Institute of Seismology, Dept. of Geosciences and Geography, Univ. of Helsinki, Finland
Geological Survey of Estonia
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The 43rd Nordic Seismology Seminar

October 24-26, 2012

Nordic Hotel Forum
Tallinn, Estonia

Programme
Abstracts
List of participants

Eesti Geoloogiakeskus
Geological Survey of Estonia

UNIVERSITY OF HELSINKI
FACULTY OF SCIENCE

DEPARTMENT OF MINING
TALLINN UNIVERSITY OF TECHNOLOGY

The 43rd Nordic Seismology Seminar

Programme

Wednesday 24th October 2012

12:00-13:00 **Registration**

13:00-13:10 **Opening address**

Pekka Heikkinen and Heidi Soosalu

13:10 **Session I**

Chairman: Pekka Heikkinen

13:10-13:40 CTBT verification, current status and future prospects
J. Carter

13:40-14:00 NordQuake - prospects and results
P.H. Voss

14:00-14:20 Developments at the ISC: new Locator, GT, Bulletin Re-Build and the CTBTO-Link
D. Storchak, I. Bondár, J. Harris and D. Di Giacomo

14:20-14:50 ***coffee break***

14:50 **Session I continued**

14:50-15:10 The Arkhangelsk seismic network
G. Antonovskaya and Y. Konechnaya

15:10-15:30 Recent developments and results of local seismicity studies in Lithuania and adjacent areas
I. Janutyte

15:30-15:50 Swedish National Seismic Network (SNSN) - present status and ongoing developments
R. Bödvarsson, H. Shomali and B. Lund

15:50-16:10 The Seismic Station TROLL, Antarctica
M. Roth, J. Schweitzer and M. Pirli

16:10-16:30 The first results of the seismic station "Franz Josef Land"
Y. Konechnaya and G. Antonovskaya

16:30-17:00 **Poster session**

Chairman: Ragnar Slunga

Use of seismic reflection profiling for 3D-modeling of mineralized regions: A case study from Pyhäsalmi, Finland
S. Heinonen, D. Snyder, P. Heikkinen and I. Kukkonen

Seismic LAB beneath the Baltic Shield – or rigid lithosphere?
M. Grad, T. Tiira, S. Olsson and K. Komminaho

Historical seismicity in the Gulf of Bothnia area: issues of completeness
P. Mäntyniemi

Experience in the peak ground velocities evaluation by the paleoseismic local rock disturbances (east part of the Fennoscandinavian shield as example)
A.A. Nikonov, M.V. Rodkin and S.V. Shvarev

Earthquakes and seismotectonics of the Gulf of Finland area: contemporary examination
A.A. Nikonov

Mine blasts - multidiciplinary approach with seismology and mining engineering
M. Ring, M. Noška, H. Soosalu, R. Iskül and I. Valgma

Earthquakes in Greenland: Achievements during the last 43 year
H.P. Rasmussen and P.H. Voss

Shallow swarm-type earthquakes in south-eastern Finland
I. Smedberg, M. Uski, T. Tiira, A. Korja and K. Komminaho

Seismic monitoring in Estonia
H. Soosalu

18:30-20:30 **Reception at the Finnish Embassy in Tallinn**

Thursday 25th October

9:00 **Session II**

Chairman: Gunnar B. Guðmundsson

9:00-9:20 ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009)
D. Di Giacomo, I. Bondár, E.R. Engdahl, D. Storchak, W. H. Lee, A. Villaseñor, J. Harris and P. Bormann

9:20-9:40 The SHARE project; Harmonization of Seismic Hazard Assessment for the European region
C. Lindholm. H. Bungum and L.W. Bjerrum

9:40-10:00 Magnitudes and felt areas for earthquakes in Fennoscandia and Baltikum
S. Gregersen, E. S. Husebye and and P. Mäntyniemi

10:00-10:20 Use of in situ stress estimates for earthquake warning - some examples.
R. Slunga

10:20-10:40 coffee break

10:40 Session III

Chairman: Jan Fyen

10:40-11:00 Stress field reconstruction from incomplete discrete data on stress measurements
A.N.Galybin, Sh.A.Mukhamediev, J.Irsa, P.Haderka

11:00-11:20 Focal depth estimation using Pn coda phases - like pP, sP and PmP
E.S. Husebye, Y.V. Fedorenko and T. Matveeva

