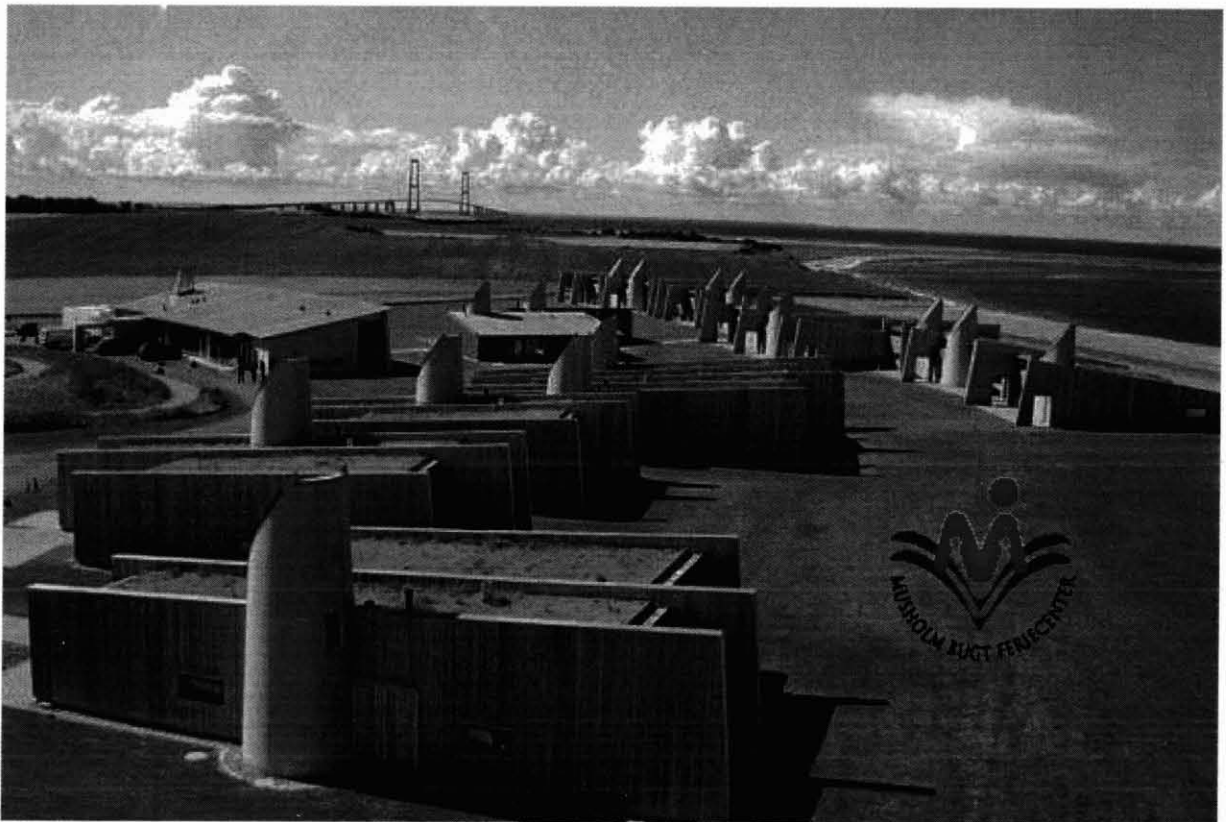


The 31st Nordic Seminar on Detection Seismology

Musholm Bugt Feriecenter
Korsør, Denmark
27-29 September 2000



The 31st Nordic Seminar on Detection Seismology

27-29 September 2000

PROGRAM

Wednesday, 27 September:

1130 Registration at Musholm

1200-1300 Lunch

1300 Opening

1315-1500 SESSION I: SEISMIC DETECTION AND
VERIFICATION, *Peter Voss*

CTBT Monitoring in Sweden, Current Developments

Nils-Olov Bergkvist

The present status of the new seismological network in
Sweden

Reynir Bodvarsson

Seismic station network in Finland

Pasi Lindblom

The CTBTO has certified IMS station PS27 - NOA - the
NORSAR Array

Jan Fyen

Reservoir microseismicity monitoring: active and passive
approaches

M. Roth, V. Oye and H. Bungum

A simple earthquake warning algorithm based on
micro-earthquakes on Iceland

Ragnar Slunga

The Danish Seismograph Network

Peter Voss

1500-1530 Coffee break

1530 Discussion on the future of the Nordic Seminars, *Anders Dahle*

1700 A walk on the beach

1800 Dinner

Thursday, 28 September:

0830 Breakfast

0915-1015 SESSION II: REGIONAL SEISMICITY AND SEISMIC HAZARD, *Rutger Wahlström*

Seismic hazard for Fennoscandia calculated from regionalization and non-regionalization models

Rutger Wahlström and Gottfried Grünthal

On the Method of Assessment of the Fennoscandian Shield Seismic Potential

B. A. Assinovskaya

Probabilistic Seismic Hazard Analysis: Zoning Free versus zoning methodology

C.D. Lindholm, S. Molina and H. Bungum

1015-1045 Coffee break

1045-1200 SESSION III: ANALYSIS OF SPECIAL EARTHQUAKE EVENTS, *Niels-Olov Bergkvist*

