VEÐURSTOFA ÍSLANDS

Report
01014

Barði Þorkelsson
Sigþrúður Ármannsdóttir
(ritstjórar)

32nd Nordic Seminar on Detection Seismology

Húsavík, Iceland, June 6-8, 2001

VÍ-JA06
Reykjavík
June 2001

Report - Greinargerð
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32nd Nordic Seminar on Detection Seismology

Organized by Bardi Thorkelsson,
Steinunn S. Jakobsdóttir and Ragnar Stefánsson

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Photo by courtesy of Gudrún Kristín Jóhannsdóttir, Húsavík

Programme

DAY ONE – WEDNESDAY, JUNE 6

10:00 Opening address
Ragnar Stefánsson

10:05 Networks – databases – instrumentation
Chairman: Peter Voss

THE SWEDISH NATIONAL SEISMIC NETWORK – ONGOING DEVELOPMENT
Reynir Bödvarsson

THE EVOLUTION OF THE SIL-SYSTEM
Steinunn S. Jakobsdóttir

MAINTAINING INTEGRITY OF THE SIL-DATABASE THROUGH EXPANSION AND DEVELOPMENT
Kristín S. Vogfjörd

11:10-11:30 Coffee break

11:30 Networks – databases – instrumentation (continued)

EVALUATION ACTIVITIES AT NDC
Jørgen Torstveit

REVIVING THE MALÅ SEISMIC ARRAY
Malin Mårtensson & Björn Lund

EARLY WARNINGS AND GEOLOGICAL HAZARDS
Páll Halldórsson & Bergthóra S. Thorbjarnardóttir

INVENTORY DATABASE WITH WEB INTERFACE
Kamran Iranpour

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14:20 Networks – databases – instrumentation (continued)

NEW INSTRUMENTATION AT THE SEISMOLOGICAL STATION HSP AT HORNSUND, SOUTH SPITSBERGEN
Marek Górski

THE ICELANDIC CONTINUOUS GPS NETWORK – ISGPS
Halldór Geirsson

15:00 Seismic hazard assessment – engineering seismology
Chairman: Marja Uski

PARAMETRIC-HISTORIC PROCEDURE FOR SEISMIC HAZARD ASSESSMENT AND ITS APPLICATION TO NORTHERN EUROPE
Päivi Mäntyniemi, Andrzej Kijko & Paul Retief

REEXAMINING ORIGINAL MACROSEISMIC DATA: EXPERIENCE OF THE EARTHQUAKES IN KUUSAMU ON 18 AUGUST 1926 AND IN CENTRAL FINLAND ON 16 NOVEMBER 1931
Päivi Mäntyniemi

THE SOUTH ICELAND EARTHQUAKES OF JUNE 2000 – SITE AMPLIFICATION IN LAYERS OF SOFT SEDIMENTS AND LAVAROCK
Bjarni Bessason & Ódinn Thórarinsson

16:05 Poster session
Chairman: Steinunn S. Jakobsdóttir

TEMPORAL AND SPATIAL VARIATION OF THE B-VALUE IN THE GUTENBERG-RICHTER MAGNITUDE FREQUENCY RELATION WITHIN THE 150000+ EVENTS SIL DATASET
Sverker Olsson

AN ENHANCED NETWORK OF BROADBAND SEISMIC STATIONS ACROSS THE CANADIAN ARCTIC REGION: THE CHASME EXPERIMENT
Fiona A. Darbyshire, Janet A. Drysdale, D. McCormack, P. Munro, P. Street & S. Dodd

DEEP LITHOSPHERIC DIFFERENCES ACROSS THE TORNQUIST ZONE ARE REVEALED IN SURFACE WAVE AND TELESEISMIC TOMOGRAPHY INVERSIONS OF DATA FROM THE TOR PROJECT
Peter Voss, Søren Gregersen & the TOR Working Group

SEISMOLOGICAL ANALYSIS OF THE GREENLAND CRATON
T. Bach, T. Dahl-Jensen, I. Wölbern, W. Hanka, T. Larsen, S. Gregersen & K. Mosegård

AXIAL MAGMA CHAMBERS IN ICELAND
Bryndís Brandsdóttir, Páll Einarsson & William H. Menke

CRUSTAL STRUCTURE OF THE NORTHERN REYKJANES RIDGE AND REYKJANES PENINSULA, SW-ICELAND
Nicholas R.W. Weir, Robert S. White, Bryndís Brandsdóttir, Páll Einarsson, Hideki Shimamura, Hajime Shiobara & the RISE Fieldwork Team

THE TWO LARGE EARTHQUAKES IN THE SOUTH ICELAND SEISMIC ZONE IN JUNE 2000 – A BASIS FOR EARTHQUAKE PREDICTION RESEARCH
Ragnar Stefánsson, Þóra Árnadóttir, Grímur Björnsson, Gunnar B. Gudmundsson & Páll Halldórsson

16:15 – 16:45 Coffee break

16:45 Tjörnes fracture zone
Chairman: Steinunn S. Jakobsdóttir

AN OVERVIEW OF THE EARTHQUAKE ACTIVITY IN NORTH ICELAND
Ragnar Stefánsson

RELATIVE FAULT STRENGTH IN THE TJÖRNES FRACTURE ZONE AS INFERRED FROM STRESS TENSOR INVERSION OF MICROEARTHQUAKE FOCAL MECHANISMS
Björn Lund

REAL-TIME EARTHQUAKE MONITORING AROUND THE HÚSAVÍK-FLATEY FAULT
Vigfús Eyjólfsson & Ragnar Stefánsson

17:50 End of day one

19:00 Icebreaker

DAY TWO – THURSDAY, JUNE 7

09:00 – 18:30 Excursion to the plate boundary areas in North-Iceland – areas of seismic activity and recent volcanism

DAY THREE – FRIDAY, JUNE 8

09:00 Seismic detection – verification
Chairman: Roland Roberts

ON THE HAGFORS STATION DETECTION CAPABILITIES AT FIVE NUCLEAR TEST SITES
Ingvar Nedgård

OPERATION AND MAINTENANCE OF THE CERTIFIED IMS STATION PS17 (FINES)
Pasi Lindblom

AN AUTOMATIC EARTHQUAKE WARNING ALGORITHM (EQWA) BASED ON MICROEARTHQUAKE OBSERVATIONS
Ragnar Slunga

10:05 General topics
Chairman: Roland Roberts

SEISMOLOGY, MORE THAN JUST EARTHQUAKES
Anders Dahle, Tormod Kværna & Svein Mykkeltveit

EVALUATION OF THE QUALITY OF DIGITISED PAPER SEISMOGRAMS
Dan Öberg

10:50 – 11:20 Coffee break

11:20 Seismicity
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TWO RECENT M=6.6 EARTHQUAKES IN THE SOUTH ICELAND SEISMIC ZONE – A CHALLENGE FOR EARTHQUAKE PREDICTION RESEARCH
Ragnar Stefánsson, Gunnar B. Gudmundsson & Páll Halldórsson

THE MW 7.7 AND MW 6.6 EARTHQUAKES IN EL SALVADOR 2001
Sigrún Hreinsdóttir & Jeffrey T. Freymueller

FOCAL MECHANISM OF THE EARTHQUAKES ON MAY 11TH AND SEPTEMBER 15TH, 2000 IN FINLAND
Marja Uski, Tellervo Hyvönen & Annakaisa Korja

MONITORING OF INDUCED MICROSEISMICITY
Michael Roth, Volker Oye & Hilmar Bungum

12:45 –14:00 Lunch break

14:00 Crustal structure – modelling
Chairman: Bardi Thorkelsson

LITHOSPHERIC STRUCTURE OF THE TORNQUIST ZONE RESOLVED BY NONLINEAR P AND S PHASES TELESEISMIC TOMOGRAPHY ALONG THE TOR ARRAY
Zaher Hossein Shomali, Roland Roberts, Laust Pedersen & the TOR Working Group

THREE-DIMENSIONAL IMAGING OF THE P- AND S-WAVE VELOCITY STRUCTURE AND EARTHQUAKE LOCATIONS BENEATH SOTHWEST ICELAND
Ari Tryggvason, Sigurdur Th. Rögnvaldsson & Ólafur G. Flóvenz