11:20-11:40 Data Processing of Large Earthquake Aftershock Sequences
T. Kværna, S.J. Gibbons, D.B. Harris and D.A. Dodge

11:40-12:00 On seismic zonation of the Eastern Baltic region
B. Assinovskaya and M. Ovsov

12:00-13:00 Lunch break

13:00 Session III continued

13:00-13:20 An artificial seismicity in the East Baltic region
V. Nikulins

13:20-13:40 The 30. August, 2012 M6.6 Jan Mayen earthquake
M. B. Sørensen, L. Ottemöller, M. Raeesi and B.M. Storheim

13:40-14:00 Postglacial paleoseismic deformations of the southeastern Fennoscandia and Estonia
Y.J. Systra

14:00-17:00 Workshops

Virtual network – Chairman: Peter Voss

Identification of explosions and local earthquakes – Chairman: Tormod Kværna

Macroseismology – Chairman: Päivi Mäntyniemi

17:30-19:30 Walking excursion in the historical Old Town or **Soviet KGB museum**

19:30 Dinner, hosted by the Institute of Seismology

Friday 26th October

9:00 **Session IV**

Chairman: Domenico Di Giacomo

9:00-9:20 Experiences from studying microseismicity from drifting sea ice at the Gakkel Ridge
G. Hope, Y., Kristoffersen, L. Ottemöller and H. Keers

9:20-9:40 Seismological studies related to the potential site of spent nuclear fuel in Finland
J. Saari

9:40-10:00 Seismicity at Húsmúli, Iceland, due to water discharge from a geothermal power plant
G.B. Gudmundsson and S.S. Jakobsdóttir

10:00-10:20 Seismicity and stressed state of the Starobin potassium salt deposit in Belarus
A.G.Aronov, Sh.A.Mukhamediev, A.N.Galybin, T.I.Aronova and R.R.Seroglazov

10:20-10:40 Mine blasts in Estonia – a multidiciplinary study using seismology and mining engineering
M. Ring, M. Noška, H. Soosalu, R. Iskül and I. Valgma

10:40-11:00 ***coffee break***

11:00 **Session V**

Chairman: Heidi Soosalu

11:00-11:20 Two aircraft accidents, two different interpretations
M. Tarvainen, O. Valtonen, E.S. Husebye and B. Lund

11:20-11:40 The Norwegian fjords sang along – observations of seiches following the 2011 Tohoku, Japan, earthquake
M.B. Sørensen, S. Bondevik and B. Gjevik

11:40-12:00 Structure of the upper mantle in the northern Fennoscandia revealed by joint inversion of P-and S-receiver functions
E. Kozlovskaya, L. Vinnik, G. Kosarev, S. Oreshin and POLENET/LAPNET Working Group

12:00-12:20 Short communications

12:20-12:30 Closing Remarks

Abstracts

The Arkhangelsk seismic network

G. Antonovskaya and Y. Konechnaya

Institute of Ecological Problems of the North UB RAS

Seismological service in the Arkhangelsk region started in 2003 when the first seismic station ARH was installed in the city of Arkhangelsk. Now ASN consists of 11 seismic stations, three of which are part of the Geophysical Survey of Russian Academy of Sciences. Arkhangelsk region has a unique geographical position which can cover vast areas of the Arctic and Subarctic, which are almost inaccessible to the seismic observations from other areas. Data Center in Arkhangelsk collects, process, stores data of the network. We created waveforms database in the Center and pick up the information from quarries about their blasts and put it to our database additionally.

Our network is carrying out a seismic monitoring within the Western Arctic sector and its surrounding areas. In addition to the previously installed on the Arkhangelsk region the broadband stations "Klimovskaya» (KLM), 2004 and "Leshukonskoye" (LSH), 2006. A significant contribution to the study of seismicity of Arctic was putting into operation two seismic stations "Amderma" (AMD), 2010 and the "Franz Josef Land" (ZFI), 2011. Data from these stations allow obtaining new information on the seismic and geodynamic processes in Arctic.

Most of the regional seismic events, which record by ASN, are the earthquakes near Svalbard and the ridges of the Arctic Ocean. The seismic activity of the East European platform is very weak but we recorded Kaliningrad earthquake of September 21, 2004 (M= 4.5). Among the local natural events we note the earthquake in 2005 near the city of Arkhangelsk with M = 2.6 (K = 8.3) and a strong seismic event (M = 4.2) at Novaya Zemlya (2010). Usually, the local and regional events, which are recorded Arkhangelsk network, are technogenic events. Most tehnogenic events are quarry blasts of Arkhangelsk and Vologda regions, Kola Peninsula, Karelia and Komi Republic.