The 12 August 2000 Sunnhordaland earthquake

Erik Hicks, Conrad Lindholm and Anders Dahle

Full waveform modelling of the August 17, 1999, Kola Peninsula earthquake

M. Roth, H. Bungum and R.A.W. Haddon

Temporal stress variations before the Ölfus, November 1998, M=5.1 earthquake

Björn Lund

The Kodiak Island, Alaska, Mw 7 earthquake of December 6, 1999

Roger A. Hansen and Natalia A. Ratchkovski

1200-1300 Lunch

1300-1400 SESSION IV: SEISMIC MODELING, *Søren Gregersen*

2D and 3D travel times for the European Arctic:
observations, modelling and implications for event location
precisions

E. Møllegaard, J.E. Faleide, J. Schweitzer and H. Bungum

Seismic modelling at NORSAR

Anders Dahle

Seismic constraints on the magma chamber of the Hekla
volcano

Heidi Soosalu and Páll Einarsson

1400-1430 Coffee break

1430-1500 SESSION VI: GENERAL TOPICS, *Susanne Lund Jensen*

Digitization of paper seismograms

Dan Öberg

1500-1530 Open COASP meeting, *Erik Hjortenber*

1530-1630 Poster session

1700 Dinner

1800 Bus/Train trip to Odense and the house of H.C. Andersen

Friday, 29 September:

0800 Breakfast

0900-1000 SESSION V: SEISMOLOGY PROJECTS, *Roger Hansen*

GLATIS

Torben Bach

MASI-Project 1999; A Seismic Survey to Study Neotectonic
Phenomena in the Finnmark Area

C. Lindholm, J. Schweitzer, F. Krüger, F. Scherbaum, G.

Richter, J. Höhne, E. Hicks and H. Bungum

STATUS OF PROJECT TOR FALL 2000.

S. Gregersen, P. Voss and the Tor Working Group

1000-1030 Coffee break

1030-1130 SESSION VI: GENERAL TOPICS, *Pasi Lindblom*

Source parameters of seismic events in the close vicinity of
Hornsund Station, Spitsbergen

Marek Górski

An overview over eruptive and seismic activity in S-Iceland
in the first half year 2000 -An eruption and two magnitude
~6.5 earthquakes-

Steinunn Jakobsdóttir

Arctic seismology, 1957-2000

Erik Hjortenber

1130 Closing remarks

1130-1230 Lunch

Last updated 26/9/2000 by Peter Voss

CTBT Monitoring in Sweden, Current Developments

Nils-Olov Bergkvist, Defence Research Establishment (FOA), Sweden, nob@sto.foa.se

Abstract

FOA is currently operating the Swedish National Data Center (NDC) being set up to monitor compliance with the Comprehensive Test-Ban-Treaty (CTBT). After Entry-Into-Force of the treaty human analysts at an NDC will review the products from the International Data Center (IDC) leading to identification and then focus on ambiguous events. The large amount of information to be used by human analyst to identify events will be stored in data bases which would include different kind of reference information. One such database is now being built up at FOA including waveforms obtained at Hagfors from verified nuclear test explosions. For this purpose a method has been developed to digitize paper-seismograms. A list of all nuclear test explosions conducted since 1945 has also been compiled in cooperation with Stockholm Peace Research Institute (SIPRI). In addition to the Hagfors array FOA is also in charge of a seismic array in Västerbotten in the northern part of Sweden. Both arrays now need upgrading. In this presentation I will give examples of CTBT-related work at the Swedish NDC and I will also comment on the current status and future plans for the array stations.

The present status of the new seismological network in Sweden

Reynir Bodvarsson, Dept. of Earth Sciences, Uppsala University, Sweden, rb@geofys.uu.se

Abstract

Seismic station network in Finland

**Pasi Lindblom, Institute of Seismology, University of Helsinki, Finland,
pasi.lindblom@seismo.helsinki.fi**

Abstract

The CTBTO has certified IMS station PS27 - NOA - the NORSAR Array

Jan Fyen, NORSAR, POB 51, N-2027 Kjeller, Norway, jan@norsar.no

Abstract

The talk will present the process of certifying an IMS station. What is required and what did NORSAR do to fulfill these requirements.

Reservoir microseismicity monitoring: active and passive approaches

**M. Roth, V. Oye and H. Bungum, NOR SAR, POB 51, N-2027 Kjeller, Norway,
hilmar.bungum@norsar.no**

Abstract

Microseismic events in oil and gas reservoirs are induced by stimulation and production. During the production of a reservoir stress is redistributed and stress release on preexisting fault systems within the reservoir results in microearthquakes. Hence the analysis of high quality microseismic data potentially provides high resolution information on the internal structure of the reservoir and its temporal change. A common technique of reservoir stimulation is high pressure fluid injection and hydro fracturing. New flow paths are opened by actively cracking the rock along the fluid front. Associated microseismic events are indicative for the propagation of the fluid front.