CRUSTAL DEFORMATION IN ALASKA, ONGOING STUDIES
Jeffrey T. Freymueller, Hilary Fletcher, Roger Hansen, Sigrún Hreinsdóttir, Doerte Mann, & Chris Zweck

15:05 Discussion on statutes for the Nordic Seminar
Introduction by Anders Dahle

15:35 General discussion

15:50 Invitation to Nordic Seminar in Finland 2002
Matti Tarvainen

15:55 Closing remarks
Ragnar Stefánsson

16:00 End of day three

List of participants

DENMARK

National Survey and Cadastre

Peter Voss	pv@kms.dk

FINLAND

University of Helsinki

Pasi Lindblom	Pasi.Lindblom@seismo.helsinki.fi
Päivi Mäntinyemi	paivi@seismo.helsinki.fi
Eva Pelkonen	Eva.Pelkonen@seismo.helsinki.fi
Matti Tarvainen	Matti.Tarvainen@seismo.helsinki.fi
Marja Uski	Marja.Uski@seismo.helsinki.fi

ICELAND

Earthquake Engineering Research Centre, University of Iceland

Bjarni Bessason	bb@hi.is

Icelandic Meteorological Office

Vigfús Eyjólfsson	vigfus@vedur.is
Halldór Geirsson	dori@vedur.is
Gunnar B. Gudmundsson	gg@vedur.is
Páll Halldórsson	ph@vedur.is
Steinunn S. Jakobsdóttir	ssj@vedur.is
Thórunn Skaftadóttir	thorunn@vedur.is
Ragnar Stefánsson	ragnar@vedur.is
Hjörleifur Sveinbjörnsson	hs@vedur.is
Bardi Thorkelsson	bardi@vedur.is
Kristín S. Vogfjörd	kristinv@vedur.is

Nordic Volcanological Institute

Heidi Soosalu	heidi@norvol.hi.is

Science Institute, University of Iceland

Bryndís Brandsdóttir	bryndis@raunvis.hi.is

Invited participant

Eysteinn Tryggvason	eysteinn@vortex.is

NORWAY

NORSAR

Anders Dahle	anders@norsar.no
Kamran Iranpour	kamran@norsar.no
Michael Roth	michael@norsar.no
Jørgen Torstveit	jt@norsar.no

SWEDEN

FOI

Björn Lund	bjolund@foi.se
Malin Mårtensson	malin.martensson@foi.se
Ingvar Nedgård	ingvarn@foi.se
Dan Öberg	dano@foi.se

Swedish Geological Survey

Ari Tryggvason	ari@sgu.se

Uppsala University

Reynir Bödvarsson	rb@geofys.uu.se
Sverker Olsson	so@geofys.uu.se
Roland Roberts	rr@geofys.uu.se
Zaher-Hossein Shomali	hs@geofys.uu.se
Ragnar Slunga	slunga@foi.se

CANADA

Geological Survey of Canada

Janet Drysdale	drysdale@seismo.nrcan.gc.ca

POLAND

Institute of Geophysics, Polish Academy of Sciences

Marek Górski	mgorski@igf.edu.pl

USA

University of Fairbanks, Alaska

Sigrún Hreinsdóttir	sigrun@giseis.alaska.edu

Abstracts

THE SWEDISH NATIONAL SEISMIC NETWORK – ONGOING DEVELOPMENT

Reynir Bödvarsson

The first six digital broadband stations in the Swedish National Seismic Network (SNSN) were started in 1998. An additional twelve stations came into operation in September 2000. More than 400 local events have been recorded since then, whereof at least 160 are earthquakes, 200 explosions and the remaining are not yet definitely classified.

Twenty more stations are now under construction and will be put into operation by the end of year 2001 or early 2002. These new stations will cover the eastern part of Svealand and Götaland. This 38 stations network of modern digital seismological stations will provide a new and unique opportunity to study intra-plate deformation processes.

THE EVOLUTION OF THE SIL-SYSTEM

Steinunn S. Jakobsdóttir

Department of Geophysics, Icelandic Meteorological Office

The SIL-system has been running for 10 years in automatic mode. There are 42 stations in the network now and it is still growing. The World Wide Web is used to display automatic locations on a map in semi-real-time. The Web also gives access to other automatic information such as a measure of the background microseismisity, the azimuth of the maximum horizontal compressions in some selected areas and the SlungaWarning (EQWA), which is based on an algorithm used for attempting short-term earthquake warnings. Continuous GPS and strain measurements are also accessible through the Web. All this real-time information is significant in attempts to provide warnings for earthquakes and eruptions. A big ongoing project aims at building up a tool that renders access on the Web to all available knowledge for real-time research and makes distribution of information to users (Civil Defence etc.) quick and easy.

As the network is growing it expands into the highland, where main power (220V) and telephone lines are not available. At these locations the power is supplied by solar cells and wind generators and, in order to minimize power consumption at the sites, the digitized signal is sent by spread spectrum modem to a computer placed in more civil environment.

Communication technology is developing rapidly in Iceland. The x25 communication protocol that we are using now is less used than before and might even become unavailable in a decade or so. In near future it will be possible to transmit the continuous signal, in a cost-effective way, from some of the digitizer through a new communication network to a computer at the center in Reykjavík. This communication network is completely independent of the x25 communication and therefore increases the security of data transmission from at least some sites. The maintenance of the stations will be easier with the computers at the center are and all data available there. To begin with some selected stations will be running in double mode using both types of communication technique.

If transmission through one network breaks down, then the other should preferably keep on sending information. One main effort at the moment is in making the SIL-system operationally robust under all circumstances.

MAINTAINING INTEGRITY OF THE SIL-DATABASE THROUGH EXPANSION AND DEVELOPMENT

Kristín S. Vogfjörd

Department of Geophysics, Icelandic Meteorological Office

In its eleven years of operation, the SIL-network has been successful at fulfilling the initial objectives of: automation, high data quality and low operational cost. During this time the network has expanded to five times its original size and has gone through several stages of development in instrumentation and software. At present the network is composed of a varied assembly of sensors and digitizers, each with its own set of problems and vulnerabilities that have needed to be solved, in order to maintain the integrity of the system and the database.

In the future the network will continue to expand, although at a somewhat slower pace than in the past. Because of constant technological advances, it will also become even more varied; in some locations be supplemented by portable stations. The system software will be changing to accommodate the hardware changes, in addition to being in constant development of its own. In order to preserve database integrity through future evolution of the SIL-system, emphasis must be placed on quality control. For example, a quality parameter such as clock accuracy has to be automatically monitored and fully utilized in the analysis software. This is critical for relative-location accuracy. A database of site noise should also be constructed in order to monitor component failure, as well as site quality. Prompt detection of hardware failure will improve data quality, and improvements in site quality will result in improved earthquake detections as well as improved location accuracy.

EVALUATION ACTIVITIES AT NDC

Jørgen Torstveit

NOR_NDC operates the 4 IMS stations PS27 (certified, Operations and Maintenance Contract pending), PS28 (under CTBTO Test & Evaluation contract), AS72 (under national funds) and AS73 (in cooperation with University of Bergen). The reporting requirements and the reporting actually done will be discussed along with the reports received from the IDC. In the build-up towards a fully functioning NDC, NOR_NDC has developed Web-based tools to monitor status on data acquisition and automatic bulletin processing with automatic alarm functions. Moreover, Web-based operator instructions and system descriptions are being developed. Examples of the Web-pages will be shown.

REVIVING THE MALÅ SEISMIC ARRAY

Malin Mårtensson and Björn Lund

Naval Sensor Systems, Swedish Defence Research Agency (FOI), 172 90 Stockholm, Sweden
malin.martensson@foi.se

FOI has a seismological array in Malå in Västerbotten, Sweden, which has been running with new instrumentation for six weeks this winter. The goals of the test were to see what kind of improvement a seismological array in the middle part of Scandinavia could give to the regional array station analysis.