Monitoring results are used for solving different practical and scientific research tasks. We have developed regional velocity models to improve the location of small seismic events for the territory of Arkhangelsk region. Also we used our recordings to control missile launches from the cosmodrome "Plesetsk" for which infrasound signals have previously been reported. We try to locate places where the rocket parts fall.

Registration of blasts has allowed us to build a local hodograph. Travel-time curves for regional Pn, Pg, Sn and Lg waves were created and compared with the ones used in routine earthquake processing practice. The obtained results allow improving the accuracy of the epicenters of seismic events in Arctic and Subarctic.

Seismicity and stressed state of the Starobin potassium salt deposit in Belarus

A.G.Aronov[1], Sh.A.Mukhamediev[2], A.N.Galybin[2], T.I.Aronova[1] and R.R.Seroglazov[1]

[1]Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[2]Shmidt Institute of Physics of the Earth of the Russian Academy of Sciences, Moscow, Russia

This paper presents the results of investigations carried out in the south-western part of the East European Platform with a special focus on the Soligorsk region, where the Starobin deposit of potassium salts of the Late-Devonian age is located. The mentioned region is of particular interest to scientists because it is in this deposit area a swarm of crustal earthquake foci is concentrated, which is in marked contrast to other seismic events that are few and far between and rather evenly distributed over the other territory of Belarus.

Instrumental record of local seismicity in the Starobin deposit region against a total absence of seismic events for several last decades over the most part of Belarus suggests the recent activation of faults in the Soligorsk region. Part of seismic stations has been installed in mining workings at depths ranging from 400 to 800 meters. Since 1983 the whole seismic network recorded more than 1,200 seismic events of the energy classes K=4.0-9.5 (magnitude M=0–3), five of them being sizeable.

The recorded earthquakes considerably correlate in space and time with the region structural plan which evidently suggests that most faults are seismically active. The epicenters of seismic shocks are mostly concentrated along faults of various directions, i.e. minor earthquakes generally trace the faults. The space-time migration of seismic activation is revealed by correlating seismicity maps compiled from data obtained for different time intervals. In this manner the impression can be gained about evolution of the seismotectonic process.

It should be noted that extraction of salts means excavation of subsurface quarries and subsequent distribution of the produced rock with inevitable pressure increasing on floor area. Of course, this technology leads to changes in the local stress state and, subsequently, to increase in seismic activity. But is this the reason to argue that the recorded earthquakes have purely technogenic nature? To answer this question we have investigated some peculiarities of seismic process outside the floor area. The results showed that some seismic manifestations recorded outside the working zone of the Soligorsk mining region evidently indicate that for some time the seismic process is mainly governed by regional geodynamic factors and to a lesser extent depends on mining works. This suggestion may be supported by at least three facts:

i) restriction of the bulk of epicenters within the fault zone junction areas, which are well seen in the map of epicenters distribution;

ii) almost a total absence of a relationship between the underground mining intensity (i.e., the rates of the rock extraction) and seismicity;

iii) absolute majority of seismic events take place outside mining areas.

The latter argument reflects a typical feature of induced seismicity, when the epicentral area migrates over the zone as a result of the seismic process evolution.

The stressed state for the studied region has been reconstructed by using:

i) seismotectonic method of inversion of earthquakes fault-slip data;

ii) tectonophysical method, based on the analysis of geometry of Mesozoic-Cenozoic sedimentary rock fracturing.

So, changes of the environment stressed state as a result of rock extraction and redistribution served as a mechanism triggering a swarm of earthquakes at boundaries of rather large tectonic blocks in deep fault zones located within the deposit region.

On seismic zonation of the Eastern Baltic region

B. Assinovskaya and M. Ovsov

Geophysical Service RAS, seismic station Pulkovo, Saint-Petersburg, Russia

Currently, GSHAP maps are improving with the project SHARE. The general seismic source zone which extends along the coastline of the Gulf of Gdansk to the north of Estonia was marked as part of this work by expert judgment based on seismological data only. It was assumed that level of seismic hazard is the same within the domain. Nevertheless, the analysis shows that the seismic occurrences are structured in space at least. This discontinuity is due to the specific geological and geophysical features of the crust. We attempted to study these relationships.