At NOR SAR we are now developing analysis tools for microseismicity for reservoir monitoring and hydrofracturing taking advantage of well-established online event detection and processing techniques for earthquake data. Our first goal is the accurate and robust real time localization and visualization of the events. This basic information allows to map active regions within the reservoir, which can be correlated to production parameters. In the case of hydrofracturing, it gives an immediate feedback to the operator providing a means to control the experiment interactively.

Besides the kinematic interpretation of the microseismic data we also aim at an offline inversion of the waveforms for source function and moment tensor. These parameters are related to the geometry and the size of the seismic sources. In a first application we are processing a hydrofracturing data set recorded with a common three component VSP configuration, as well as data from passive reservoir monitoring. Initial results will be provided for both cases.

A simple earthquake warning algorithm based on microearthquakes

Ragnar Slunga, Dept. of Earth Sciences, Uppsala University, Sweden, ragnar@geofys.uu.se

Abstract

In SW Iceland we have analysed 130,000 microearthquakes during 1991 - 2000. Six $ML > 5$ earthquakes have occurred, the largest one on June 17 2000 with $M_s = 6.6$. I will discuss an Earthquake Warning Algorithm (EQWA) based on the number of microearthquakes per sqkm and time interval and on their dynamic source parameters. If the threshold is set to give warnings less than 24 hours but more than 1 hour before all of these 6 EQ and within a radius of 6 km the false alarm rate can be estimated. For the SIL area (the area of the two largest events) there will then be 2 correct alarms while the false alarms are about 20 during the nine year period. A false alarm is any exceedence of the threshold value without having a $ML > 5$ EQ within 24 hours and within 6 km.

The Danish Seismograph Network

Peter Voss, National Survey and Cadastre, Rentemestervej 8, DK-2400 Copenhagen NV, Denmark. pv@kms.dk. Tel. +45 35 87 50 50. Fax +45 35 87 50 52.

Abstract

A short presentation of the status and the latest improvements to the danish seismograph network.

Seismic hazard for Fennoscandia calculated from regionalization and non-regionalization models.

Rutger Wahlström and Gottfried Grünthal, GeoForschungsZentrum Potsdam, Div. 5, Telegrafenberg, D-14473 Potsdam, Germany, rutger@gfz-potdam.de

Abstract

A logic tree technique (a modified version of FRISK88M) is used to calculate probabilistic PGA based seismic hazard for Fennoscandia. The input parameters include two M_w sets, two attenuation functions and different seismicity models - regionalisation, quasi-regionalisation and non-regionalisation, each type which different sets of seismicity parameters. Two gross zones, land and sea, are specified. Five representative focal depths are assigned to each zone, and earthquake recurrence parameters and five representative maximum expected magnitudes, M_{max} , are assigned to each M_w set - gross zone combination. Three regionalisation models contain a total of 87 source regions specified by criteria of seismicity and structural geology. For this type of model, two sets of recurrence parameters are calculated for each region and M_w set: (1) based on the seismicity of the region and (2) the seismicity rate calculated from the applicable gross zone $\ln(\text{frequency})$ -magnitude slope. In the quasi-regionalisation models, the two M_w sets are combined with geographically uniform space windows (2° longitude by 1° latitude), each window with the seismicity rate derived from the gross zone recurrence slope. The first of two quasi-regionalisation models has the same threshold magnitudes as the regionalisation models, whereas the second model has the lowest threshold increased from $M_w=2.3$ to 3.3. In the final model, the seismicity is smeared out over the whole respective gross zone (non-regionalisation model). For this model, the higher threshold magnitude, $M_w=3.3$, is used. Merging all twelve combinations of seismicity models and M_w sets in one run, a seismic hazard map of the 90% probability of non-exceedence in 50 years is produced by interpolating values calculated over a grid of points spaced at 1° longitude by 0.5° latitude. For the sites with the highest median hazard in each of the four countries, the full mean and fractile hazards curves are derived. The corresponding 90% probability of non-exceedence in 50, 100, 500 and 1,000 years are: Norway 0.7, 1.0, 1.9 and 2.3 m/s^2 , Sweden 0.3, 0.4, 0.8 and 1.1 m/s^2 , and Finland and Denmark (similar) 0.2, 0.3, 0.7 and 1.0 m/s^2 .