To evaluate the result, noise studies have been made. Beam forming were applied to reduce the noise. Azimuth and slowness were compared for known events in Kiruna and Aitic by f-k analysis. The standard NORSAR detector was run on the data and also an automatic single-station localisation. These results were compared to known event localisations. The NORSAR General Beam Forming scheme (GBF) was rerun with Malå data included. The GBF with and without Malå data was compared to each other and to the Uppsala University bulletin. We here present preliminary results from these analyses.

EARLY WARNINGS AND GEOLOGICAL HAZARDS

Páll Halldórsson and Bergthóra S. Thorbjarnardóttir

Department of Geophysics, Icelandic Meteorological Office

Early warnings are based on:

- The accessibility of geophysical and geological data, as well as information on previous events.
- The availability of detailed information on possible hazard areas.
- Automatically issued warnings using algorithms, that process real-time data; real-time data are compared to previous events.
- Algorithms, that help professionals to quickly evaluate the situation and possible development, after an automatic warning has been issued.
- A relational system which is based on informing concerned parties: The National Civil Defence, other scientists and the public.

The Icelandic Meteorological Office, the Systems Engineering Laboratory of the University of Iceland and TrackWell Software collaborate on this project.

INVENTORY DATABASE WITH WEB INTERFACE

Kamran Iranpour

A database containing data for all the instruments and other inventories at the arrays and stations and the corresponding acquisition and communication facilities at the Norwegian NDC (NORSAR) is under development. This work intends to gather all the information, quantitative as well as qualitative, into one single library using a relational database thus facilitating an easier access and reducing the amount of work spent on updating these information at a different levels. Using various web technologies the database will allow staffs both at the field and at NORSAR to easily access and update these information as well as providing an interface to visually monitor available channels at different stations. In addition the database will include information about various activities at the stations and arrays such as repairs, different levels of maintenance, data availablity etc., to meet the requirements imposed by the CTBTO for providing monthly and annual reports to the organization on member countries. The database and the corresponding interface will also work closely with the process monitoring system and access and archive information on the status of all the communication, acquisition/archiving and data processing systems.

Keywords: oracle, web, cgi, java, DHTML.

NEW INSTRUMENTATION AT THE SEISMOLOGICAL STATION HSP AT HORNSUND, SOUTH SPITSBERGEN

Marek Górski

Institute of Geophysics, Polish Academy of Sciences ul. Ksiecia Janusza 64, 1-452 Warszawa, Poland

In April 2001, a new seismological instrument KMSS MK-6 was installed at the seismological observatory of the Polish Polar Station Hornsund in April 2001. Instruments of this type are used at the Polish seismological network.

- Coordinates of the HSP station: Latitude 77.007°N, Longitude 15.545°E, Altitude 25 m.
- Resolution 26 bit.
- Dynamics 146 dB.
- Sensitivity below LNM.
- Sampling: 100 Hz for the recording with detection.
20 Hz for continuous recording.
- Band: 0.5-45 Hz for 100 Hz sampling.
0.5-8 Hz for 20 Hz sampling.
- The detection algorithm may be chosen from STA/LTA to algorithms based on artificial neural networks.
- Time synchronized by GPS.
- Cooperates with PC, operating system LINUX.
- Data format: mini-SEED, or, on request, GSE2 or ESSTF.
- Seismometers SM-3,T=1.5 s.

In the second half of 2001 the Hornsund station will be equipped with INMARSAT satellite system. This will enable fast access to the data recorded at the station.

THE ICELANDIC CONTINUOUS GPS-NETWORK - ISGPS

Halldór Geirsson

Department of Geophysics, Icelandic Meteorological Office

The Icelandic Meteorological Office operates a growing network of continuous GPS-stations in Iceland to monitor crustal deformation. The network is called ISGPS. Most of the 10 operational stations are as of yet sited in South Iceland.

Data is collected and processed automatically on a daily basis, using predicted satellite orbits from the Center of Orbit Determination in Europe, in order give researchers a near real-time overview of active deformation processes. We process the data using the Bernese v. 4.2 software and calculate daily station coordinates and uncertainties.

The time series are still short for most of the stations, so velocity estimates are rather uncertain. Non-linear velocity trends have been observed at numerous stations. Although most of the ISGPS stations were not sited close to the June 2000 earthquakes in the South Iceland seismic zone, a significant deformation signal was detected at all operational stations. Stations near Katla and Eyjafjallajökull volcanoes show that magma accumulation is currently not occurring rapidly at shallow depths.

PARAMETRIC-HISTORIC PROCEDURE FOR SEISMIC HAZARD ASSESSMENT AND ITS APPLICATION TO NORTHERN EUROPE

Päivi Mäntyniemi (1), Andrzej Kijko (2) and Paul Retief (2)

(1) Institute of Seismology, University of Helsinki, POB 26, FIN-00014 Helsinki,Finland
(2) Council for Geoscience, Geological Survey of South Africa, Private Bag X112, Pretoria 0001, South Africa

A new methodology for Probabilistic Seismic Hazard Assessment (PSHA) was applied to parts of the northernmost intraplate Europe. The purpose was to gain more experience of the applicability of the technique to low-seismicity areas, where PSHA is often difficult because of a sparseness of data.

The new methodology proposed by Kijko and Graham (1998, 1999) offers interesting features for PSHA for low-seismicity regions, although its use is by no means limited only to such cases. It can be classified as parametric-historic, because it combines the best features of the deductive (Cornell, 1968) and historical (Veneziano et al., 1984) procedures. The new technique does not rely on the subjective judgement involved in the definition of seismic source zones, when active faults have not been identified. It permits the use of both the incompletely reported pre-instrumental and complete instrumental data and takes into account magnitude uncertainty. Either peak ground acceleration, peak ground velocity, or peak ground displacement can be selected as the ground-motion descriptor. The technique has been developed specifically for the estimation of seismic hazard at individual sites, but hazard maps can be obtained by applying it to grid points covering larger areas.

Two exercises were conducted: in the first one seismic hazard parameters were estimated for a site of a Hypothetical Engineering Structure (HES), and in the second one a seismic hazard map was obtained by applying the procedure to grid points covering a larger area.

The procedure was applied to earthquake data inside a selected distance from the HES. This affected the output if different distances meant different observations of the largest events, but otherwise the results for the regional part of computations were not that dependent on the choices made when preprocessing the data. In contrast, the site-specific activity parameter was quite sensitive to the number of observations. The paucity of observations available for the site did not allow the consideration of only the earthquakes large enough to exceed a certain ground-motion value of engineering interest but all available events were included in the analysis. The seismic hazard was expressed as probabilities that a maximum ground amplitude will be exceeded in given time intervals at the site.

The generated map gave rather a realistic assessment of the level of seismic hazard on the basis of knowledge of past seismicity. The areas of more concentrated and quite scattered seismicity were discernible and the output was not dominated by the largest historical events. Events with identical epicentres originating from the macroseismic era may cause spots of apparently enchanced seismicity. In short, the proposed methodology proved to be a useful tool for quantifying different aspects of seismic hazard in areas of low to moderate seismicity, and its main features are advantageous to these cases.

REEXAMINING ORIGINAL MACROSEISMIC DATA: EXPERIENCE OF THE EARTHQUAKES IN KUUSAMO ON 18 AUGUST 1926 AND IN CENTRAL FINLAND ON 16 NOVEMBER 1931

Päivi Mäntyniemi

Institute of Seismology, University of Helsinki, POB 26, FIN-00014 Helsinki, Finland
E-mail: paivi@seismo.helsinki.fi

The regionally important earthquakes that occurred in Finland between 1880-1935 were basically investigated during the next few years following the events, and the results were then published. The much later construction of parametric earthquake catalogues was based on these early studies; thus the original data have not been used since the events occurred.

Substantial progress has been made in the field of historical earthquake research during the past few decades. For instance, an updated macroseismic scale (EMS 1992, or MSK-92), as well as improved methodologies for the interpretation of original felt reports are now available. It is thus instinctive to wonder if a more reliable classification of important earthquakes also in northern Europe could be obtained by applying the new seismological tools to the first-hand reports of the shaking and/or minor damage caused by the regionally important events.

