He was sought out for dinner company in the evenings since few, if any other GSE-member, mastered menus in French, and besides he was exceptional due to his spirited debates. In Denmark it was considered several times to build seismograph stations in Greenland for detection purposes, possibly even arrays of seismographs. One experiment was made in the northern part of the Greenland ice cap. It was a winter-over camp called Inge Lehmann, Greenland (ILG), which was only in operation one year because of the large cost.

Another societal seismological issue is the seismic hazard and its mitigation issue. Jørgens involvement here was twofold; i) participating in the Swedish/Danish temporary network operation aimed at collecting data for improved seismic hazard estimation for the Swedish nuclear power plants (and possible Danish ones) and (ii)earthquake hazards for the Southern Iceland Lowlands (SIL). Jørgens contributions here were to find the proper solution among national competitive ones and foremost to ensure that the project work moved forward. All of us are grateful for the mediation of Jørgen.

Jørgen was during his whole career dedicated to promoting cooperation between seismologists in the Nordic countries. He was instrumental in setting up the annual Nordic Detection Seismology meetings and also ensured that the initial scope of so-called "detection seismology" was widened to take in all current aspects of seismology. An outstanding meeting was that in Roskilde in 1974, under the chairmanship of Jørgen, with a nice blend of Danish and Jørgens own hospitality.

Jørgen was a person easy to get along with. A pleasant atmosphere surrounded him. He was always ready for a thorough conversation concerning seismology as well as many developments in modern society. He developed many international connections especially with the seismological colleagues working with detection and discrimination of nuclear explosions.

Jørgen was not a prolific scientific writer although he was very knowledgeable in seismology and well updated. His publication list contains 14 titles. He had soon become responsible for Danish seismology, so he was busy with administrative and technical duties. In recognition of his service to the Danish Defence Ministry he was "promoted" Knight of Dannebrog in 1978, Medal of the Danish Defence Ministry in 1980, and Knight first class of Dannebrog in 1984. Jørgen retired in 1995, when he turned 67 years. He died March 4 2006, at an age of 77 years. His wife died many years ago. He is survived by his son, Erik.

We have lost a valued colleague and a good friend.

Programme

DAY ONE – MONDAY, AUGUST 21

09:00 Opening address
Steinunn S. Jakobsdóttir

Chairman: Peter Voss

09:05 Keynote lecture
Presentation of International Centre for Geohazards (ICG) and discussion on challenges in geohazards-related research
Farrokh Nadim

09:45 Seismic hazard assessment – engineering seismology

The confidence of earthquake damage scenarios; Examples from the capacity spectrum method
Sergio Molina & Conrad D. Lindholm

Public usage of a website for real-time seismicity in Iceland: Insights into hazard perception
Deanne Bird, Matthew J. Roberts & Dale Dominey-Howes

10:30 – 10:50 Coffee break

10:50 Seismic detection - verification

The mb(Ms) diagram for Iranian earthquakes obtained from the International Monitoring System
Ingvar Nedgård

Data processing and analysis of infrasound signals in Fennoscandia and NW Russia
Tormod Kværna, Johannes Schweitzer, Frode Ringdal & Steven J. Gibbons

Considerations in event detection and location using small-aperture seimic arrays
Steven J. Gibbons, Tormod Kværna & Frode Ringdal

Microseismic monitoring at the unstable rock-slope site at Åknes, Møre og Romsdal, Norway
Michael Roth & Lars H. Blikra

12:15 – 13:30 Lunch break

Chairman: Björn Lund

13:30 Keynote lecture
Earthquake prediction research and the June 2000 earthquakes
Ragnar Stefánsson

14:10 Seismicity – noise studies

Analysis of seismic noise at Icelandic Network (SIL) stations
Kristín S. Vogfjörð

Microseimic studies at Hagfors array, Sweden
Leif Persson

Seismicity in Sweden from five years of digital recordings
Reynir Böðvarsson & Björn Lund

Seismological monitoring in Lithuania during the period 1999-2005
Andrius Pačėsa

15:35 Poster session

Strain and stress on the Reykjanes Peninsula
Marie Keiding, Þóra Árnadóttir, Björn Lund, Erik Sturkell, Halldór Geirsson & Ragnar Slunga

15:40 - 16:00 Coffee break

16:00 Seismicity – noise studies (continued)

Earthquake activity in the Rana region recorded by a local seismic network and a seismic array
Mathilde B. Sørensen, Steven J. Gibbons & Jens Havskov

Increasing earthquake activity along the divergent plate boundary near the Askja volcano, Iceland
Heidi Soosalu, Páll Einarsson, Ásta Rut Hjartardóttir, Steinunn S. Jakobsdóttir, Rikke Pedersen, Erik Sturkell & Robert S. White

Increasing seismicity beneath Vatnajökull ice-cap: artifact or reality?
Matthew J. Roberts & Hannah Evans

17:05 End of day one

17:10 Meeting in "*The Nordic seismic educational network*"

19:00 Dinner

After dinner we can take a walk and/or relax in the hot tub

DAY TWO – TUESDAY, AUGUST 22

Chairman: Annakaisa Korja

08:30 Keynote lecture

Fire and ice on shaky grounds: Living with natural hazards in Iceland
Freysteinn Sigmundsson

09:10 Crustal deformation

EarthScope: Exploring the structure and evolution of North America
Michael E. Jackson, David Mencin, Gregory E. van der Vink & Christel B. Hennet

High-rate continuous GPS observations in Iceland
Halldór Geirsson, Þóra Árnadóttir, Rick Bennett, Sigrún Hreinsdóttir, Sigurjón Jónsson, Peter LaFemina, Erik Sturkell, Thierry Villemin & Shinichi Miyazaki

Crustal stress anomaly before the M=6.5 17 June 2000 earthquake in South Iceland
Björn Lund, Reynir Böðvarsson & Ragnar Slunga

Monitoring the crustal stress tensor field by microearthquake analysis - new possibilities for eathquake warning algorithms
Ragnar Slunga

10:35 - 10:55 Coffee break

10:55 Crustal structure – modelling

Subsurface faults in southwestern Iceland mapped by relatively located microearthquakes
Sigurlaug Hjaltadóttir, Kristín S. Vogfjörð & Ragnar Slunga

Asymmetric Plume-Ridge interaction around Iceland: The Kolbeinsey Ridge Iceland Seismic Experiment
Bryndís Brandsdóttir & Emilie E.E. Hooft

Tomography of Rayleigh wave group velocity in South Greenland from correlation of ambient seismic noise
Peter Voss, Peter Kyhl Knudsen, Ólafur Guðmundsson, Søren Gregersen, Trine Dahl-Jensen, Winfried Hanka and Tine B. Larsen

Lithospheric anisotrophy beneath Greenland from SKS splitting
Nur Ucisik, Ólafur Guðmundsson, Winfried Hanka, Trine Dahl-Jensen, Klaus Mosegaard and Keith Priestley

12:20 – 13:30 Lunch break

Chairman: Berit Paulsen

13:30 Crustal structure – modelling (continued)

Crustal investigation of the Danish Basin based on ESTRID-1 seismic data
Alessandro Sandrin, Lars Nielsen and Hans Thybo

A new 3D seismic tomography model reveals the terrane distribution of Svecofennian Orogen
Tellervo Hyvönen, Annakaisa Korja, Timo Tiira, Kari Komminaho and E. Rautioaho

Seismic images of the accretionary Svecofennian Orogen
Annakaisa Korja, Pekka Heikkinen, Timo Tiira, Tellervo Hyvönen and FIRE Working Group

Receiver function analysis of the broad band data of Finnish seismograph network
Jari Kortström, Monika Wilde-Piórko, Timo Tiira and Kari Komminaho

14:55 Special topics

Status of the Lehmann archive
Erik Hjortenberg

Fifteen years of SIL automatic monitoring
Steinunn S. Jakobsdóttir

15:40 - 16:00 Coffee break

16:00 Discussion on statutes for the Nordic Seminar
Introduction by Ólafur Guðmundsson

16:45 Closing remarks
Steinunn S. Jakobsdóttir

16:50 End of day two

17:00 Sightseeing at the Nesjavellir geothermal power plant and a reception invited by Reykjavík Energy

19:00 Dinner

DAY THREE – WEDNESDAY, AUGUST 23

09:00 – 19:00 Field trip through the South Iceland Lowland in conjunction with the FORESIGHT meeting. The trip will cover earthquakes, hydrothermal processes, volcanic eruptions, glacial floods etc.

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Abstracts

Presentation of International Centre for Geohazards (ICG) and discussion on challenges in geohazards-related research

Farrokh Nadim

Director of ICG

"Geohazards" are events due to geological features and processes that may pose severe threats to humans, property and the natural and built environment. Earthquakes, floods, landslides, volcanoes, avalanches and tsunamis are typical examples of such events. Landslides, caused by heavy rainfall, flood, earthquake, erosion, and human activities, are the most common geohazards on land. Near-shore and offshore, various geological processes, earthquakes and human activities, for instance in connection with petroleum exploration and production, can trigger slides and large mass flows. There is an urgent need to improve the basic understanding of geohazards and the ability to deal with the risks. The need is accentuated by increased sliding and flooding in many regions, increased concern for geohazards in production and transport of oil and gas, increased vulnerability of to earthquakes, and the catastrophic Indian Ocean tsunami in December 2004.