On the Method of Assessment of the Fennoscandian Shield Seismic Potential

**B. A. Assinovskaya, Central Astronomical Observatory Russian Academy of Sciences
Geodynamical Laboratory, Saint-Petersburg, Pulkovskoye shosse 65, k. 1, 196140, Russia,
e-mail: bela@ba2248.spb.edu**

Abstract

The basis for the regionalization of any area for the further seismic hazard assessment is determination of its seismotectonic potential and revealing active faults inside the area. From this point of view the old and practically uncovered Fennoscandian Shield with the deep wells, bored in it, seems to be natural laboratory. In the scope of this work we have investigated the interrelation of seismicity with geological features and mechanical rock properties taking into an account Kola deep drilling data. It has been found that earthquake occurrence depends on the rock lithology, geological memory (age and evolution), structural features and sizes. The possibilities for revealing empirical relationship of above mentioned factors and magnitude M_{max} are investigated. Specifically, the relationship between rock brittleness, elastic modulus and lithological characteristics has been discovered. It was found that occurrence of large earthquakes is connected with granitoid batholites with high quartz contents wich have been associated with compression processes... The method was applied to the process of seismic hazard assessment of the north part of Kola Peninsula. Tectonically this region consists of 2 main terrains of Archean crust: partly Murman terrain and Central -Kola terrain that in their turn are divided on small blocks. Each block is characterized by specific deep structure, strength properties, and seismotectonic potential and maximum possible magnitude. So, the most volume density of potential energy has Teriberka block composed mostly by granite-charnokite zones of more 15 km depth, Tuloma block of similar geological structure where comparable strong historical earthquakes occurred in 1772 and 1873, the Ustojarvi fault with seismicity is to be connected with early Proterozoic granite intrusions. The most part of Central-Kola Terrain has Archean layered highly fractured granulite crust which according Kola drilling data is destroyed very much and is characterized by mafic contents with low strength and reduced efficient brittleness on the level of possible earthquakes. This feature prevents structures to conserve considerable tectonic stresses essential for the occurrence of strong earthquakes.

Probabilistic Seismic Hazard Analysis: Zoning Free versus zoning methodology.

C.D. Lindholm, S. Molina and H. Bungum, NORSAR, POB 51, N-2027 Kjeller, Norway, conrad@norsar.no

Abstract

A seismic hazard computation without definition of source zones, as proposed by Woo (1996), has been compared with the Cornell-McGuire method. The new method for computation of seismic hazard amalgamates statistical consistency with an empirical knowledge (earthquake catalogue), and also incorporates the structural fractal character of the earthquake distribution. Statistical kernel techniques are used to compute probability density functions for the size and location of future events, including uncertainties in magnitude and epicentral location. The kernel method has been explored in terms of parameterisation, particularly aimed to understand how tectonic knowledge of a region and expert judgement can be used in reasonable and statistically significant ways. The two computation methods were compared with synthetic data and with seismicity catalogues from Norway and Spain. When using real data it was found that the kernel method generally yields lower hazard results than the Cornell-McGuire approach. The differences increase when the earthquake catalogue approaches a characteristic earthquake behaviour rather than the Gutenberg-Richter behaviour. We conclude that the Kernel method is an important contribution in seismic hazard computation that should be applied in future hazard computations.

The 12 August 2000 Sunnhordaland earthquake

Erik Hicks, Conrad Lindholm and Anders Dahle, NORSAR, POB 51, N-2027 Kjeller, Norway, anders@norsar.no

Abstract

Sunnhordaland is one of few areas on the Norwegian mainland which often experiences earthquakes.

The earthquakes in this region are shallow, generally less than 15 km in depth and therefore normally felt by the population.

The 12 august 2000 earthquake was felt widely in South Norway, and felt-reports acquired by the University of Bergen indicate an intensity of V (MMI) in the epicentral area.

A striking similarity with a similar size event occurring at the same location in 1983 implies reactivation of the same seismogenic structure.

Full waveform modelling of the August 17, 1999, Kola Peninsula earthquake

M. Roth*, H. Bungum* and R.A.W. Haddon**

*** NORSAR, POB 51, N-2027 Kjeller, Norway, hilmar.bungum@norsar.no**

**** Formerly Geological Survey of Canada, Ottawa**

Abstract

The Revda event from August 17, 1999, is one of the strongest ($M_S=4.2$) observed earthquakes on the Kola Peninsula within the last few years. It occurred close to the Revda mining site near the city of Lovozero, coinciding with a collapse in the mine, and therefore the immediate speculation of an mining induced earthquake arose. The Revda earthquake was recorded with a temporary 13-station network (MASI-1999) in Finnmark, northern Norway, in cooperation with the University of Potsdam.

Based on high-quality three component broadband seismic data from this network we analyzed the event by full waveform modelling using a frequency-wavenumber method. We varied systematically the source depth, the size and orientation of the fault plane and the crustal velocity model and compared the resulting synthetic seismograms with the observed data, matching both Rg and Lg quite well. The spectra of the recorded data could be matched reasonably well with synthetics for a circular fault plane with 1.6 km radius, an effective stress drop of 45 bars and a seismic moment of 6.0×10^{22} dyn-cm. In this analysis we have used a constant $Q(Lg)$ of 1400 (consistent with similar results from eastern Canada) as derived independently from an ML 2.7 earthquake inside the Masi network.

The fault plane solution is mainly characterized by a reverse focal mechanism with strike 240, dip 60 and rake 70 degrees, consistent with first motion analyzes of independently observed data. In order to match the frequency content of the Rg phase a source depth of 5.5 km was required, making the possibility of the event being mining induced unlikely. An interesting feature was the pronounced dispersion of the observed data, which could only be explained by introducing a relatively strong shear-wave velocity gradient in the uppermost crust.