As population in northern Europe is both sparse and unevenly distributed, and seismicity is low to moderate, this region is not best suited to macroseismic analyses. Two events were thefefore chosen for testing if reexamining the original historical data in Finland is profitable. They were the Kuusamo earthquake on 18 August 1926 and the central Finland earthquake on 16 November 1931. The former case represented more problematic data collected in the very sparsely populated northern part of the country, while the latter one was more favourable with over one thousand observations located away from borders and offshore areas.

The data available comprised the original macroseismic questionnaires returned to the responsible agency soon after the events augmented with contemporary press reports collected for this reinvestigation. MSK-92 intensities were assessed at each locality using correspondence analysis, and macroseismic fields were determined using different spatial techniques.

It was found for instance that newspaper data increased the number of available data points obtained with the help of the mail survey, and they included important documentary material. However, the search for usable newspaper reports tends to be somewhat time-consuming, as it is difficult to tell beforehand those cases in which the reporter took a special interest in the phenomenon. Also, an important consideration in the use of these data is the spatial distribution of the press from which the data were derived. The guidelines related to the use of MSK-92 scale were helpful in arranging the original data. Statistical methodologies and modern computational facilities allowed versatile and fast data analysis. The new maps produced are advantageous for instance when communicating earthquake-related matters to the general public.

THE SOUTH ICELAND EARTHQUAKES OF JUNE 2000 – SITE AMPLIFICATION IN LAYERS OF SOFT SEDIMENTS AND LAVAROCK

Bjarni Bessason and Ódinn Thórarinsson

Earthquake Engineering Research Centre, University of Iceland, Austurvegur 2a, 800 Selfoss. E-mail: bb@hi.is , Fax: (+354) 525 4140, Tel.: (+354) 525 4141

The seismicity and volcanic activity in Iceland are related to the Mid-Atlantic plate boundary that crosses the island. Within Iceland, the boundary is shifted towards east through two complex fracture zones. One is located in South Iceland, and called the South Iceland Seismic Zone while the other is mostly of the northern coast of Iceland. In addition to the seismic zones there are volcanic zones and through the ages volcanoes have been active and caused number of eruptions and lava flows that have led to alternating layers of alluvium, glacial drift and lava at some sites. This heterogeneous geology can in some cases affect the site-specific ground motion during earthquakes.

The Earthquake Engineering Research Centre of the University of Iceland operates a strong motion network in Iceland. At one of the measurement sites, that is, the Thjórsá-bridge site, the geology is quite different on each side of an approximately 80 m wide river canyon. On the east side, there is solid dolerite rock, which can be considered bedrock conditions. On the west side, there is an 8 m thick lava rock, which covers approximately 20 m thick alluvium of loose sand and fine grain gravel. This site is instrumented by a three-axial accelerometer on each side of the canyon. The accelerometers are fastened to short and stiff (rigid) concrete piers, which are a part of the Thjórsá-bridge and can be considered to measure ground motion on both sides of the canyon.

In June 2000 two earthquakes of magnitude 6.6 (M_w) and 6.5 (M_w) occurred in the South Iceland Seismic Zone. In the first earthquake the epicentre was in a northeast direction from the Thjórsá-bridge and the epicentral distance was 16 km. For the second earthquake the direction was west-northwest and the distance 6 km. A peak ground acceleration (PGA) of 0.53g was recorded at the site during the first earthquake and in the second one a PGA of 0.84g was recorded at the site. In both cases the PGA was recorded on the west side of the canyon but considerable lower values were recorded at the east side where the conditions are similar to bedrock.

Recorded time histories at the Thjórsá-bridge site from the two main earthquakes of June 2000 and from eighteen aftershocks from the same period have been used for studying site amplification in the lava rock and the soft sediments at the west side of the canyon. The time histories from the east side, which is classified as bedrock site, are used as basis to evaluate the site-amplification in the layers on the west site. Various parameters are considered, such as PGA, total power, which is based on integration of the squared acceleration signal, Fourier amplitude spectra, and response spectra.

The analysis has shown that there is significant amplification of ground motion on the west side lava rock base. This effect is of great importance in determining design criteria for sites with similar geology which are common in the volcanic zones of Iceland.

TEMPORAL AND SPATIAL VARIATION OF THE B-VALUE IN THE GUTENBERG-RICHTER MAGNITUDE FREQUENCY RELATION WITHIN THE 150000+ EVENTS SIL DATASET

Sverker Olsson

Department of Earth Sciences, Uppsala University

The South Iceland Lowlands (SIL) network has been in operation for 10 years. During that time more than 150000 earthquakes have been recorded. This study investigates the proposed Gutenberg-Richter relation, $\log N = a - bM$, for the SIL data.

Plotting the data shows a clear break in the magnitude-frequency relation at magnitudes greater than 3. However, using magnitudes calculated from seismic moments will give a better fit.

To investigate temporal and spatial variations, the slope in the Gutenberg-Richter relation (the b-value) has been estimated for various subdivisions of the dataset. Among the observations made are large differences in the average b-value between areas in Iceland, temporal fluctuations in the b-value in connection to major seismic events and for some areas a clear depth dependence.

AN ENHANCED NETWORK OF BROADBAND SEISMIC STATIONS ACROSS THE CANADIAN ARCTIC REGION: THE CHASME EXPERIMENT

F.A. Darbyshire, J.A. Drysdale, D. McCormack, P. Munro, P. Street and S. Dodd

CTBT Verification Office, Geological Survey of Canada, 7 Observatory Crescent, Ottawa, Ontario, Canada K1A 0Y3
Phone: 613-992-0249, Fax: 613-992-8836, E-mail: fiona@seismo.nrcan.gc.ca, cormack@seismo.nrcan.gc.ca, drysdale@seismo.nrcan.gc.ca, munro@seismo.nrcan.gc.ca, street@seismo.nrcan.gc.ca, dodd@geolab.nrcan.gc.ca

CHASME (Canadian High Arctic Seismic Monitoring Experiment) is a study of the Earth structure and seismicity of northernmost Canada and the Baffin Bay region. During late summer 2000, seven three-component broadband seismic stations were deployed in communities across the Canadian High Arctic and western Greenland, significantly improving the seismic network coverage for the region. The seven temporary stations will remain in place until summer 2001.

Signals from local, regional and teleseismic earthquakes are being used to constrain the crustal and upper mantle velocity structure beneath each of the seismic stations and across the region. This includes receiver function and surface wave analysis studies. The information provided by these studies will add significantly to our knowledge of the structure and tectonics of northern Canada. In addition, the improved velocity-depth models will be used to provide more accurate local and regional earthquake locations.

The denser seismic network provided by combining the permanent seismic stations with the seven temporary stations will also serve to improve the determination of earthquake locations and mechanisms across the region, thereby enhancing our understanding of the seismicity of the Arctic.

DEEP LITHOSPHERIC DIFFERENCES ACROSS THE TORNQUIST ZONE ARE REVEALED IN SURFACE WAVE AND TELESEISMIC TOMOGRAPHY INVERSIONS OF DATA FROM THE TOR PROJECT

Peter Voss, Søren Gregersen and the TOR Working Group

National Survey and Cadastre (KMS), Rentemestervej 8, 2400 Copenhagen NV, Denmark

The difference in the lithospheric structure between the Proterozoic and the Phanerozoic Europe is more than 300km deep and almost vertical, this is the major conclusion of the TOR project. TOR was a 900km long and 100km wide antenna of mobile broad band and shortperiod seismographs, that continuously collected data in Sweden, Denmark and Germany, for half a year from 1996 to 1997. Surface wave studies show differences in lithospheric thickness between northern Germany and Denmark but beneath southern Sweden surface wave inversion shows no lithosphere-asthenosphere transition in the upper 200km. Teleseismic tomography inversion shows that the transition zone is narrow, near vertical and more than 300km deep. The inclination of the transition was by the first results a SW-slope, whereas an extended P-wave study and a study of S-waves indicates a NE oriented slope. Synthetic teleseismic tomography inversion results are presented to illustrate the problem of interpreting such data.