On this background, the International Centre for Geohazards (ICG) was established in January 2003, as one of the 13 "Centres of Excellence" awarded by the Research Council of Norway. ICG is hosted by the Norwegian Geotechnical Institute (NGI) and is organised as a consortium of five partners. The other ICG partners are the Geological Survey of Norway (NGU), Norwegian University for Science and Technology (NTNU), University of Oslo (UiO), and Norwegian Seismic Array (NORSAR). The goal of ICG is to be a unique international arena on geohazards for conducting scientific and technological research, with the aim of developing knowledge that can help save lives and reduce material and environmental damage. Since its establishment in 2003, ICG has become a unique expertise centre on land and offshore geohazards, mainly because of the scientific interaction and synergy of the five partners, and international cooperation with organisations and universities who have similar goals.

The director of ICG, Dr. Farrokh Nadim, will present some of the ongoing projects at ICG and outline the challenges and focus areas for research on geohazards in coming years.

The confidence of earthquake damage scenarios; Examples from the capacity spectrum method

Sergio Molina and Conrad D. Lindholm

Earthquake loss modelling is about to become an important tool in mitigation planning. Loss modelling is based on a parameterized mathematical representation of the damage problem, and while the mathematical representation models will certainly improve, the question of sensitivity to uncertain parameterization becomes vital. We have applied the capacity spectrum method (CSM), as described in FEMA (2003), and investigated the effects of selected parameters. The results demonstrate that loss scenarios may easily vary by as much as a factor of 2 due to simple parameter variations. Of particular importance for the uncertainty is the craftsmanship *quality* of the structure. The results is a warning against naive acceptance of unbounded damage scenarios and strongly support the development of computational methods in which parameter uncertainty is carried through the computations facilitating confidence bounds for the damage scenarios.

Public usage of a website for real-time seismicity in Iceland: insights into hazard perception

Deanne Bird [1], Matthew J. Roberts [2] and Dale Dominey-Howes [3]

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Located on the divergent boundary between the American and Eurasian tectonic plates, Iceland is subjected to large earthquakes and volcanic eruptions. Such events are often preceded by changes in earthquake activity over varying time scales. Although most seismicity is confined to micro-earthquakes, large earthquakes have occurred within populated regions. The most recent, hazardous earthquake took place in June 2000 in southern Iceland; this prompted the Icelandic Meteorological Office (IMO) to develop an early warning and information system (EWIS) web-site for displaying earthquake data in near-real-time. In February 2005, the first version of this web-site was released publicly. Here we assess data on the usage of EWIS during periods of heightened seismicity and consider the role of such web-sites for increasing public awareness of natural hazards. Between February 2005 and May 2006, 13,121 earthquakes were recorded by IMO, the largest of which had a moment magnitude (Mo) of 4.7; this earthquake, which struck 20 km from Reykjavík – Iceland's capital – was followed by an immediate, ten-fold upsurge in usage of the EWIS web-site. In comparison, over a period of more than 30 hours, an earthquake swarm occurred 300 km offshore from Reykjavík. Within this swarm, 59 earthquakes greater than Mo 3 were detected, resulting in the release of a news bulletin by IMO. During the period of the swarm, and following the broadcast of the media bulletin, usage of EWIS increased five-fold. In summary, the usage data reveal a spatial aspect to public perception of earthquake risk. Temporal analysis of daily web-site usage suggests that the public utilises the Internet immediately after experiencing a local earthquake, whereas distant, unfelt earthquakes generate gradual interest prompted by media bulletins. We conclude that the Internet is a useful tool for displaying seismic information in near-real-time, thereby helping to increase public awareness of natural hazards. We recommend continued development of the EWIS web-site to further hazard education.

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The $m_b(M_s)$ diagram for Iranian earthquakes obtained from the International Monitoring System

Ingvar Nedgård

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More than 2000 nuclear tests have been carried out since the first nuclear explosive test Trinity was conducted by the USA at Alamogordo, New Mexico, July 16 1945. Almost all tests were carried out by the five acknowledged nuclear weapon states, USA, the former USSR, China, France and the United Kingdom. Two nations India and Pakistan have conducted three respective two nuclear tests of which some presumably were multiple charges. Israel is also known to be in possession of nuclear explosive devices. The last few months the conflicts in the middle-east have increased between Palestinian organizations and Israel in the Israel-Gaza region and between Hezbollah (supported by Iran and Syria) and Israel in the Israel-Lebanon region. Iran and Israel have signed but not ratified the Comprehensive Nuclear-Test-Ban Treaty and Iran has recently threatened to withdraw from the Nuclear Non-proliferation Treaty. One of the most reliable discrimination methods separating nuclear explosions from earthquakes is the mb(Ms)-method. It is important to know something about the natural earthquake distribution of mb(Ms)-values not to mistake an earthquake for an explosion. Events in Iran and border area covering the period Jan 1, 2000 to March 31, 2006 are presented here. The data is obtained from the Reviewed Event Bulletin of the International Data Centre in Vienna. Only events with both m_b, M_s, and depth measurements are included. The data is divided in eight geographical regions of Iran and for each region linear regression is made on the data. The largest slope and intercept are selected for a threshold line over which data presumably could be from a nuclear explosion.

Data processing and analysis of infrasound signals in Fennoscandia and NW Russia

Tormod Kværna, Johannes Schweitzer, Frode Ringdal and Steven J. Gibbons

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The International Monitoring System (IMS) for verifying compliance with the CTBT consists of 60 infrasound stations. Station no. 37, which is planned to be built near Karasjok, northern Norway, is located about 6 km from the seismic array ARCES. During the last year we have run a research activity aimed at understanding the characteristics of infrasound signals in our region. Investigation of different automatic data processing algorithms has been an integrated part of this research. The most important data sources for these studies have been the three-element infrasound array near Apatity, NW Russia, and the infrasound signals recorded on the ARCES seismic array.

On 7 June 2006 a large meteor exploded over Troms, northern Norway. The meteor explosion was both seen and heard by several people in the region, and strong infrasound signals were observed both at the ARCES array and other seismic stations in Norway and Finland. Based on the dominant frequencies of the observed signals, we estimate the yield of the explosion to be of the order of 2 tons TNT equivalents. From the arrival times of the infrasound signals we were able to locate the explosion using a constant velocity for sound propagation. This location corresponds very well with human observations of the meteor. Another meteor exploded over southern Norway on 14 July 2006, causing detectable infrasound signals on the NORSAR array. This event could also be located, now utilizing the large aperture of the NORSAR array. The event location corresponds well with the area where meteor rocks were found on the ground.

For continuous automatic processing of data from the Apatity and the ARCES arrays we have developed and tested different infrasound processing algorithms. In particular, an algorithm based on the broad-band f-k analysis has proven successful for detection of long-duration low SNR infrasound signals, which are often observed at these stations. For 2005, 793 infrasound detections were found at the ARCES seismic array, and about 21% of these could be associated to seismic events caused by surface explosions at active mines and an ammunition demolition site in the region. Notice that the infrasound signals at ARCES are detected at a seismic array, which is not designed to observe infrasound signals.

At the Apatity infrasound array, this algorithm created as many as 13952 detections for 2005. Initial analysis suggests that the vast majority of these detections are real infrasound signals, and that this will be quite typical for an infrasound station in this region. Results from analysis of the Apatity data will be given in the presentation.

Considerations in event detection and location using small-aperture seismic arrays

S. J. Gibbons, T. Kværna and F. Ringdal

The current trend in Nuclear Explosion Monitoring is the detection, location and identification of seismic events of ever decreasing magnitude. This leads to a large increase in the number of earthquakes needing to be processed and also in the volume of industrial seismicity which should ideally be associated with the correct source.

The ARCES regional array in northern Norway is within 450 km of many sources of man-made seismicity and collection of Ground Truth information over recent years has allowed an excellent basis for a comparison between known source locations and location estimates, both fully-automatic and analyst-reviewed. The spread in automatic locations is due to three principal factors: (1) complicated firing sequences which preclude the correct interpretation of the observed arrival sequences, (2) spurious phase identification and association, and (3) the estimation of slowness and azimuth in varying frequency bands. Processing in fixed frequency bands can result in a dramatic improvement in the stability of slowness estimates for a given phase from a given site. However, different frequency bands may be associated with significant biases which vary greatly from band to band - and the frequency band providing the most stable estimates for a given phase can vary greatly from one site to another. As an example, we examine a series of over 100 military explosions in northern Finland.