The results from this analysis have potentially important implications for the influence of Rg (i.e., path effects) on seismic source spectra, for source scaling laws and thereby also for seismic hazard in intraplate regions.

Temporal stress variations before the Ölfus, November 1998, M=5.1 earthquake

Björn Lund, Defence Research Establishment (FOA), bjolund@sto.foa.se, FOA

Abstract

The Kodiak Island, Alaska, Mw 7 earthquake of December 6, 1999

Roger A. Hansen and Natalia A. Ratchkovski, Geophysical Institute, University of Alaska Fairbanks, USA, roger@kiska.giseis.alaska.edu

Abstract

A Mw 7 earthquake occurred on December 6, 1999 at 2:12 pm AKST in the Kodiak Island region of Alaska. This event was felt strongly in the towns of Kodiak and Old Harbor as well as surrounding communities. It caused some minor damage including power and phone outages in Kodiak. Felt reports were received from as far as Fairbanks, 900 km away. The earthquake was located by the Alaska Earthquake Information Center (AEIC) at 57.51°N and 154.67°W at 45.8 km depth. Aftershocks of ML 5.4 and MW 6.4 followed the main shock by ten minutes and one hour, respectively. Aftershock activity decreased rapidly from about 25 events per hour in the first few hours after the main shock to 5 events a day 10 days later. It appears that the main shock triggered a swarm of earthquakes in the Katmai volcano field that subsided in a few hours (Power et al., 2000). Convergence of the Pacific and North American plates dominates the tectonic framework of the Kodiak region (Figure 1). The plate boundary lies along the Aleutian trench about 100 km seaward of Kodiak Island. A typical volcanic arc accompanying subduction is located on the Alaska Peninsula and the west coast of Cook Inlet. Most of the seismic energy in southern Alaska is released in major earthquakes that rupture the shallow part of the megathrust. The Great 1964 Prince William Sound earthquake (MW 9.2) ruptured a 800-km-long portion of the megathrust including the Kodiak Island segment (Christensen and Beck, 1994). In 1938, an MW 8.2 earthquake ruptured the segment of the boundary south of Kodiak Island. Recent GPS studies of the deformation processes near Kodiak showed that the down-dip width of the locked portion of the megathrust can be as much as 158 km (Savage et al., 1999).

A number of significant earthquakes occurred beneath the Kodiak Island region in the 1900's including seven earthquakes with magnitude 6.8 or larger (Figure 2 and Table 1). While the majority of these shocks are associated with the megathrust ruptures, two earthquakes of mb 7.3 and an mb 6.9, in 1912 occurred at a depth of 90 km within a 20 km radius of the 1999 Kodiak Island earthquake. Allowing for some uncertainty in their locations, it is safe to suggest that both earthquakes occurred within the subducting plate. Therefore, strong earthquakes in the Kodiak region are known to be originated inside the subducting plate, not only on the interplate contact. The 1999 MW 7 event and its aftershocks recorded by the regional seismic network were relocated using the *Joint Hypocenter Determination (JHD)* method. Regional broadband data has been used to calculate moment tensors for the main shock and its largest aftershock. This article will concentrate on discussing the aftershock distribution of the MW 7 event and its source mechanism.

The relocated hypocenter of the 1999 Kodiak Island MW 7 earthquake is positioned at 57.32°N and 154.29°W at 36.1 km depth (Figure 7). The majority of the relocated aftershocks are distributed between 27 and 85 km depth along a steeply dipping plane with a southwest to northeast orientation. The moment tensor inversion for the main shock results indicate a fault plane trending at 29° azimuth and dipping at 67°. The moment tensor inversion for the MW 6.4 aftershock shows a nearly pure dip-slip mechanism with the fault plane striking at 233° azimuth. The moment tensor solutions for the main shock and four of its aftershocks (Figure 7) are consistent with the stress regime in the slab beneath the Kodiak Island region which is characterized by along-arc compression and down-dip extension (Lu and Wyss, 1996). Therefore, the aftershock relocation and moment tensor inversion results indicate that the 1999 Kodiak Island MW 7 earthquake was located within the subducting Pacific plate down-dip of the locked portion of the megathrust (Savage et al., 1999). The fault plane is parallel to the strike

direction and cut across the plate through nearly its entire thickness (Figure 8). The 1999 Kodiak Island earthquake is the first well documented large intraplate event in the Alaska-Aleutian subduction zone. The strong intraplate subduction zone events, such as 1970 MS 7.8 Peru (Dewey and Spence, 1979), 1994 MW 8.3 Kurile (Katsumata et al., 1995) and 1999 MW 7.5 Oaxaca (Singh et al., 2000) earthquakes are less commonly observed than the megathrust ruptures. It appears that the stress changes caused by the MW7 earthquake triggered a MW 6.5 earthquake, which occurred seven months later north of the December earthquake aftershock zone (Figure 7). It has been observed that strong intraplate earthquakes in the subducted slabs display a temporal behavior (Lay et al., 1989). Prior to large thrust earthquakes the events in the down-dip subducted slab are tensional; following the rupture of the interface the down-dip events became either compressional or the tensional ones become less frequent. However, only tensional down-dip intraplate events were found in the Kodiak Island region (Lay et al., 1989) including the time period after the Great 1964 Prince William Sound earthquake. Tensional mechanism of the 1999 Kodiak Island earthquake and its location close to the down-dip end of the rupture zone of the 1964 earthquake (Christensen and Beck, 1994) is consistent with the slab-pull concentrating stress at the edge of a coupled interplate contact.