SEISMOLOGICAL ANALYSIS OF THE GREENLAND CRATON

T. Bach (1,2), T. Dahl-Jensen (3), I. Wölbern (4), W. Hanka (4), T. Larsen (2), S. Gregersen (2) and K. Mosegård (1)

(1) Niels Bohr Institute, University of Copenhagen. (2) National Survey and Cadastre - Denmark. (3) Geological Survey of Denmark.
(4) GeoForschungsZentrum - Germany.

The GLATIS project (Greenland analysed Teleseismically on the IceSheet) has completed its main data acquisition phase. With 18 broad band seismometers deployed from 60°N to 77°N, both along the coastline and on the icesheet, the project is the largest teleseismic experiment ever performed on the Greenland ice sheet.

Since very little prior knowledge exist about the crustal thickness and upper-mantle structures under the ice sheet, the project is interesting both commercially and scientifically. Speculations have been made about the prior location of the Iceland mantle plume, and the project has deployed broad band stations both along proposed plume tracks, and in regions which are unlikely to be affected by a mantle plume. Commercially, knowledge of the lithosphere thickness in SW-Greenland may help in the localisation of diamond prone areas.

The first results from the GLATIS project are presented.

AXIAL MAGMA CHAMBERS IN ICELAND

Bryndís Brandsdóttir (bryndis@raunvis.hi.is) and Páll Einarsson, Science Institute, University of Iceland, Reykjavík, Iceland; William H. Menke, Department of Geological Sciences and Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964, USA.

Iceland is crossed by a slow spreading plate boundary which, due to its interaction with the Iceland mantle plume, contains many tectonic features of a fast spreading ridge. Enhanced crustal production within the plume has generated crust beneath Iceland which is 3-5 times thicker than normal oceanic crust. The Iceland region lacks a median valley and is characterized by higher variations in ridge-crest topography and fewer but tectonically more complicated fracture zones than other parts of the Mid-Atlantic Ridge. The divergent plate boundary is made up of volcanic systems (axial rifting segments) consisting of central volcanoes and their associated fissure swarms. Doming of the lower crust is observed beneath the central volcanoes. Where detected, 1-2 km thick, localised magma chambers sit on top of these high-velocity domes, at around 3 km depth, i.e. approximately at the level of buoyant equilibrium for basaltic melt within the crust. The domes likely consist of olivine-rich cumulates, formed at the base of magma chambers and subsequently advected downward and outward during the spreading process. The magma chambers in Iceland are thus different from those recently found on the Mid-Atlantic Ridge itself, where a thin axial melt lens is underlain by a zone of lower velocities, interpreted as crystalline mush containing partial melt. The height of the high-velocity domes reflects their evolutionary stage and their volume is indicative of their lifespan. For instance, the 33 km wide Krafla dome may be at least 1.8 million years old based on a 0.9 cm/year half spreading rate. The crustal magma chambers are intermittently replenished during rifting episodes and act as buffers on the magma upwelling from the mantle as they regulate the magma residence time within the plumbing system, the rate and volume of magma output, and alter the composition of the magma. Central volcanoes thus play a major role in crustal genesis along the plate boundary.

CRUSTAL STRUCTURE OF THE NORTHERN REYKJANES RIDGE AND REYKJANES PENINSULA, SW-ICELAND

Nicholas R. W. Weir (1), Robert S. White (1), Bryndís Brandsdóttir (2), Páll Einarsson (2), Hideki Shimamura (3). Hajime Shiobara (4), and the RISE Fieldwork Team

(1) Bullard Laboratories, University of Cambridge, Madingley Road, Cambridge CB3 OEZ, United Kingdom.
(2) Science Institute, University of Iceland, Dunhaga 3, 107 Reykjavik, Iceland.
(3) Institute of Seismology and Volcanology, Hokkaido University, Sapporo 060-0810, Japan.
(4) Earthquake Research Center, University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo, 113-0032, Japan.

Results from the combined onshore-offshore Reykjanes-Iceland Seismic Experiment (RISE) show that the thickness of zero-age crust decreases from 21 km in southwest Iceland to 11 km at 62°40'N on the Reykjanes Ridge. This implies a decrease in mantle potential temperature of ~130°C, with increasing distance from the center of the Iceland mantle plume, along this 250 km transect of the plate boundary. The seismic Moho is clearly identified by PmP and SmS reflections, both from local earthquakes and controlled explosive sources. The crust thins off-axis at 63°N, from 12.7 km at 0 Ma, to 9.8 km at 5 Ma, most likely due to a ~40°C change in asthenospheric mantle temperature between these times. This provides evidence for the passage of a pulse of hotter asthenospheric mantle material beneath the present spreading center. A reflective body, the top of which lies at 9-11 km depth, is identified in the lower crust just west of the tip of the Reykjanes Peninsula. Synthetic seismogram modeling of the wide-angle reflections from this body suggests that it corresponds to a zone of high velocity (>7.5 km/s), high magnesium rocks in the lower crust. The P- to S-wave velocity ratio beneath the peninsula is 1.78, implying crustal temperatures are below the solidus. Gravity modeling shows the RISE models to be consistent with the observed gravity field, with mantle densities lower beneath the ridge-axis than beneath older crust, consistent with lithospheric cooling with age.

AN OVERVIEW OF THE EARTHQUAKE ACTIVITY IN NORTH ICELAND

Ragnar Stefánsson

Department of Geophysics, Icelandic Meteorological Office

As is the case in Southwest Iceland, large earthquakes occur in North Iceland on EW-oriented shear zones at the North coast or just north of it. Historical documentation of these earthquakes is sparse, much sparser than in Southwest Iceland. However, during the last century two earthquakes of magnitude (Ms) 7 occurred approximately 50 km off the coast, one probably north of Skjálfandi bay or Tjörnes peninsula in 1910 and another north of Skagafjörður bay in 1963. Two earthquakes with Ms 6.5 occurred on the coast, in 1934 near Dalvík and in 1976 near Kópasker.

The earthquakes occurred all in the Tjörnes fracture zone (TFZ), which is a complicated junction area between the Kolbeinsey ridge (KR), i.e. the presently active mid-Atlantic ridge (MAR) north of Iceland and the presently active northern rift zone of Iceland, which is offset 100 km to east compared to the KR. This offset was developed during more than 10 million years as a part of the interaction between the general EW-extension across the MAR and the upflow and outflow of the Iceland mantle plume, which governs where rifting takes place in Iceland. A significant feature of the Tjörnes fracture zone is the WNW-ESE trending Húsavík-Flatey fault, 70 km long, going through Húsavík town. This is often considered to be the only well developed transform fault of Iceland. It is sometimes also considered that it extends all the way from the Krafla fissure swarm in the east, towards west to the mouth of Skagafjördur bay, i.e. 140 km.

Interaction between extension episodes of the rift zones and of the rifting branches of the TFZ and locking and stress release in the seismic fault zones cause a variablity in stress conditions and rate of fault motions in the area. Geological studies of excavated parts of the Húsavík-Flatey fault reveal significant perturbations and even reversals in stress fields during geologically short-time spans. Even on a very short time scale, i.e. since 1995, repeated GPS measurements as well as observations by SAR have revealed variablity in deformation in time and space.

The Húsavík-Flatey fault has had no large earthquakes since 1872. The Krafla rift zone extensional episode that started in 1975 further helped to lock the fault, and thus delay an earthquake on the fault. How long this locking may help to delay an earthquake on the fault cannot be estimated. Although this area is far to complicated to expect repetitons of geological events it can be reminded that the Krafla rifting episode which started in 1725, was followed in 1755 by an earthquake of estimated magnitude 7 on the Húsavík-Flatey fault.

Earthquakes in North Iceland, especially in the Húsavík-Flatey fault, and conditions leading to them, have been a significant issue of the recently finished PRENLAB projects, and of the recently started SMSITES project.

RELATIVE FAULT STRENGTH IN THE TJÖRNES FRACTURE ZONE AS INFERRED FROM STRESS TENSOR INVERSION OF MICROEARTHQUAKE FOCAL MECHANISMS

Björn Lund

Naval Sensor Systems, Swedish Defence Research Agency (FOI),
172 90 Stockholm, Sweden; bjolund@foi.se

The Tjörnes fracture zone in northern Iceland has two distinct zones of earthquake activity, the Húsavík-Flatey fault and the Grímsey lineament. We have used microearthquake focal mechanisms to invert for the local stress tensor using two different criteria to select the earthquake fault plane from the two nodal planes. First a stability criterion which selects the nodal plane with the highest instability (I = tau - mu*sigma_n) in the tested stress field. The second criterion instead uses information from high accuracy relative location of the events to pick the fault plane from the nodal planes.