Waveform correlation analysis indicates that all these events occurred within very close proximity of each other, and automatic location estimates based upon a calibrated template scheme are demonstrated to be far more stable than the corresponding analyst network solutions. This is because the template specifies the same frequency band for each event whereas the analyst picks a different band for each event examined; the band resulting in the most stable estimates has neither the best SNR nor the highest beam gain.

It is unclear as to how the spectacular improvements possible in site-specific studies can be applied to general detection algorithms.

Microseismic monitoring at the unstable rock-slope site at Åknes, Møre og Romsdal, Norway

Michael Roth[1] and Lars Harald Blikra[2]

[1] NORSAR & ICG
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Unstable rock slopes pose a threat to people and infrastructure. In the last century alone three major rock slides and associated flood waves claimed the life of 175 people in fjord areas in Western Norway. One site presently under investigation is Åknes in the county of Møre og Romsdal. Already in 1985 geological mapping revealed instabilities of the site, and continuous extensometer measurements showed an opening of fractures at an average rate of about 4 cm/year in the upper part of the slope. The volume of the instable part is about 40 to 70 million cubic m. In 2005 it was also found that a previously unmonitored part of the site moves with 15 cm/year. A sudden failure of the slope could generate a local tsunami threatening the close-by villages and the cruise ships carrying thousands of passengers in the summer time.

One of the experiments in 2004 was a small-scale seismic network in the upper part of the slope. The goal of this temporary pilot installation was the passive monitoring of seismic events that may be associated with the movement of the slope. The network consisted of 6 vertical geophones, and during the monitoring period of 72 days we recorded about 3 events per day.

In autumn 2005 we installed a permanent network for passive seismic monitoring. The permanent network will allow us to investigate the seismic activity and its variability, and to correlate our results with findings from other direct measurements (e.g. extensometer, GPS). Eventually, the activity rate will provide input for an early warning system. A further goal is to localize the microseismic events, to identify regions of high activity, and thus obtain information on the depth of the instability and on the internal structure of the slope.

The seismic network is located at the upper part of the unstable slope, and it covers an area of about 220x100 meters. It consists of 8 three-component geophones with 4.5 Hz natural frequency (GS-11D, GeoSpace). The geophones are cemented in shallow dimples directly to the solid rock. Each geophone is connected to the central data acquisition system in a concrete bunker with a reinforced data cable with customized lightning protection units on both ends. The cables (in total about 2 km) were solidly bolted to the ground to withstand damages caused by snow creep.

The acquisition system was customized by NORSAR engineers and contains as main components a Geode digitizer (Geometrics), a rugged industrial PC (MPL), a GPS clock and a GSM phone, which sends an alarm in case of power outage and which allows us to reboot all system components individually, if neccessary. The PC has an internal hard drive with a capacity of 30 Gbyte for temporal data storage. The concrete bunker houses a central power supply (diesel generator, batteries) and a 10 Mbit radio link that provides a connection to the closest internet access point in the village Hellesylt in about 13 km distance. From there we have an SDSL connection to NORSAR for contineous data transfer and for remote access to the field system.

The monitoring started on 27. October 2005 and has been running continuously since then. Currently we are recording continously with 125 Hz sampling rate on 24 channels, which results in about 1 Gbyte data per day. The data are transfered in near-real time, and forwarded to a basic automatically processing.

Earthquake prediction research and the June 2000 earthquakes

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In June 2000 two earthquakes with magnitude 6.6 (Ms) occurred in the central part of the South Iceland seismic zone (SISZ). Earthquakes in this region have, according to historical information, in some cases caused collapse of the majority of houses in areas encompassing 1000 km^2 in this relatively densely populated farming region.

Because large earthquakes were expected to occur soon much attention was given to preparedness in the region and for the last two decades it has been the subject of multinational, mainly European, cooperation in earthquake prediction research and in the development of a high-level microearthquake system, the SIL-system.

Despite intensive surface fissuring caused by the earthquakes and measured accelerations reaching 0.8 g, the earthquakes in 2000 caused no serious injuries and no structural collapse. The relatively minor destruction led to some optimism regarding the safety of living in the area. But it also led to some optimism about the significance of earthquake prediction research. Both earthquakes had a long-term prediction and the second of the two earthquakes had a short-term warning about place size and immediacy.

In this presentation I will describe the warnings that were given ahead of the earthquakes. Also I will reconsider these warnings in light of new evidences from multinational earthquake prediction research in Iceland. This research work reveals several observable patterns ahead of the earthquakes, patterns which are caused by beginning of crustal processes ahead of the earthquakes. This evidence points forward to even better results in providing useful warnings ahead of earthquakes in the future, based on more observations, new emerging modelling of earthquake processes, and an early information and warning system, which is in development parallel to ongoing earthquake prediction research.

According to the experience, microearthquakes, i.e. earthquakes down to or even below magnitude zero are the most significant indicator of the pre-earthquake process, and they provide information which makes possible a physical interpretation and modelling of it.

It is interesting to remind here that the scientific vision of the research activities, which have led to this development, started through Iceland in the European scientific community, not least within the Nordic scientific community.

In response to an appeal from the European Council Ad Hoc committee for earthquake prediction research around 1980 the members of the Nordic Detection Seminar discussed it at the seminar in 1981, and at the 17th Seminar held in Iceland 1986 a special panel meeting was organized to discuss an emerging Nordic project for earthquake prediction research with the South Iceland Lowland as a test area. This meeting together with a special meeting in Oslo earlier that year laid the basis for the SIL-project. SIL became the basis for continuous row of European earthquake prediction research projects, and gradually the basis for Icelandic and European projects in the field of practical earthquake warnings and early information.

The basic concept of the SIL earthquake prediction research project was from the beginning to study the physics of the processes leading to large earthquakes. The most significant information about these processes would be carried to the surface by signals from microearthquakes, down to magnitude zero. To be able to get to so low magnitudes we would have to develop an automatic acquisition and evaluation system capable of being a real-time link between the deep processes and the scientists. This was the SIL-system.

The development of the SIL-system in many ways opposed the prevailing ideas among seismologists at that time. However, the experience of later research and risk mitigation work have shown the significance of this scientific step for earthquake prediction research and for geosciences and geohazard warnings in general.

The SIL-system and the following development of earthquake prediction research has led to wishes from several earthquake-prone countries for coopearation on basis of the experience in the often named "Iceland Natural Laboratory".

Analysis of seismic noise at Icelandic Network (SIL) stations

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The SIL network has been in operation for 15 years and has grown from 8 short period (SP) stations in the South Iceland Seismic Zone (SISZ) to a 48-station national network, of which 7 stations have broad band (BB) instruments. In addition to monitoring seismicity in the SISZ, the network now covers the Tjörnes Fracture Zone (TFZ) and parts of the volcanic zones. The emphasis of the SIL network has been on sensitivity in order to collect the information carried by the vast number of microearthquakes occurring in Iceland. This has been achieved at the expense of recording the larger earthquakes, with especially the BB stations saturating and clipping events of M>5. Five of the network´s BB sensors, which were on long-term loan are being returned and will be replaced by new BB sensors in the coming year. To minimize the loss of information carried by the larger earthquakes, without significantly decreasing the sensitivity of the system, the sensitivity and self-noise of the replacement sensors need to be evaluated with respect to background noise conditions in Iceland.

To monitor noise at the SIL stations and to generate a background noise model for Iceland, 4-minute-long noise windows have been collected and analyzed approximately monthly over the last 5 years, accumulating up to 45 windows for some stations. As expected, microseismic noise is strongest at coastal stations and decreases away from the coast, being lowest at the inland stations. Amplitude variation in the microseismic peak, around 0.2 Hz, can be as great as 40 dB, with greatest amplitudes generally acquired during winter months and smallest amplitudes in the summer months. Wind is also a strong noise generator at some stations and, in the worst cases, can cause a noise increase of up to 30 dB in the SP range. Stations in the volcanic zones generally exhibit greater noise levels and many show a broad peak in the 2-6 Hz range. The worst such case is at station **snb**, east of Katla volcano. Man-made noise can be significant at stations located near towns and roads. These stations show a clear diurnal variation in noise amplitude. The noisiest station is **ves** located in Vestmannaeyjar off the south coast.

Microseismic studies at Hagfors array, Sweden

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Microseisms are the most dominant natural noise on broad-band seismograph records. Microseisms are a class of waves with various origins. Some have local causes due to human activity such as traffic or machinery. Other is related to local wind effects, storms, and the effect caused by rough surf along the coast. In this study we perform some noise analysis on the first three months 2005. The microseisms generated by the storm "Gudrun" that hit the southern part of Sweden on January 8th to 9th is studied in more details.

Seismicity in Sweden from five years of digital recordings

Reynir Böðvarsson and Björn Lund

Sweden is a low seismicity area, with most earthquakes being observed in the south-west, around Lake Vänern, along the north-east coast and in Norrbotten. South-eastern Sweden is on the contrary relatively inactive. Seismicity is also, generally, episodic in time which together with the short period of instrumental observation, approximately 100 years, makes our knowledge about the activity far from complete. Although very large earthquakes (magnitude about 8) have occurred in Sweden, it is generally agreed that these were connected to the late stages of deglaciation at the end of the previous ice-age. At the time scales considered in this report, inferences from current seismicity is of more relevance. This data suggests that we should expect at least one magnitude 5 earthquake in our region every century and one magnitude 6 earthquake every one thousand years.