2D and 3D travel times for the European Arctic: observations, modelling and implications for event location precisions

E. Møllegård, J.E. Faleide, J. Schweitzer and H. Bungum NORSAR, POB 51, N-2027 Kjeller, Norway, hilmar.bungum@norsar.no

Abstract

The CTBT monitoring tasks have created a renewed interest for more precise estimation of local and regional travel times through a laterally varying lithosphere. As an initial effort to this end we have used some seismic reflection surveys west of Spitsbergen as a basis for comparisons with 2D and 3D (ray tracing and FD) modelling results for a 300 km long profile between the spreading ridge of the mid-atlantic ridge system and the SPITS array. While the match between observed and synthetic data are reasonably good for some parts of the profile, the study also shows that travel time errors of up to 2 seconds may occur if a standard 1D model is used and that for distances of around 100 km west of SPITS the highly heterogeneous crust needs more modelling work.

In another part of the study we have developed 1200 km long 2D crustal profiles between Novaya Zemlya and the SPITS and ARCES arrays, as well as between SPITS and ARCES, all with very strong lateral inhomogeneities. Depending on the distance, travel time errors of up to 2-3 seconds are found also here when comparing to the standard 1D model.

These results have important implications for location precisions and shows that 2D and 3D modelling of travel times for the European Arctic are both feasible and desirable, aiming at producing source-site specific corrections as used and needed by IMS/CTBTO. Within this context it will also be necessary to address upper mantle velocities, as a basis for Pn travel times. This modelling is based on reflection and refraction data observed during the last decades and is providing no explicit information about the corresponding S velocities in this region. Better knowledge of these velocities is also needed for a successful calibration of the European Arctic.

Seismic modelling at NORSAR.

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Abstract

Research in seismic modelling was taken up at NORSAR about 20 years ago, and today it comprise about 1/3 of NORSARs total activity. While the 10 first years may be characterized as a phase of *intense contract research for major clients in the petroleum industry*, a different policy has been followed over the last 10 years. In the past few years, we have seen an increasing interest in seismic modelling for survey planning, processing and interpretation of reflection seismic data, and the focus is more and more on the 3D versions of modelling applications. Research and development within seismic modelling are therefore currently very much centered around the software package NORSAR-3D and its applications.

Seismic constraints on the magma chamber of the Hekla volcano

Heidi Soosalu, Institute of Seismology, University of Helsinki and Páll Einarsson, Science Institute, University of Iceland, heidi@seismo.helsinki.fi

Abstract

The Hekla volcano is situated in a special plate tectonic location, at a junction of a transform-section of the mid-Atlantic ridge (South Iceland seismic zone) and a spreading section (Eastern volcanic zone). It erupts with irregular intervals up to 120 years. Since 1970 Hekla has been abnormally active, having small eruptions approximately once in a decade, last time in February-March 2000.

We estimate the location of the Hekla magma chamber with seismic means. Our data set consists of earthquakes observed at Hekla in 1991-2000 and seismic rays of local earthquakes passing the Hekla area. No clearly outstanding magma volume can be found, rather we are able to set constraints to possible locations of magma.

Hekla is practically aseismic during non-eruptive times. Between the 1991 and 2000 eruptions few smallish earthquakes occurred at Hekla, typically at depths of 8-14 km, following the trend of the South Iceland seismic zone activity. They had strange low-frequency outlooks but clear shear waves. Thus the events express brittle failure and existence of molten material is excluded at these spots. The strange appearance is likely due to weak, eruption-heated crust.

We have a data set of 534 seismic rays of earthquakes at Hekla or its vicinity that travel via Hekla and/or its fissure swarm. The Hekla volcano is scanned quite well at 8-16 km and partly at 4-8 km depth. Very few rays travel above 4 km and below 16 km. Northern flank of Hekla, under which the earthquakes at the onset of the 2000 eruption occurred, is not covered at 0-8 km, and a part of it not at 10-12 km. The rays are divided into three classes: normal, uncertain and abnormal according to the existence of shear waves in the seismograph records and appearance in general. Most rays passing Hekla and/or its fissure swarm (517 rays) look normal and do not point to anything unusual on the way. Only 13 rays were classified as uncertain and 4 rays as abnormal. These few rays have rather similar travel paths as the normal rays. Much of their appearance can have been originated at the neighbouring volcano Torfajökull, through which many of them also travel.

Seismic rays of earthquakes at Hekla and in the vicinity do not give much indication of molten material under Hekla, at least no major magma volume is seen in the areas which the seismic rays can scan. Also, the magma source cannot be a big bulge from the mantle but must have a bottom in the crust and be connected to deeper source just with smaller conduits.