Using data from the Húsavík-Flatey fault we infer similar states of stress with both fault selection criteria, however, the instability criterion frequently chooses the wrong fault planes. The correct fault planes, which are usually parallel to the strike of the Húsavík-Flatey fault, are thus not the ones most likely to fail in the estimated stress field. The fact that they nevertheless do fail indicates that the Húsavík-Flatey fault is a relatively weak fault. This weakness can be explained either as a zone of low coefficient of friction in the vicinity of the fault or as in increase in pore pressure in the fault zone. We estimate the necessary decrease/increase in these parameters. Preliminary results from the Grímsey lineament show that the faults inferred from relative location are also the most instable, i.e. they are selected by the instability criterion. These results points towards a possible procedure for identifying seismically active but relatively weak faults.

REAL-TIME EARTHQUAKE MONITORING AROUND THE HÚSAVÍK-FLATEY FAULT

Vigfús Eyjólfsson and Ragnar Stefánsson

Department of Geophysics, Icelandic Meteorological Office

Húsavík and nearby areas are threatened by effect of a possible earthquake on or near the Húsavík-Flatey fault. The largest known historical earthquakes were in 1755, estimated magnitude 7 and in 1872 there were two earthquakes on the fault of magnitude around 6.5. For this reason earthquake prediction research was carried out in the area during 1996-2000, based on monitoring of the SIL-system and on geological and deformational observations, i.e. the PRENLAB project, coordinated by the Icelandic Meteorological Office (IMO). Based on good results of the PRENLAB project a new project started in 2000, the so-called SMSITES project, coordinated by University of Edinburgh. The core of the SMSITES project is an active shear-wave splitting experiment, lead by Stuart Crampin of the University of Edinburgh, where shear waves activated in a borehole are recorded in two nearby boreholes to monitor shear-wave splitting induced by stress changes.

The part lead by IMO is on one hand to monitor near-fault seismic activity and on the other hand hydrological monitoring in a wider area around the fault system. For this purpose three SIL-type seismic stations have been installed close to the fault and incorporated in the SIL-evaluation center. Further evaluation of the data are in the hands of IMO, Uppsala University and University of Edinburgh. The Icelandic Energy Authority has built the hydrological monitoring system in cooperation with IMO. Real-time automatic monitoring of these two networks started in the beginning of this year, and is visualized on the Internet for warnings and for scientific purposes.

ON THE HAGFORS STATION DETECTION CAPABILITIES AT FIVE NUCLEAR TEST SITES

Ingvar Nedgård

There are three principal objectives with this paper. The first objective is to indicate a lower bound for the present detection capability of the Hagfors station, the second objective is to select non-nuclear events that might be used as reference events for the purpose of identification, and the third objective is to have some method to compare the detection capability before and after the rearmament of the Hagfors station. Two sources of information are used: the Reviewed Event Bulletin (REB) of the International Data Centre (IDC) and NORSAR automatic single-station event/detection lists for the Hagfors station. The bulletins consist of 350 MB text files covering the time interval 1995 to March 9, 2001. Events are selected from the REB from chosen areas around Lop Nor (China), Chagai/Kharan (Pakistan), Pokhran (India), Novaya Zemlya (Russia) and Semipalatinsk (Russia). The size of the areas are adjusted to the number of events in the area and the proximity to the test site. For most test sites the area chosen is of the order 111000 km^2 (3x3 great circle $degrees^2$) but at Novaya Zemlya the area is four times this order depending on the lower seismic activity. Theoretical arrival times to Hagfors, from the selected events, are estimated by the IASPEI91 Earth model (Kennett and Engdahl) for first P-phase, first S-phase, Lg-phase and Rg-phase. A deviation of 5 seconds between theoretical and measured arrival time is accepted as a probable associated phase. The results are presented as event lists containing the REB source data, measured event/detection list data, calculated travel time to Hagfors for the found phases, time deviation and distance to Hagfors. In the Lop Nor area 78 events are selected (four are nuclear explosions) and 42 events (four are nuclear explosions) have at least one associated phase. Around Chagai/Kharan 49 events are selected (two are nuclear explosions) and 30 events (two are nuclear explosions) have at least one associated phase. In the Pokhran area 29 events are selected (one is a nuclear explosion) and 14 events (one is a nuclear explosion) have at least one associated phase. Around Novaya Zemlya 21 events are selected and 10 events have at least one associated phase. In the Semipalatinsk area 18 events are selected and 12 events have at least one associated phase. After removing the nuclear explosions 11 of 12 events are detected at Lop Nor, 9 of 11 events are detected at Chagai/Kharan and 8 of 12 events are detected at Pokhran above a lower bound of detection $m_b > 4.0$ (IDC REB). At Semipalatinsk 12 of 13 events are detected above a lower bound of detection $m_b > 3.6$ (IDC REB) and at Novaya Zemlya 5 of 6 events are detected above a lower bound of detection ML > 3.6 (IDC REB). These figures indicate the order of the lower bound for the present detection capability of the Hagfors station but care must be taken considering the few events available. Next step will be to study the waveforms of the events with associated Hagfors detections and select non-nuclear reference events. Future work will include other test sites and the present detection capability of the Hagfors station will be compared to the future capacity.

OPERATION AND MAINTENANCE OF THE CERTIFIED IMS STATION PS17 (FINES)

Pasi Lindblom

Contract between the Preparatory Comission for the CTBT Organisation and the Institute of Seismology, University of Helsinki for the Provision of Services relating to the Testing and Evaluation of PS17 was signed December 2000. In the contract, Institute of Seismology has obligated to operate and maintain the station and keep it as a Mission Capable array.

This presentation will show how the station has been built and how it can be operated and maintained so that the requirements would be fulfilled.

AN AUTOMATIC EARTHQUAKE WARNING ALGORITHM (EQWA) BASED ON MICROEARTHQUAKE OBSERVATIONS

Ragnar Slunga

Uppsala University
email: slunga@foi.se

An automatic earthquake warning algorithm has been implemented into the Icelandic seismic network operated by the Icelandic Meteorological Office in Reykjavík. It is based completely on microearthquake observations and makes use of: foreshock activity patterns in time and space, fault radius variations, quiescence and combinations of these. The main new concepts are the use of fault radius and a nucleation pattern or "domino pattern" defined by the microearthquakes. The algorithm is defined so it gives alarms before the six largest earthquakes so far observed within the network during the last ten years which contains more than 173,000 microearthquakes.

SEISMOLOGY, MORE THAN JUST EARTHQUAKES

Anders Dahle, Tormod Kværna and Svein Mykkeltveit

NORSAR

Seismic stations may be regarded as earth stethoscopes listening to when and where something has happened.

The use of seismological data may therefore be extended beyond its traditional role to provide valuable information for the investigation of accidents, possibly also in search- and rescue operations, or in public safety assessment.

The scientific and technological development and the increasing density of seismological recording facilities makes it more likely than before to record accidents by seismic stations whenever an impact is produced in the ocean, in the earth, or at the surface of the earth. Sound waves in the air also couple into the ground and transmit through the earth as seismic waves and thus phenomena like supersonic aeroplanes and meteorites passing through the barrier of sound over seismological facilities may also be tracked.

This paper summarizes some accidents and incidents where seismological recordings from NORSAR have provided crucial important additional information in the search for likely causes and valuable information about time and place.

EVALUATION OF THE QUALITY OF DIGITISED PAPER SEISMOGRAMS

Dan Öberg

Digitisation of paper seismograms is an ongoing process at FOI. The overall goal is to establish a library of reference events for the Hagfors seismic station. Both explosions and earthquakes from different areas of the world should be included. Historical nuclear explosions recorded on paper are important to include in the library.

Clearly errors both in time and amplitude are introduced in the digitisation process.