Seismological monitoring in Lithuania during the period 1999-2005

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Territory of the Baltic countries and adjacent areas feature a low seismic activity. Earth's crust of early Precambrian consolidation and large distances to active tectonic zones causes situation of this kind. Nevertheless, according to historical and instrumental a few dozens of local earthquakes with intensities up to VII took place in the Baltic countries and Belarus since 1616 to 1987. Two Kaliningrad earthquakes with magnitudes 4.5 and 5.0 stroke the Baltic region in 2004 and that was a clear indication of seismogenic potential of this region.

Seismic Alarm System and complementary Seismic Monitoring System were installed at Ignalina Nuclear Power Plant (INPP) in 1999. Four seismic stations of SMS equipped with vertical short period sensors were deployed around INPP on distances of 30 km. At the same time Lithuanian Geological Survey (LGS) took responsibility to process, analyse and store seismological data of SMS and project of seismological monitoring was initiated there.

Processed data of SMS, analyses of seismological bulletins of NORSAR and Seismological institute of Helsinki University (HU) related to Lithuania's territory and some other results have been presented in the annual seismological bulletins and internal reports of LGS (e.g. www.lgt.lt/seismo). Copies of the seismological bulletins were sent to ISC regularly and to EMSC lately.

Results of seismological monitoring (year 1999–2005) supported the idea of low seismic activity of the territory of Lithuania and adjacent areas. Just a few local tectonic events have been registered by the seismic system of INPP during this period and none of them was located in Lithuania. Analysis of data of seismic bulletins of NORSAR and Seismological Institute of HU has shown the similar results. Seismic bulletins of NORSAR and HU reports approximately 50 explosion events located on the territory of Lithuania and nearby areas each year. Vast majority of them can be associated with quarry blasts and some military exercises. Meanwhile, just a very few events of this kind have been registered by SMS of INPP and a few probable explanations of this situation were found recently. Nevertheless, earthquakes with magnitudes above 5.0 can disturb long periods of quietness in this area, as Kaliningad seismic events have shown. Earth trembling of Kaliningrad events was felt on the large part of territory of Lithuania and significant amount of efforts was dedicated for collecting and processing of macroseismic data during the last years.

Strain and stress on the Reykjanes Peninsula

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The Mid-Atlantic ridge comes on-shore on the Reykjanes Peninsula and forms an oblique spreading centre oriented about 25° from the direction of spreading of N103°E. The obliqueness of the plate boundary, volcanic unrest, seismic activity and subsidence caused by geothermal exploration results in a highly complicated deformation field. Here we present results of GPS and seismic data analysis in an attempt to investigate the contemporary strain and stress along the Reykjanes Peninsula.

We use GPS velocities from 1993-1998 and 2000-2006 to estimate the horizontal strain rate field. The plate boundary zone is generally characterised by negative shear strain rates (ε_{xy}), consistent with left-lateral plate boundary motion, but the strain rate maps reveal spatial and temporal strain variations within the plate boundary zone. The strain rate fields are influenced by the inflation of Hengill 1994-1998, subsidence at Svartsengi, and by subsidence around a new power plant at Hellisheiði west of Hengill.

We estimate the state of stress at seismogenic depths along the Reykjanes Peninsula from 1997-2006, using earthquake focal mechanisms from the SIL network. The earthquakes primarily occur within two clusters at the central part of the Peninsula, near Krísuvík and Fagradalsfjall. In both areas, the seismicity occurs in response to a strike-slip state of stress, with a tendency towards normal faulting at Fagradalsfjall.

Earthquake activity in the Rana region recorded by a local seismic network and a seismic array

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The Rana region in Nordland, Norway, has long been known to be a highly seismically active region located within the stable continental interior. Previous studies of the seismicity have indicated that earthquakes occur in shallow clusters with a NW-SE orientation. A possible explanation for this elevated level of seismicity is the influence of uplift following the deglaciation, however, other local sources of the activity cannot be excluded. Since the installation of the STOK station in the region in 2003, the Norwegian National Seismic Network (NNSN) has recorded a large number of the events in the region. This has motivated the installation of an additional two stations within 20 km from the STOK station for more intense monitoring of the region since the summer of 2005. Due to the temporary nature of the installations, data availability has been unstable, and only few of the events have been recorded by all three of the local stations. Despite this, more than 750 events are registered in the region during 2005, confirming the continuous high level of earthquake activity. Preliminary locations of the recorded events indicate clustering of the events at shallow depths, in agreement with previous results. Hopefully, increased data availability after continued operation of the local network will make more exact event location based on Double Difference techniques possible. In addition to providing new information about the earthquake activity, the data from the local network can be used as ground truth for testing event detection based on waveform cross correlation over a seismic array at regional distances. This has been tested for recordings of the NORSAR array in southern Norway at ca. 700 km distance from the Rana region. Based on standard energy detectors, the array detected five earthquakes in the Rana region during 2005 of which three have highly correlated waveforms. Using one of these events as master event in a cross correlation based event detector over the array leads to the detection of 32 signals of which 31 can be confirmed by the local data. In this respect, the detection threshold for the array is lowered by at least an order of magnitude using waveform cross correlation over the array.

Increasing earthquake activity along the divergent plate boundary near the Askja volcano, Iceland

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Askja is a nested caldera volcano located within the northern segment of the Icelandic spreading plate boundary. It had its latest eruption in 1961. Geodetic measurements show that it has been continuously deflating for three decades. The volcano itself is characterised by persistent minor seismicity, principally related to geothermal activity in the eastern part of its caldera system. However, the main seismic activity in the region now is focusing in an area off the volcano, within a belt extending from Askja towards the north-east across the hyaloclastite mountains of Herðubreiðartögl and Herðubreið. This seismicity appears to be increasing and is also spreading to the north-east. The earthquakes typically occur in bursts of tens of events below magnitude 3 lasting from a few hours to a few days and the locations of event clusters shift within the active zone. A 3-week dataset in August 2005 based on a temporary 5-station local network and data of the permanent stations of Icelandic Meteorological Office indicates typical hypocentral depths of about 2-8 km.

Detailed mapping of fissures and faults in the surroundings of Askja reveals a multitude of structures. Curiously, the currently seismically active area lacks such fissures and faults: only few surface features were found to exist across the Herðubreiðartögl mountain and they cannot be directly linked to the ongoing seismicity. The epicentral clusters occur in a few kilometres broad belt of activity, probably forming an en-echelon system of left-lateral strike-slip faults. Their strike is north-east, somewhat off the north-north-east trend of the mapped extensional surface features.

Possible candidates for causes of the seismicity in the Herðubreið area are: 1) intrusive activity fed from the magma chamber system of Askja, 2) regional stress field due to movements across the plate boundary, or 3) adjustments due to the deflation of Askja. Geodetic measurements do not give indications of magma being piled up under the seismically active area. Thus stress field changes related to spreading of the plate boundary, possibly combined with the sinking of Askja and general uplift of central Iceland seem a more plausible explanation for this seismicity.

Increasing seismicity beneath Vatnajökull ice-cap: artefact or reality?

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Typically, volcanic eruptions are preceded by an increase in earthquake rate on a timescale ranging from days to years. Upsurges in seismicity can, in conjunction with other observational data, be used to forecast volcanic eruptions successfully. Modern-day volcanism in Iceland and the United States illustrates the utility of high-quality seismic data for following runaway increases in earthquake rate in the hours before an eruption. But the challenge of diagnosing changes in seismicity at a volcano whose eruption signature is unknown is greater – especially if the detection capability of the seismic network has improved during the period of apparent unrest. Here we evaluate changes in seismicity beneath Iceland's Vatnajökull ice-cap, seeking to understand whether increasing seismicity is real or a consequence of a progressive increase in the detection of small earthquakes. With three eruptions since 1996 – all monitored by the SIL seismic network – volcanic systems beneath Vatnajökull offer insight into seismic precursors to volcanism. We compare temporal changes in earthquake rate to accelerating seismicity observed recently at Bárðarbunga central volcano. We find that there is a genuine increase in seismicity within Bárðarbunga since mid 2005 (Figure 1); measured against the 2004 time-series from the neighbouring Grímsvötn volcano, it seems that the seismic prelude to the next eruption beneath Vatnajökull has begun; however, crucially, neither the timing nor the location of the next eruption can be specified at present. Long-term recognition of pre-eruptive seismicity remains a primary challenge in volcano seismology.