Our seismic rays do not reach the upper parts of Hekla and with that data a shallow, i.e. at upper a couple of kilometres, magma chamber cannot be excluded. However, Hekla is lacking a geothermal area, a typical sign of a shallow magma chamber, also absence of volcanic earthquakes and very scarce seismicity in the non-eruptive periods do not speak for a shallow magma chamber.

The 2000 eruption started suddenly without long-term seismic warning, what is typical to Hekla. First related small earthquakes were observed less than 80 minutes before the onset. We did not observe any advancing front of earthquakes in ahead of an intrusion from the magma source. The very first, very small earthquakes occurred at shallow depth. After first fifteen minutes the seismicity jumped to the depth of about 5-9 km and earthquakes continued to occur at varying depths between 3-11 km, below the northern flank of the volcano. The hypocentral distribution of these events forms a sketchy pipe-like structure at 0-11 km.

Digitization of paper seismograms

Dan Öberg, Defence Research Establishment (FOA), dano@sto.foa.se

Abstract

From 1968 until now, numerous nuclear detonations have been registered by seismic stations, operated by FOA, Sweden. However, many of the events were recorded on paper, which makes accessing and analysing data cumbersome. Therefore, a project at FOA is to digitize these events, and save them as time series. The process involves scanning and image processing. The quality of the resulting time series are practically just limited by the paper quality and the accuracy of the scanning. I will talk about how we choose the scanner, and also generally about the image processing that I have implemented. During the summer of 2000 we successfully digitized 124 events.

GLATIS

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Abstract

Greenland Analysed Telesismically on the Ice Sheet. The GLATIS project is the largest teleseismical experiment ever performed on Greenland. The project is presented along with preliminary data results.

MASI-Project 1999; A Seismic Survey to Study Neotectonic Phenomena in the Finnmark Area

C. Lindholm, J. Schweitzer, F. Krüger, F. Scherbaum, G. Richter, J. Höhne, E. Hicks and H. Bungum, NOR SAR, POB 51, N-2027 Kjeller, Norway, conrad@norsar.no

Abstract

In the Fennoscandian region, one of the most spectacular phenomena is that of postglacial rebound, responsible for large earthquakes (possibly magnitude 7+) less than 10.000 years ago. Several fault lines of late glacial or Holocene age are observed on the Finnmarksvidda, northern Norway. The NNE-SSW striking 80 km long Stuoragurra fault near Masi appears as a well defined step in the otherwise smooth till covered relief. The maximum observed displacement is 9 meters. Two trenches have been excavated and indicate at least one major seismic event of magnitude 7.4-7.7 around 9.000 BP. Recent seismicity (including a magnitude 4 earthquake near Masi on 21 January 1996) matches the observed surface expression of the fault nearly perfect. Two groups from NOR SAR and the University of Potsdam initiated a temporary seismological field experiment: Thirteen 3-component seismic stations from the Potsdam working group were deployed on the Finnmarksvidda from May to October 1999. The network was complemented by the ARCESS array and 3 permanent stations. The station distribution allows to locate events within the network with unprecedented precision. The broadband characteristic of the instruments facilitates the application of receiver function analysis. The first results will be presented.

STATUS OF PROJECT TOR FALL 2000

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Abstract

Results are now coming from Project Tor, which is about Teleseismic Tomography across the Tornquist Zone in Germany-Denmark-Sweden. We are able to distinguish very significant deep lithosphere differences, and the sharpness laterally is discussed. Our 120 seismographs constituted in 1996-1997 the largest seismic antenna ever in Europe. The Tor area was chosen along a well studied crustal profile of an earlier project, and the inversion efforts are concentrated on the deep lithosphere and asthenosphere differences to depths around 300 km. The Tor investigation can be called two-and-a-half dimensional, being a 900 km profile with 100 km width plus a few seismographs off the profile. It includes several seismic methods besides travel time tomography, surface wave and receiver function analysis as well as anisotropy and scattering measurements. Through ray tracing in a compiled crustal model and subtraction of the modelled travel time anomalies, the influence of the lower lithosphere/asthenosphere on the seismic rays from distant earthquakes is established. Travel-time tomography results confirm very large lithosphere differences. For several events of the large data base it is shown that the observed travel time anomalies of 1-2 seconds can be divided almost equally between known crustal effects and lower lithosphere/asthenosphere differences, which then must account for about one second of travel time differences. The transition is interpreted to be sharp and steep in two places. It goes all way through the lithosphere at the northern rim of the Sorgenfrei-Tornquist Zone near the border between Sweden and Denmark, and here the lithosphere difference is large. A smaller lithosphere difference is found at the southern edge of the Ringkøbing-Fyn High just north of the border between Denmark and Germany. Here the transition is similarly sharp and steep, and all through the lithosphere. These two sharp transitions divide the Tor region into 3 different lithosphere structures distinguishable in P-wave travel time tomography, surface wave dispersion, S-wave anisotropy and partly in P-wave scattering.