One important question is therefore if the degradation of the signals are acceptable. The errors in time is at maximum around 0.01s (which is the sampling time) and the quantisation is comparable to a 7-bits A/D-converter. Correlation analysis for short period signals shows that events that are geographically close generally correlates well. This is an expected and desired result. The conclusion is that the signals could be used for correlation analysis, and that further work should be done in the digitisation process.

Also it is desired to decide for which areas (or test sites) we should make an effort to digitise more events.

TWO RECENT M=6.6 EARTHQUAKES IN THE SOUTH ICELAND SEISMIC ZONE – A CHALLENGE FOR EARTHQUAKE PREDICTION RESEARCH

Ragnar Stefánsson, Gunnar B. Gudmundsson and Páll Halldórsson

Department of Geophysics, Icelandic Meteorological Office

In June 2000 two earthquakes with magnitude 6.6 (Ms) struck in the central part of the South Iceland seismic zone (SISZ), immediately followed by seismic activity to a distance up to 100 km from the epicenters. This occurred after 88 years of relative quiescence in this 70 km long EW transform zone. Earthquakes in this region have, according to history, frequently caused almost total destruction in areas encompassing 1000 km^2. In spite of open surface faults and measured accelerations reaching 0.8 g no serious injuries were reported and no homes collapsed. Prevailing ideas about the nature of strain release in the area have been confirmed. As far as the epicenter of the first earthquake is concerned, hazard assessments or long-term predictions were confirmed, and in hindsight precursors have been observed. Around 24 hours before the earthquake on June 21 a warning was issued to the Civil Defence claiming that an earthquake with, as it showed to be, the right location and size could be expected anytime within short. Significant observations were made of the earthquakes as well as of their premonitory and following processes which will be a basis for better models of the SISZ earthquakes as well as for better hazard assessments and warnings in the future. Among significant observational systems are the SIL-system, which is especially aimed at retrieving information from microearthquakes, strong motion instruments with a good coverage in the area, continuous GPS measurements, borehole strainmeters and hydrological observations in boreholes. Earlier GPS-net measurements were repeated after the earthquakes, and detailed analysis of extensive surface fissures was carried out. It is expected that only around one fourth of the moment build-up in the zone has been released in these two earthquakes, and that even larger earthquakes may occur in the zone during the next decades.

THE MW 7.7 AND MW 6.6 EARTHQUAKES IN EL SALVADOR 2001

Sigrún Hreinsdóttir and Jeffrey T. Freymueller

Geophysical Institute, University of Alaska, Fairbanks

On the 13th of January 2001 a Mw 7.7 earthquake occurred off coast of central America, 100 km SW of San Miguel, El Salvador. The earthquake was a normal faulting event at a depth of ~60 km within the subducting Cocos plate. On the 13th of February a Mw 6.6 strike-slip earthquake occurred in the overriding Caribbean plate about 30 km east of San Salvador, El Salvador. Deformation due to the earthquakes was measured at permanent GPS stations located in Central America. A coseismic deformation was detected at stations within 250 km radius of the January 13th earthquake, a station NW of the event moved towards the earthquakes epicenter but two stations NE of the event moved away from its epicenter. In the February 13th earthquake ~4 cm horizontal signal was observed on the GPS station closest to the earthquake epicenter (~20 km). A relatively small postseismic signal, possibly afterslip, was observed at the station for few days following the earthquake. Using the aftershock distribution from the January earthquake in addition to deformation data we model at the coulomb stress change caused by the Mw 7.7 earthquake and compare it to observed seismicity following the earthquake. The 13th of February earthquake occurred about 85 km away from the 13th of January earthquake and is probably a response to the altered regional stresses.

FOCAL MECHANISM OF THE EARTHQUAKES ON MAY 11th AND SEPTEMBER 15th, 2000 IN FINLAND

Marja Uski, Tellervo Hyvönen and Annakaisa Korja

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

On May 11th, 2000 an earthquake of magnitude 2.5 took place in Toivakka, Central Finland. With four seismic stations situated within 80 km from the epicenter, the event was exceptionally well recorded by our national network. Therefore, this event was selected as a test case in searching for a method to determine focal mechanisms for small earthquakes in Finland.

The original arrival time picks were re-examined and the event was relocated using a velocity model designed here for Central Finland. A set of acceptable fault plane solutions was obtained from the P-wave polarities as well as P/SV and P/SH amplitude ratios. To further constrain the source parameters we calculated synthetic seismograms with the reflectivity method and compared the observed waveforms with theoretical ones. The best fit fault plane solution of the Toivakka earthquake is well constrained, almost pure thrust fault mechanism with both possible nodal planes trending N-S and dipping 30°W or 60°E. By comparing these with the the structural and geological data of the epicenter area, we suggest the eastward dipping plane to be the fault plane.

Our second test event, an earthquake of magnitude 3.5, shaked the Kuusamo area in northeastern Finland on September 15th, 2000. This was the largest earthquake in Finland in over 20 years. The acceptable fault plane solutions were determined as described above. The nodal planes of the Kuusamo earthquake were however not as constrained as for the first event, due to the uneven azimuthal and distance distribution of the seismic stations around the epicenter. A preliminary solution indicates normal faulting mechanism along a steeply dipping plane trending NNE-SSW.

MONITORING OF INDUCED MICROSEISMICITY

Michael Roth, Volker Oye and Hilmar Bungum

NORSAR, P.O. Box 51, 2027 Kjeller, Norway

Microseismic events in oil and gas reservoirs are induced by production and stimulation. Changes in pore pressure and loading results in cracking of rock or sudden stress release along existent fractures and faults accompanied by the emission of seismic signals. Hence, the analysis of microseismic events can provide means to delineate the internal structure of a reservoir and to monitor dynamic processes within the reservoir during production.

We are developing an analysis package with the objective of real-time processing of microseismic data as recorded at arrays of three-component sensors deployed in boreholes and/or at the surface. We are addressing two different scenarios: (i) long-term reservoir monitoring using permanently deployed geophones and (ii) short-term hydrofracturing experiments. The package so far comprises an interface to commonly used seismic data formats, setup-modules for geometry and calibration, and the the basic automatic processing modules for event detection, onset picking, polarization analysis, localization and corresponding graphical output.

The detection module is based on a multi-trace evaluation of the signal-to-noise ratio. Once an event is detected, the P- and S-wave arrival times are estimated automatically by evaluating changes of statistical features of the seismograms. Within a time window of the P-wave onsets an automatic polarization analysis is performed, which gives the azimuth and the angle of incidence at each geophone. All of the technical parameters for the processing modules can be adjusted interactively in order to optimize the procedures for different data characteristics.

Subsequently the event parameters are inverted for the event location. We implemented two localization routines. One is a linearised inversion based on the assumption of a homogeneous velocity model. Considering the magnitude of possible estimation errors of the seismic wave traveltimes and polarization angles, this inversion scheme seems to be appropriate for hydrofracturing experiments, where the source-receiver distances are short, and the small-scale velocity structure of the site is unknown. The second localization method that we prefer for the case of long-term seismic monitoring in reservoirs, is based on a directed grid search allowing for an arbitrary 3D velocity structure. The velocity structure in and near the reservoir is usually well mapped by conventional reflection seismics and/or VSP surveys. Using NORSAR's 3D Ray Modelling software we compute look-up tables for traveltimes and polarization angles for any source-receiver configuration. The effort to establish such tables depends on the spatial resolution of the velocity model and the desired data resolution.

Due to the modular structure the processing package is easily expandable and flexible. All of the processing modules were tested thoroughly with synthetic data sets and applied to a hydrofracturing data set and to microseismic data from the Ekofisk field.