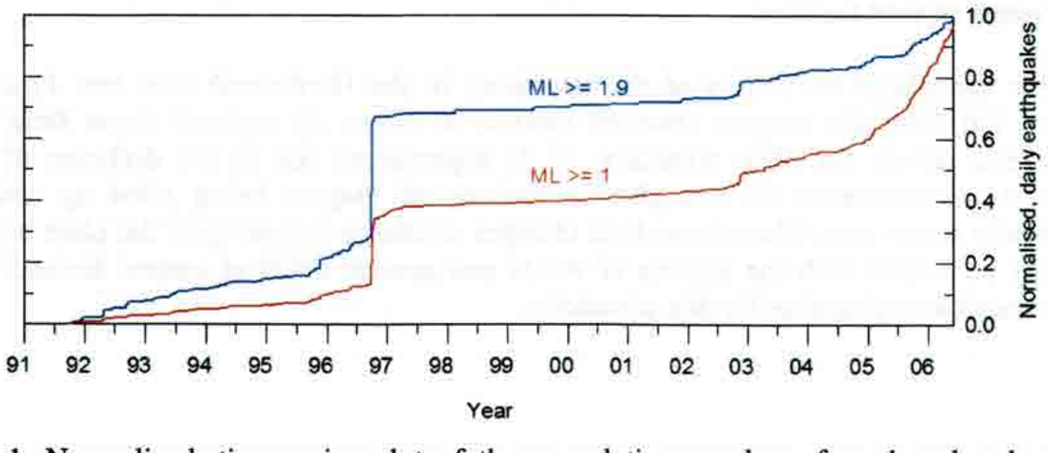

Figure 1. Normalised, time-series plot of the cumulative number of earthquakes between 1991 and 2006 within the Bárðarbunga region of Vatnajökull. Data are plotted using two minimum-magnitude thresholds: M_L 1 (n = 397) and M_L 1.9 (n = 135); the latter threshold represents the minimum value of completeness for the region. For both thresholds, increasing earthquake activity is apparent since mid 2005.

Fire and ice on shaky grounds: Living with natural hazards in Iceland

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Natural hazards have pronounced influence on society and living conditions in Iceland. Geologic hazards include earthquakes, volcanic eruptions and jökulhlaups (glacial outburst floods), which add to meteorological hazards. The hazards are often coupled, earthquakes occur in relation to magmatic/volcanic activity, and subglacial eruptions cause jökulhlaups related to rapid melting of ice by heat transfer from eruptive products. The rate of hazard occurrence is high in Iceland. In the last centuries, damaging earthquakes have occurred at an average rate of 1 per decade and volcanic eruptions at an average rate of about 2 per decade (with significant clustering). Living conditions in areas prone to geologic hazards can be increased by mitigation of the effects of the hazards. The basis for such mitigation is: (i) understanding of the hazards, (ii) monitoring of crust/mantle conditions, and (iii) well prepared interaction of society and hazards. Seismic and geophysical observations are of relevance for all these aspects – most useful when interpreted in a multidisciplinary approach.

The understanding of geologic hazards in Iceland rests on basic understanding of the forces that drive the hazards, plate spreading across the island and mantle upwelling under it. Information about the plate boundary zone in Iceland accumulates, with new information still modifying the boundaries of active zones. Past geologic activity provides scenarios for future activity. Coupling phenomena are frequent, exemplified by the recent eruptions at the Vatnajökull ice cap where magma movements, earthquakes, eruptions and jökulhlaups are coupled. Research efforts, including international cooperation, continuously add to the understanding of various coupling phenomena. Geophysical monitoring of crust/mantle conditions can reveal precursors to eruptions and earthquakes. Crustal conditions have been mostly monitored in the past, but new techniques will provide constraints on magma transfer at deeper levels than before. Magma accumulation has e.g. been suggested near the crust-mantle boundary under the Krafla volcanic system, based on satellite radar interferometry after 1992.

The interaction of society and hazards is relevant for hazard mitigation in several ways. Proper land use reduces vulnerability and leads to risk reduction. This is particularly relevant as the city of Reykjavík and towns in SW-Iceland expand into areas of fractured crust. Activation of fractures and/or occurrence of lava flows within inhabited areas are likely within a period of few hundred years. Areas used for geothermal and hydropower projects are also in general prone to hazards. Another factor is a well prepared response plan when hazards occur. The most recent addition to these plans in Iceland is a response plan for an eruption of the Katla volcano causing a jökulhlaup to an inhabited flood plain west of Katla. Finally, society may have a direct influence on the hazards. Man-made water reservoirs for hydropower projects can cause reservoir triggered seismicity and fault movements. Such scenarios have been considered for the Kárahnjúkar hydropower project in north Iceland. A 2.4 km^3 water reservoir will be formed as a part of the project, with water impoundment beginning in the fall 2006.

EarthScope:
Exploring the structure and evolution of North America

Michael E. Jackson, David Mencin, Gregory E. van der Vink and Christel B. Hennet

EarthScope is a national science initiative to explore the structure and evolution of the North American continent and to understand the physical processes controlling earthquakes and volcanoes. EarthScope is taking a comprehensive "systems" approach to investigate its scientific questions atall scales - from the active nucleation zone of earthquakes, to individual faults and volcanoes, to the deformation along the plate boundary, and to the structure of the continent and plate tectonic motion.

EarthScope is unprecedented, both in its interdisciplinary approach to Geosciences and in its scope. With approximately $200 million in funding from the National Science Foundation's Major Research and Equipment and Facility Construction account, EarthScope will be developed over five years in partnership with the US Geological Survey. Once completed, EarthScope is anticipated by NSF to be operating for an additional 15 years, providing a primary source of data for the next generation of Earth scientists and educators.

To meet the project's scientific goals, EarthScope will drill a 3.2 km borehole into the San Andreas Fault and install thousands of stations across the country: EarthScope's San Andreas Fault Observatory at Depth (SAFOD) is a comprehensive effort to drill and instrument a borehole through the San Andreas Fault directly in the area of active earthquake generation. A suite of instruments in the borehole will directly measure the physical conditions under which these plate boundary earthquakes occur. Covering North America and Alaska, EarthScope's network of 875 permanent Global Positioning System (GPS) and 100 borehole strainmeters will measure deformation across the active boundary between the Pacific and North American plates. EarthScope's USArray will install a dense array of 400 transportable seismic stations occupying 2000 sites across the continental United States and Alaska to record local, regional, and teleseismic earthquakes and produce high-resolution images of the Earth's interior. In addition, a pool of 100 GPS and 2400 seismic campaign instruments will be available for temporary deployments.

Most of these stations will transmit data in real-time via telemetry to data collection centers where the data will be freely and openly available to the scientific community, the educational community, and the public. EarthScope is expected to collect more than 70 TB of seismic and geodetic data during the first eight years of the project. Scientists will integrate the data with a diversity of geological data to address unresolved issues of the continental structure, evolution, and dynamics.

High-rate continuous GPS observations in Iceland

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A significant expansion of the current continuous GPS network in Iceland is now underway. The goal of the project is to introduce a new type of crustal deformation monitoring in Iceland by installing 25-30 new continuous GPS stations with a sampling rate of 1 second in selected areas in Iceland. High rate GPS observations have been used successfully to study dynamic earthquake rupture processes, for example the the Denali earthquake in Alaska and the 2003 Tokachi-Oki Earthquake in Japan. The project will apply the high-rate GPS technology in several different areas in Iceland. We will study volcanic processes by installing high rate GPS stations near the three most active volcanoes in Iceland: Grímsvötn, Hekla and Katla. These volcanoes have been active recently or are currently showing signs of unrest. Recent campaign GPS measurements indicate rapid uplift (up to 2 cm/yr) over a wide area in central Iceland. The network planned in central Iceland will obtain more detailed information on the rate and extent of the uplift. Stations will also be installed in seismically active areas in the South Iceland Seismic Zone, the Reykjanes Peninsula and in Northern Iceland. Implementing the 1-Hz technology in Iceland studies of both the dynamic as well as slower rate processes related to earthquake and volcanic activity will be possible. The high level of volcanic and earthquake activity in Iceland makes it an ideal site for this project. In addition, these new continuous GPS stations will double the number of continuous GPS stations in Iceland and provide important data on the rate of deformation along the plate boundary in Iceland, as well as increase our understanding of volcanic and tectonic interaction.

Crustal stress anomaly before the M=6.5 17 June 2000 earthquake in south Iceland

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In June 2000, the South Iceland Seismic Zone (SISZ) experienced two Mw 6.5 earthquakes less than four days and 17 km apart. We study the stress field in the SISZ during the decade preceding these events using stress inversion of earthquake focal mechanisms. In 1996, the background seismicity level increased by a factor of two in the hypocentral region of the first event of June 17. We show that this change in activity was accompanied by a significant stress anomaly in the lower part of the seismogenic crust. The direction of maximum horizontal stress, which was relatively uniform all through the seismogenic layer prior to 1996, varies considerably over short distances below 7.5 km depth. This stress anomaly persists until the occurrence of the June 17 earthquake.

We discuss possible driving mechanisms for the anomaly using intrusive and pore pressure models.