Source parameters of seismic events in the close vicinity of Hornsund Station, Spitsbergen

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Abstract

In the direct vicinity of Hornsund Station, Spitsbergen, we observe weak seismic activity connected with tectonic structure of the area. Selected seismic tremors observed there in the period 1994-2000 have been analysed. Physical parameters of foci have been determined on the basis of spectral analysis. Scaling relations are presented.

An overview over eruptive and seismic activity in S-Iceland in the first half year 2000 -An eruption and two magnitude ~6.5 earthquakes-

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Abstract

On Februar 26th an eruption started in Hekla and lasted for about 2 weeks. Almost 4 months later, on June 17th, the first South Iceland Lowland earthquake since 1912 shook the SW corner of Iceland. In the period from June 17th to June 21st 9 earthquakes magnitude ~4 and bigger shook this area. The eruption in Hekla was predicted. This will be described and compared with the 1991 eruption in Hekla. The magnitude ~6.6 earthquake on June 17 occurred in that part of the S-Iceland Seismic Zone where it was expected, but no short time prediction was made. A warning was sent to the civil defence 24 hrs before the magnitude ~6.6 earthquake on June 21st. Some different signals can be seen before the June 17th earthquake, which are promising for future prediction possibilities. Both the prediction of the eruption and the warning of place and magnitude of the June 21st earthquake are based on registrations of very small earthquakes <2 in magnitude.

Arctic seismology, 1957-2000

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Abstract

The reason that I became a seismologist was the desire to continue the cooperation between Henry Jensen and me during the "International Geophysical Year (1957-1959)", when I was station operator for the seismic station at NOR (Nord). The station was installed with a Willmore (moving coil) short-period vertical instrument and a Strobach (mechano-optical) 6 second period seismograph from University of Hamburg for the N and E components. It showed, that the seismic noise was very small in North Greenland, and that the station was very efficient for detecting nuclear explosions and small seismic events. Henry Jensen was very interested in the microseisms with periods around 6 seconds, and the phase difference between the two seismographs was determined by Jørgen Hjelme to be 180 degrees at 6 seconds, so it was easy to analyse the particle motion of the noise by Jensen's method and get the distribution of directions of approach. The temporary station was later replaced by the WWSSN station NOR with Beniof short-period and Press-Ewing long period seismographs.

The seismic station SCO (Scoresbysund) was installed by Inge Lehmann in 1928, and the station was replaced by the WWSSN station KTG (Kap Tobin, near Scoresbysund) and later again moved back to Scoresbysund, the distance of the movement being 8 km. The WWSSN station GDH (Godhavn) was installed in the early sixties, but it is now replaced by the GSN station SFJ (Søndre Strømfjord, STS-1 + Quanterra). The WWSSN instruments at Nord (NOR) were moved to DAG (Danmarkshavn), which is today the only Danish WWSSN station still using the old technology, but a digital GEOFON (STS-2 + Quanterra) station was started 1998 to work in parallel. Unfortunately such a surface vault is very noisy at very long periods, as shown by W. Hanka (<http://www.gfz-potsdam.de/geofon/manual/>). NRS (Narsarsuaq) was installed summer 2000, and regains the coverage of south Greenland, that was lost after the 1927-1960 operation of IVI (Ivigtut).

In 1966 - 1967 a temporary array station was operating on the Greenland Ice Cap, it was called Inge Lehmann station, and some hoped that it would develop into a NORSAR (LASA) type station, but that did not happen.

In 1991 three temporary stations with GS-13 seismometers and REFTEK recorders were installed in Northeast Greenland at NOR, DBG (Daneborg) and SCO. The results (BSSA, v. 83, pp 1939-1958, 1993) show that DBG, even though it is much nearer to SCO than to NOR, still has similar noise directions of approach as NOR, and hence can be expected to have the same good signal to noise ratio as NOR and DAG. Another result is that the old findings of Inge Lehmann and Henry Jensen are confirmed. It was hoped that the temporary stations could be changed to permanent stations, but that did not happen.

The new temporary Greenland network used by project GLATIS (<http://research.kms.dk/~glatis/>) is describe elsewhere at this meeting. The DBG station is now reoccupied.

The activities in other Arctic areas than Greenland have been considered by COASP (Cooperative Arctic Seismological Project). The COASP goal is a joint effort to determine Arctic earthquakes, in particular those of the Arctic Ocean. Another goal, that could be considered is the determination of microseismic storm events, using not only the seismic networks, but also the infrasound data collected at the CTBTO IDC. The microbarographs used for infrasound recording detects microbaroms originating from the same interfering ocean waves (Longuet-Higgins, 1950) as the microseismic storms.

Another new possibility for a COASP project could be an investigation of multifractality of Arctic earthquakes, the paper, Geilikman, M. B., Golubeva, T. V. and Pisarenko, V. F., Multifractal

patterns of seismicity, *Earth and Planetary Science Letters*, 99, 127-132, 1990 explains the *multifractal formulation* and describes the multifractality derived from earthquake catalogs of Pamir, Caucasus and California. This should be tested in other areas such as the Arctic.

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