LITHOSPHERIC STRUCTURE OF THE TORNQUIST ZONE RESOLVED BY NONLINEAR P AND S PHASES TELESEISMIC TOMOGRAPHY ALONG THE TOR ARRAY

Z. Hossein Shomali[1], Roland Roberts[2], Laust Pedersen [3] and the TOR Working Group

Department of Earth Sciences, Uppsala University, Villavägen 16,
752 36 Uppsala, Sweden.[1] hs@geofys.uu.se, [2] rr@geofys.uu.se, [3] lbp@geofys.uu.se

The TOR project investigates the lithosphere-asthenosphere boundary under the Tornquist Zone between Denmark and Sweden. Teleseismic P and S phases' relative arrival-time residuals from 51 earthquakes recorded by 150 seismic stations along the TOR array were used to delineate the transition zone in the studied area. The effects of crustal structures were excluded from the tomographic inversion by correcting the teleseismic residuals for travel-time variations in the crust based on a 3D crustal model derived from other data. Two different inverse methods (SVD and QP) were used to investigate whether or not the blocks and major boundaries in the inversion are required by the data or are artifacts by the inversion. The inversion was carried out for P and S phase separately and simultaneously. Recent results show that the transition zone between thin lithosphere in Germany and the Baltic Shield in Sweden occurs in two sharp and steep steps. A sharp and steep subcrustal lithosphere-asthenosphere boundary is found below the Tornqusit Zone with surficial expression coincident with the Sorgenfrei-Tornquist Zone. Another less significant transition is recognised under central edge of the Tornquist Zone, more or less beneath the Elbe-lineament. Separate and simultaneous P and S phase inversion confirm a transition from a thin lithosphere beneath the Central Europe to a 120km thick lithosphere under the Tornquist Zone and more than 200km thick continental lithosphere beneath the Baltic Shield. The heat-flow data is also consistent with this structure. Relatively higher Vp/Vs ratios under the Tornquist Zone indicate relatively low S-velocity in an area where the gravity high anomaly suggests the idea of extensive mafic intrusions.

THREE-DIMENSIONAL IMAGING OF THE P- AND S-WAVE VELOCITY STRUCTURE AND EARTHQUAKE LOCATIONS BENEATH SOUTHWEST ICELAND

Ari Tryggvason[1,4,*], Sigurdur Th. Rögnvaldsson[2,+] and Ólafur G. Flóvenz[3]

[1]Department of Earth Sciences, Uppsala University, Villavägen 16,
SE-753 36 Uppsala, Sweden

[2]Icelandic Meteorological Office, Bústadavegur 9,
IS-150 Reykjavík, Iceland

[3]National Energy Authority of Iceland, Gensásvegur 9,
IS-108 Reykjavík, Iceland, email: ogf@os.is

[4]Instituto de Ciencias de la Tierra, "Jaume Almera", CSIC, Barcelona, Spain

*Now at: The Swedish Geological Survey, Box 670,
SE-751 28 Uppsala, Sweden, email: ari@sgu.se

+Tragically passed away on October 25, 1999

Using a combination of more than 100000 travel times from a selection of local earthquakes and explosions recorded on the three-component seismic network operating in Southwest Iceland, the three-dimensional velocity structure has been modelled to depths of 10-15 km. The tomography algorithm simultaneously inverts for both P- and S-wave velocities and hypocentral locations. Major tectonic features within the 224x112 km^2 rectangular study region include the South Iceland Seismic Zone, the Hengill volcanic system and the Reykjanes Volcanic Zone. Reduced velocities from the surface to as deep as we can resolve, or about 9 km, are associated with the Hengill central volcano. As low Vp/Vs ratios prevail in the entire anomalous region, we suggest supercritical fluids within the high-porosity volcanic fissure system cause the reduced velocities, rather than any large fractions of partial melt. Along the Reykjanes Volcanic Zone relatively low velocities down to depths of 6-8 km are observed in the centre of the zone indicating elevated temperatures, but due the relatively recent expansion of the seismic network in this region the ray-coverage here is rather poor. Normal velocities are observed in the South Iceland Seismic Zone with a slight reduction in Vp/Vs ratio. The thickness of the brittle crust, defined as the depth above which 90% of the earthquakes occur after relocation in the three-dimensional models, increases from about 5 km in the relatively young crust of the Reykjanes Volcanic Zone to about 12 km in the eastern end of the South Iceland Seismic Zone. These depths correspond to temperatures in the range of 580-750° C, estimated from borehole heat flow measurements.

CRUSTAL DEFORMATION IN ALASKA, ONGOING STUDIES

Jeffrey T. Freymueller, Hilary Fletcher, Roger Hansen, Sigrún Hreinsdóttir, Doerte Mann and Chris Zweck

Geophysical Institute, University of Alaska, Fairbanks

Part of the plate boundary between the Pacific plate and the North American plate lays along the southern margin of Alaska. There the Pacific plate subducts under the North American plate resulting in high seismicity and volcanic activity. Of the 10 world largest earthquakes in recorded history three occurred in Alaska and the largest eruption of the twentieth century occurred on the Alaska Peninsula. Crustal deformation studies in Alaska aim at measure active motions to better understand their source processes. Here we present few examples of ongoing work.

Subduction related deformation in southern Alaska:
Geodetic measurements have been conducted in several locations along the 1200 km Alaska margin. The data show variation in plate coupling along the plate boundary. We find lack of deformation in the overriding plate in the Shumagin Islands, indicating very weak plate coupling in the Shumagin segment, where there have been no great earthquakes for at least 80 years and possibly as long as 200 years. Slip maxima of the last great earthquakes (Mw 8.3, 1938 and Mw 9.3, 1964) however correspond to areas that we find strongly coupled today.

Active seismic zone of the Alaskan interior:
The most obvious tectonic feature in the interior of Alaska is the Denali fault that extends in a broad arc for more than 2000 km. 250 km north of the Denali fault is another major tectonic feature, the Tintina fault. The pattern of seismicity in the region between these two fault systems show NE-SW lineations, which have been interpreted as edges of elongate crustal blocks, indicating a right-lateral shear. Since 1995 GPS measurements have been conducted in the interior of Alaska with the goal of trying to understand the present-day tectonics of the region.

Alaska-Aleution arc:
The Alaska-Aleution arc extends 3600 km from the Gulf of Alaska to Kamchatka Peninsula, Russia. It marks the convergent plate boundary between the North American Plate and the Pacific Plate and hosts over 80 major Quaternary volcanic centers. At least 40 of these have been active in historical time (since 1760). Geodetic measurements have been conducted on few of these volcanos.

STRESS FIELDS AND LOCKING OF SEISMIC ZONES: IMPLICATIONS FOR LARGE EARTHQUAKES

Ágúst Gudmundsson

Geological Institute, University of Bergen, Allegaten 41, N-5007 Bergen, Norway
agust.gudmundsson@geol.uib.no

The largest earthquakes of a seismic zone are generated when the greater part, or the whole, of that zone ruptures. Because a propagating fault rupture normally becomes arrested when it enters parts of a seismic zone where the stress conditions are unfavourable to that type of fault slip, a whole-zone rupture is likely to occur only when the state of stress in the entire zone favours fault slip of a particular type. This implies that the state of stress in a seismic zone must be essentially homogeneous for a whole-zone rupture to occur (Gudmundsson and Homberg, 1999). For example, large-scale dip-slip faulting is unlikely to occur in a seismic zone that is subject to a stress field favouring strike-slip faulting. And, in turn, a seismic zone where the long-term controlling stress field favours dextral strike slip is unlikely to produce large earthquakes related to sinistral strike slip.

As an example, we may consider the Húsavík-Flatey Fault. This is a strike-slip fault where the controlling long-term stress field favours dextral slip, the estimated cumulative displacement during the past 9 Ma being around 60 km. There was considerable seismicity associated with this fault until early 1976. Then, dyke injection (and normal faulting) in the northern part of the nearby Krafla Volcanic System which generated horizontal compressive stresses favouring sinistral movement lead to locking of the Húsavík-Flatey Fault and an abrupt diminution of its seismic activity (Gudmundsson, 2000).

Following a M5.5 earthquake in early 1994 (Rögnvaldsson et al., 1998) at its junction with Kolbeinsey Ridge, the Húsavík-Flatey Fault has been subject to renewed seismicity which has gradually increased and migrated to the southeast along the fault. This indicates that the Húsavík-Flatey Fault is currently being unlocked as a result of normal plate-pull movements that gradually relax the horizontal compressive stresses attributed to the dyke injection of 1976. When a large part, or the whole, of the Húsavík-Flatey Fault has become subject to an essentially homogeneous stress field favouring dextral fault slip, a large earthquake may be expected.

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