Monitoring the crustal stress tensor field by microearthquake analysis – new possibilities for earthquake warning algorithms

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Based on knowledge from rock mechanics, from direct stress measurements, and from detailed studies of large earthquakes a new method for estimating the complete rock stress tensor from microearthquake fault plane solutions has been designed.

It gives not only the complete stress tensor but rejects also the auxiliary plane. Tests on Icelandic data has confirmed the value of the method. Large scale modelling of the crustal field based on plate tectonics and the effects of large earthquakes of the SISZ area 1706-2000 (Roth (2004)) give results consistent with the stress tensor field observed by use of microearthquakes with this new approach.

Also the changes in Coulomb frictional stress at the June 21 2000 fault due to the June 17 2000 EQ given by Árnadóttir et al. (2003) are observed by the microearthquakes.

The two June 2000 EQs occurred in totally different stress conditions. The June 17 occurred in a stress field which was very heterogenous and included volumes of very high shear stresses. The June 21 area was very homogenous and oriented such that it was favourable for the coming earthquake slip. Although the two EQs showed very different stress situations before they occurred both stress pictures were extreme which is good for the possibilities to better earthquake warnings.

The six largest EQs within SISZ were used in a test for checking if they are preceeded by microearthquakes within highly stressed volumes. Statistically significant results were achieved, the asperity breaking can be seen but it requires that microearthquakes well below ML=1 are included in the analysis. These possibilities are valuable for short term warning.

The concept also gives an explanation to precursory swarms which often are observed for years before larger EQs.

I think this new step from fault plane solutions with two possible fault planes to complete rock stress tensors with only one plane for each earthquake is a major step in our work for understanding the crustal deformations and the processes leading to earthquakes.

Subsurface faults in southwestern Iceland mapped by relatively located microearthquakes

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Selected seismological data recorded by the Icelandic seismic network, SIL, between 1997 and 2006 have been relocated using a double difference location method and are then used to map faults in various areas in southwestern Iceland. The method uses cross correlation of similar wave forms to determine relative travel times of waves from events to stations with increased accuracy, and then inverts these relative travel times for an improved location. This increases location accuracy to such a degree that fault patterns may become resolvable. Mechanisms are calculated for each event using polarities and spectral amplitudes of P- and S-waves. Joint interpretation of focal mechanisms with the event distribution allows the determination of slip direction on individual faults.

This method has been used to reveal a detailed image of the faults of the two M=6.5 earthquakes which occurred in the South Iceland Seismic Zone (SISZ) in June 2000. The aftershock distribution of the nearly vertical, N-S striking 17-June fault, is mainly confined to its margins and center. The fault is made up of three patches, each striking a few degrees more east than the overall fault. The June 21 fault, on the other hand, is more linear but with varying dip. South of the epicenter the fault is vertical, but north of it the dip changes to 77 degrees, and aftershocks are much more sparse compared to the southern end. Furthermore, a large conjugate fault extends westwards from the southern part of the main fault. The two June events induced thousands of smaller earthquakes during the following six months. These events have also been relocated and used to map several other smaller faults, including separate patches of historical faults in the SISZ and the rough fault-outlines of two earthquakes on the Reykjanes Peninsula dynamically triggered by S-waves of the June 17 event.

Several other faults have been mapped as well on the Reykjanes Peninsula. Data recorded between 1997 and October 2005 have been relocated and used to map faults in the vicinity of Fagradalsfjall. The faults either strike north or northeast, similar to previously mapped surface faults in the area. Some faults seem to be active through more than one swarm, in other cases only parts of faults seem to show any activity in the time period. In most cases the fault plane solutions show right lateral motion accompanied by either a normal or a thrust component, as also seen in the SISZ. In general faults striking between 353° and 25° show right lateral motion whereas those striking between 200° and 243° show left lateral motion.

Faults have also been mapped in the Western Volcanic Zone, north of the SISZ. In 2004 two earthquake swarms occurred in Guðlaugstungur, about 20 km north of the geothermal area Hveravellir. Seismicity is not very frequent in this area and earthquake epicenters located between 1995 and 2003 are mostly concentrated further south, or west of the main geothermal area. In total, roughly 130 earthquakes were recorded in Guðlaugstungur and after double-difference relocation, the two swarms form two distinct clusters, one striking north but the other striking northwest. Mapped surface faults and fissures in the vicinity of

Hveravellir show a NE strike but signs of less distinct NW striking faults are also observed. None have been mapped in the exact area of the 2004 activity.

Asymmetric Plume-Ridge interaction around Iceland: The Kolbeinsey Ridge Iceland Seismic Experiment

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The geodymamic interactions between mantle plumes and mid-ocean ridge spreading centers give rise to notable variations in ridge morphology, mid-ocean ridge basalt chemistry, crustal thickness and presumably mantle flow. Iceland and adjacent ridges provide a natural laboratory for developing a comprehensive model of the dynamics of hotspot-ridge interactions. The KRISE2000 seismic refraction experiment was designed to constrain crustal evolution across the southern Kolbeinsey Ridge and the Iceland Plateau, from the Tjörnes Fracture Zone to the extinct Ægir Ridge in the Norwegian Sea. Here, we present the results from a 225 km long along axis profile which quantifies the present influence of the Iceland hotspot on melt flux at the spreading center north of Iceland. Crustal thickness along the Kolbeinsey Ridge is relatively constant north of the Iceland shelf, 9.4 km, increasing to 12 km along the shelf, into the Tjörnes Fracture Zone.

Gravity inversion indicates a residual crustal gravity anomaly that decreases by about 30-40 mGal toward Iceland. We infer that the variations in crustal thickness and gravity are accompanied by mantle temperature changes of 40 to 50°C. At similar distances from the Iceland hotspot, crustal thickness along the Kolbeinsey Ridge is 2-2.5 km less than at the Reykjanes Ridge, consistent with the asymmetry in plume-ridge interaction that has been inferred from the axial depth and geochemistry of these ridges. Average lower crustal velocities are also higher along the Kolbeinsey Ridge consistent with a lower degree of active upwelling than along the Reykjanes Ridge. Topography and crustal thickness patterns at the spreading centers around Iceland are consistent with isostatic support for normal crustal and mantle densities. Crustal thickness variations and geochemical patterns suggest that deep melting is spatially limited and asymmetric about Iceland while shallow melting is enhanced over a broad region. This asymmetry may be due to a mantle plume that is tilted from south to north in the upper mantle and preferentially melts deeper enriched material beneath the Reykjanes Ridge.

Tomography of Rayleigh wave group velocity in South Greenland from correlation of ambient seismic noise

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Seismic tomography is traditionally based on known sources like explosions or earthquakes, in this study we have applied a technique of cross-correlation long time series of seismic recordings from pairs of broad band seismic stations, to extract information on surface wave velocities from the ambient seismic noise. From a cross-correlation of one month of vertical component recordings we show that the Rayleigh wave group velocity can be determined between station pairs in South Greenland. Our result shows that the intensity of the ambient seismic noise is highest in coastal areas and that the intensity changes with the season, which correlates with the extent of sea ice around Greenland. The Rayleigh wave group velocity is obtained at three frequency intervals 5-10, 10-20 and 30-50 s. Tomography inversion at these frequency intervals is presented. Furthermore we present different aspects in the preparation and processing of the data set.

Lithospheric anisotropy beneath Greenland from SKS splitting

Ucisik, Guðmundsson, Hanka, Dahl-Jensen, Mosegaard and Priestley

Greenland is a relatively little studied continental block due to its remote setting and glacial cover. In the past 5-6 years a number of seismographs have been operated on the island in connection with seismic experiments (GLATIS and NEAT) in addition to an increased number of permanent seismographs (GEUS, GEOFON, IRIS). Data of significant duration are now available from about 20 sites in Greenland. These have already led to new information about crustal thickness, seismic velocity structure and lithospheric thickness beneath Greenland (Dahl-Jensen et al., 2003; Darbyshire et al., 2004; Kumar et al., 2005).

Anisotropy is known to be a significant seismic parameter near the surface of the Earth often modelled to be of a similar magnitude to lateral heterogeneity. Mapping seismic anisotropy is therefore important for describing seismic wave propagation. Seismic anisotropy arises due to fracturing of rock or alignment of anisotropic crystals and can also yield information about mantle flow and deformation processes.

Seismic anisotropy (azimuthal) in the Greenland region has previously been studied using Rayleigh waves (Pilidou et al., 2004, 2005). This gives a smooth pattern of anisotropy (500 km lateral resolution) strongest in the 100-150 km with a NS orientation of the fast polarization in southern Greenland turning to an EW orientation in northern Greenland and with a NW-SE orientation at the central east coast of Greenland.

Here we analyse the birefringence of SKS waves at 19 seismographs in Greenland (see also Ucisik et al., 2005). SKS waves are well suited for the study of azimuthal anisotropy because they exit the Earth´s core with a known (Sv) polarization on their upward path. Due to relatively short observation periods and high microseismic noise levels at predominantly near-coastal sites we apply a stacking method (Wolfe and Silver, 1998) which assumes a single layer of anisotropy. Time delayes are on the order of one second, which corresponds to 3-4% anisotropy distributed throughout the lithosphere (100-150 km).

The results are in reasonable agreement with results from surface waves. For nine sites in southern Greenland the fast polarization is oriented 10-30° east of north with one exception. In north-central Greenland this orientation is N30E and in north and northeast Greenland it is close to E. One site on the central east coast has a N45W orientation similar to the results of Pilidou et al. for that region. This site, together with three other in central Greenland, break up a simple, broad pattern. They represent details beyond the resolution limit of Pilidou et al. 2004. We speculate that this complication may be associated with the impact of the Iceland plume beneath central Greenland approximately 60 million years ago.

Dahl-Jensen, Larsen, Woelbern, Bach, Hanka, Kind, Gregersen, Mosegaard, Voss & Guðmundsson. Depth to Moho in Greenland: receiver-function analysis suggests two Proterozoic blocks in Greenland. *Earth Planet. Sci. Lett.*, **205**, 379-393, 2003.

Pilidou, Priestley, Guðmundsson & Debayle. Upper mantle S-wave speed heterogeneity and anisotropy beneath the North Atlantic from regional surface wave tomography: the Iceland and Azores plumes. *Geophys. J. Int.*, **159**, 1057-1076, 2004.

Darbyshire, Larsen, Mosegaard, Dahl-Jensen, Guðmundsson, Bach, Gregersen, Pedersen & Hanka. A first detailed look at the Greenland lithosphere and upper mantle, using Rayleigh wave tomography, *Geophys. J. Int.*, **158**, 267-286, 2004.

Pilidou, Priestley, Debayle & Guðmundsson. Rayleigh wave tomography in the North Atlantic: high resolution images of the Iceland, Azores and Eifel mantle plumes. *Lithos*, **79**, 453-474, 2005.

Ucisik, Guðmundsson, Priestley & Larsen. Seismic anisotropy beneath east Greenland revealed by shear wave splitting *Geophys. Res. Lett.*, **32**, Art. No. L08315, 2005.

Kumar, Kind, Hanka, Wylegalla, Reigber, Yuan, Woelbern, Schwintzer, Fleming, Dahl-Jensen, Larsen, Schweitzer, Priestley, Guðmundsson & Wolf. The lithosphere-asthenosphere boundary in the North-West Atlantic region, *Earth Planet. Sci. Lett.*, **236**, 249-257, 2005.

Crustal investigation of the Danish Basin based on ESTRID-1 seismic data

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The project ESTRID-1 (Explosion Seismic Transects around a Rift In Denmark) aims at investigating the crustal velocity structure of the Danish Basin at the Silkeborg Gravity High. This gravity anomaly is proposed to be caused by a high density gabbroic intrusion in the middle to lower crust. The seismic experiment involved 6 shots of 300-500 kg of explosives and 240 seismometers, deployed across the Jutland Peninsula, from the North Sea to the city of Århus, for a total profile length of about 150 km.

The seismic refraction/wide angle data are used to define the velocity field in the sediments and in the upper crust through first arrivals travel-time tomography. The velocity structure thus obtained is used as a starting point for ray-inversion modeling. This technique implies the use of first and second arrivals travel-times. The main seismic phases identified in the data are diving waves in the sediments (Ps), diving waves in the crystalline crust (Pg), diving waves in the supposed intrusion (Pi) and P-waves reflected from the Moho (PmP). The length of the profile and the anomalously high crustal velocities do not permit the identification of clear arrivals of waves traveling in the upper mantle (Pn). The results show the presence of high velocities (>6.8 km/s) at depths as shallow as 11-12 km. Furthermore, high velocity gradients (ca. 7.0 to 7.7 km/s) are obtained between 16 and 30 km depth. Below the central part of intrusion, the PmP is not clearly identified, due to the low velocity contrast (from 7.6/7.7 to 7.9 km/s). Along the profile the Moho reflectivity varies from 'ringing' to sharp. In the first case a coda of about 1 s is seen for the PmP. This peculiarity was noted in other rifted areas and it has been suggested to be associated with magmatic underplating. For the ESTRID-1 data, synthetic seismograms, based on a 1D velocity model, are produced to investigate the possible existence of layered structures at the Moho level. Synthetic seismograms based on a 2D velocity field are also created to better constrain the velocity gradients/contrasts of the final velocity model.

A new 3D seismic tomography model reveals the terrane distribution of Svecofennian Orogen

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The Paleoproterozoic part of the Fennoscandian Shield is composed of several arcs, microcontinents and sedimentary basins that were accreted to the Archean nucleus during Svecofennian Orogen. To study the real spatial distribution of these fragments a rather detailed 3D velocity model is required. Local seismic tomographic method is used to explore the terrane distribution within the central Svecofennian. A new 3D crustal *P* wave velocity model was created, as well as, the first *S* wave velocity and *Vp/Vs* models of the SVEKALAPKO area covering 700×800 km^2 in southern and central Finland. The *Vp/Vs* ratio distribution is especially interesting. This parameter is independent of density and determines the Poisson's ratio, and carries information on elastic properties of bedrock and thus on its composition and deformational history.

The data comprise of crustal *Pg* and *Sg* wave traveltime data from: 1) local events recorded by the SVEKALAPKO seismic tomography array in 1998-1999, 2) controlled source shots recorded at portable stations as well as at permanent stations, and 3) non-controlled chemical explosions recorded at permanent seismic stations. Tomographic inversion of 12086 first *P* and 9804 *S* wave arrivaltimes from 359 local explosions created 3D *P* and *S* wave velocity models independently of each other, thus enabling the calculation of the *Vp/Vs* model.

The results reveal that the crust is composed of alternating high- and low-velocity blocks (Figure1). According to resolution tests recognizable velocity structures in the central study area are horizontally at least size of 60×60 km^2 to depths of 40 km. The observed block size is between 100×100 and 200×200 km^2 in horizontal direction. The block geometry is best imaged in *Vp/Vs* ratio maps. Schist belts and their continuations at depth are associated with lower velocities and *Vp/Vs* ratios (Vp<6.2-6.8 km/s; Vs<3.6-3.9 km/s; Vp/Vs=1.68-1.73) than the granitoid areas (Vp=6.3-7.4 km/s; Vs=3.6-4.2 km/s; Vp/Vs=1.72-1.78). High *Vp* and *Vp/Vs* bodies suggest presence of mafic material, and low *Vp* and *Vp/Vs* areas map the metasedimentary belts between the accreted terranes. The tomographic model supports the idea that the thick Svecofennian crust was accreted from several terranes and that the crust was later modified by underplating.

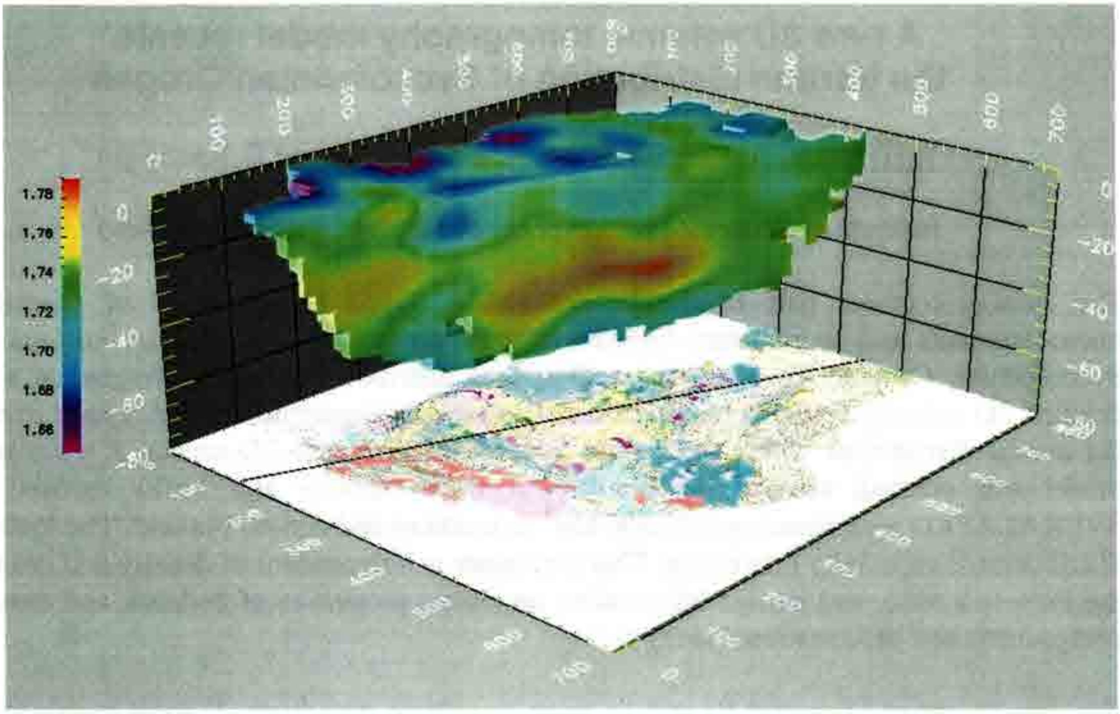

Figure 1. A 3D section of the *Vp/Vs* ratio distribution in Finland. The geological map is shown at the bottom, and the view is from SE to NW.

Seismic images of the accretionary Svecofennian Orogen

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Recently the accretionary Svecofennian Orogen has been surveyed by EUROPROBE/ SVEKALAPKO tomographic network and by large scale reflection experiment FIRE in southern Finland. A new 3D-tomographic inversion supports the idea that the Svecofennian Orogen is a collage of microcontinents, arcs and intervening sedimentary basins. The older continental nuclei – micro continents and arcs – have slightly higher P wave velocity and Vp/Vs ratio than the sedimentary basins. The thick crust has been stabilized by high velocity high Vp/Vs ratio underplating material residing in the lower crust.

In seismic reflection sections, the older crustal fragments are imaged as poorly reflective units whereas the metasedimentary units display more variable reflectivity associated with layering and deformation. The lower crustal underplate is visualized by homogenous, rather featureless reflectivity gradually decreasing at the Moho boundary. The underplate and associated extensional deformation in the middle and upper crust are interpreted to image gravitational collapse of the orogen.

Receiver function analysis of the broad band data of Finnish seismograph network

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The aim of this work is to study structure of the lithosphere and mantle down to 660 km discontinuity by applying receiver function methods to the data of Finnish broad band seismograph stations. Institute of Seismology of University of Helsinki has a network of 11 broad band stations in all parts of Finland. In addition Sodankylä Geophysical Observatory (SGO) of University of Oulu has 3 broad band stations in Southern and Central Lappland.

We started the study on a line along coast of Bothnian Bay. The line includes data from two permanent broad band station VAF and OUL and five temporary broad band stations of SVEKALAPKO experiment. For a 350 km long line we applied receiver function migration technique. Migration of receiver functions is useful tool to study deep mantle structures with 2-D sections. The moho depth was also determined with Zhu & Kanamori (2000) method.

In Figure 1 is shown the stations and the line from which the migrated section of Figure 2 is calculated. From the migrated section we can see the discontinuities of depths 413-430 and 643-658 km. The moho depths obtained with Zhu-Kanamori method for each station are also marked to the Figure 2.

Figure 1.

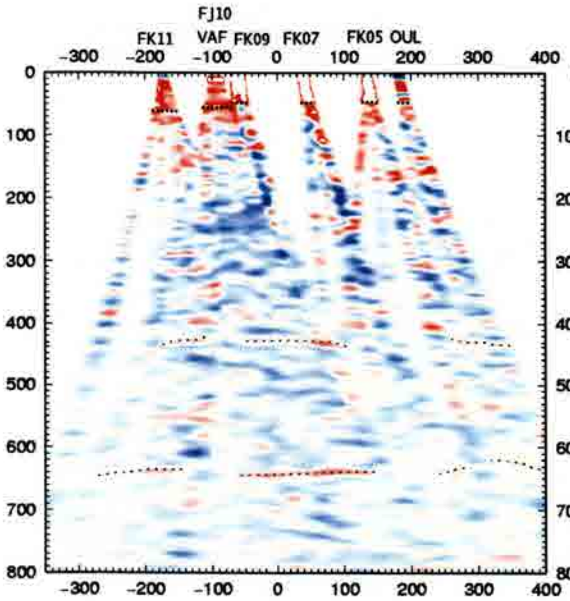

Figure 2.

Status of the Lehmann archive

Erik Hjortenberg

When Inge Lehmann at an age of 99 wrote her last seismological paper, I helped her in getting typing assistance etc., the paper was published in EOS and it is a translation of a paper she had been giving previously for the Danish Geophysical Society. Her seismological epistological archive was left to me in her will, and it was scanned 2005-2006 by SGA Storia Geofisica Ambiente (Bologna).

Fifteen years of SIL automatic monitoring

Steinunn S. Jakobsdóttir

The SIL-system has now been running for more than 15 years in automatic mode. The automatic version of the software was started on 23 May 1991 and officially the database reaches back to 1 July 1991. The system was designed as a part of the Nordic SIL-project and the first 8 stations were built in South Iceland Lowland. The aim was to detect and locate earthquakes down to magnitude 0 with accuracy to tens or hundreds of meters and to get automatic fault plane solutions and focal mechanisms for most earthquakes. In 1989, when the first stations were built, the fastest available PC-computers had 16 MHz processors with an extra math processor. The size of the hard disk was 150 Mb and one disc contained the operating system, which was Interactive Unix, the processing software, the ringbuffer and data files. Because of lack of space the ringbuffer could only be of 3 days duration. No clock was available at that time with the required accuracy of 1 msecond, so it had to be developed and built, using the omega positioning signal to obtain precise time. Today the computers in the system have 500-1600 MHz processors and it is hardly possible to get discs smaller than 40 Gb. This means that the ringbuffer has been expanded to 31 days and all data can be saved to files on the site computer without a problem. The software is basically the same as originally, with slight modifications and adaptions to first PC-Solaris and then to RedHat Linux, but the communication and data transmission, that originally was only through x-25 connections is now gradually moving to the internet through ISDN, ADSL and other net connections.

There are almost 250.000 earthquakes in the database. Earthquakes are detected and located at up to distance of 700 km from the station network. The smallest earthquakes located are of size less than -1 and the biggest earthquakes reach the size 6,5.

During the operation of the network 5 eruptions have been monitored with the system and 4 earthquakes larger than 5 have been recorded, in addition to the large earthquakes during 17 to 21 June 2000, where the two largest ones reached magnitude Ms=6,6.

The high quality data acquired by the SIL-system has been the basis for several EC-funded projects. The results from these projects are gradually being added to the system as valuable methods to monitor and eventually send warnings to scientists in case of changes in the seismic activity. An early warning and information system, that facilitates access to new and old data of both seismic and other origin and the visualization of data and other relevant information, has been developed as a continuation of the SIL-system.

SENSES

Seismological Network for Science and Education in Schools

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Seis-School-Norway

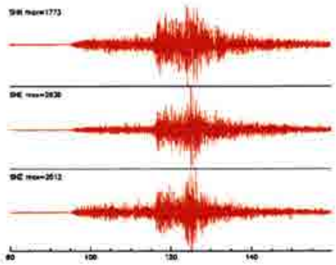
http://pcg1.geo.uib.no

Strategic Objectives

- Gateway for introducing Geosciences in Schools
- Do and learn and solve geoscience problems
- Increasing awareness of natural hazards like earthquakes
- Enhancing recording capabilities of local earthquakes
- Near real time access to all school station recordings
- Foster interest of students to scientific studies and careers
- Highlights; advanced design using freeware and Internet access to recording and their analysis

COSSACK RANGER II Seismograph Station

- To ensure School interest professional equipment must be used
- The low cost, high quality Cossack Ranger II meets requirements
- 3-component seismic sensor unit with preamplifier & A/D-converter
- Optional GPS clock, data logger and preferably Internet access
- Operates in trigger mode; recorded signal sent Hub and then accessible
- Records from any school stations available for analysis by students

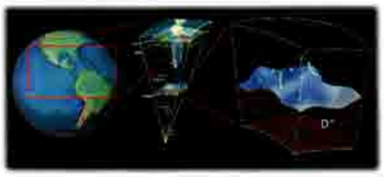


Monitoring Local Earthquake Activity

- Earthquake records are just a few clicks away from students anywhere
- Software would enable students to locate earthquakes and their size
- Analysis of past earthquake occurences in a tectonic framework
- Undertake earthquake hazard studies for local areas
- Undertake crustal studies in the local areas
- Locate mining and quarry activities close to schools
- Study global earthquake occurences using international data bases

Topical issues in Geoscience & Seismology

- The Dynamic Earth
- Wave propagation and seismogram analysis
- TSUNAMIS - how, where and when
- Our planet Tellus - its composition
- Glaciation - sea level rises



Geoscience in Schools - the Environment

- Active Cooperation between Schools and Academia
- Learning by Videos and Electronic Means
- Regular School visits by Scientists
- Carrot; Summer Schools for Teachers + some Students
- Students to take parts in Young Scientist Competitions

References:

Boulaenko, M. E. and Husebye, E. S., 2003: Electronic learning modules for high school students in seismology. Seis. Res. Lett., 74, 580 - 587.

Fedorenko, Yu.V., Boulaenko, E. and Husebye, E.S., 2000: School yard seismology, ORFEUS Newsletter, Vol 2, No 3.

Filatov, P.V., Yu. V. Fedorenko and E. S. Husebye, 2003: SeisSchool Norway Project: equipment, network operation, data acquisition, and processing system. Seis. Res. Lett., 74, 574 - 579.

Husebye, E. S., Beketova, E. B. and Fedorenko, Yu. V., 2003: School yard seismology, J. Geosci. Edu., 51, 329 - 355..