The maps and arrays of information for magnetometry, gravimetry, bathymetry and topography, heat flow and geodynamics (Korhonen J.V, Aaro S., Elo S., Haller L.A, et al ., 2002, Korhonen J.V, Aaro S., All T., Nevanlinna H., et al., 2002, Majorowicz J., Wybraniec S., 2009, Balling N., 1995, the heat flow map of the European USSR, 1987, Lidberg M., Johansson J. M., Scherneck H-G., Milned G. A., 2010, http://www.io-warnemuende.de/topography-of-the-baltic-sea.html) were used as input data that were translated into a digital form. The digital models of geophysical features covered the area within the trapezium from 15°E up to 30° E and from 54°N to 60° N were created. The seismic data from the FENCAT database, as well as the published reports of historical earthquakes of Aronova et al, 2008 and Nikonov, 2009 were applied for analysis.

Data processing was based on computer methods of structural analysis that use the idea that all nature data including geological and geophysical information form specific hierarchical system. The technology processing can reveal data internal structure. Structural analysis method is implemented as 3 universal software's [Ovsov, 2000, 2001, 2004]. The study includes some steps of pre-processing and data integration. First, the separation of the individual data on the components with approximately equal in order of spatial variability is realized. Second, the building of the complex data structures is carried out. Third, the modeling of depth distribution of effective geophysical parameters is conducted. As a result, the structure of plane and depth parameters is revealed.

Maps of averaged characteristics and their standard deviations were compiled to show monolithic weakly deformed structures as well as small-block area of significant fragmentation. The blocks prolonged offshore are identified. The rock lithology can be established using some data totally. The maps of standard deviations help to reveal active fracture zones.

The total maps of classes, domains and zones were constructed finally. 15 relatively homogeneous large blocks such as Estonian, Finnish, Swedish, Riga, Pskov-Paldissky, Southern Baltic and others with dimensions of 100-200 km in diameter were identified on the map. Each block was characterized by own internal structure and heterogeneity. The block size is related to its depth. The large blocks of varying tectonic activity and interblock suture zone are notable for characteristics of variation of features. The latter can be regarded as potentially active faults especially in comparison with seismicity. The Kaliningrad, Gotland - Baltic – Latvian and Estonian zones can be marked as earthquake sources.

6 deep sections through the study area were built also with the use of structural analysis. It was noticed an important detail that all potentially seismogenic areas are connected with the massive, deep, sometimes penetrating the entire crust, high-density clusters and with disjunctive borders between neighboring structures.

The zoning of the Eastern Baltic region in terms of the proposed earthquake sources carried out using various geophysical data and the structural analysis method. The active linear and areal structures are marked on plans and in the sections in order to calculate the magnitude of the maximum possible earthquake in the future.

Swedish National Seismic Network (SNSN) – present status and ongoing developments

R. Bödvarsson, H. Shomali and B. Lund

Department of Earth Sciences, Uppsala University

The Swedish National Seismic Network (SNSN) now consist of 66 broad-band high-gain seismological stations. All stations are transmitting waveform data to Uppsala in real-time. Data from ten stations are now transmitted via Internet to Orfeus and we have bilateral data exchange with Denmark, Finland and Norway. Until now, the network has mainly been used to locate local earthquakes and evaluation of their source parameters using the SIL software. We now also use Seiscomp3 to locate and estimate magnitudes of local,regional and global earthquakes. In this talk we will give an overview of the present status of the network.

CTBT verification, current status and future prospects

J. Carter

CTBTO

ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009)

D. Di Giacomo[1], I. Bondár[1], E.R. Engdahl[2], D. Storchak[1], W. H. Lee[3], A. Villaseñor[4], J. Harris[1] and P. Bormann[5]

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We present the final results of a two-year project sponsored by the GEM (Global Earthquake Model) Foundation. The ISC-GEM global catalogue consists of some 19 thousand instrumentally recorded, moderate to large earthquakes, spanning 110 years of seismicity. We relocated all events and recalculated the body and surface wave magnitudes for each event in the catalogue following the IASPEI recommendations.

The relocations is done using a two-tier approach: the EHB location methodology (Engdahl et al., 1998) was applied first to obtain improved hypocentres with special focus on the depth determination; then the locations were further refined by fixing the depths to those from the EHB analysis and applying the new ISC location algorithm (Bondár and Storchak, 2011) that reduces location bias by accounting for correlated travel-time prediction error structure. To facilitate the relocation effort, some 900,000 seismic P and S wave arrival-time data were added to the ISC database for the period between 1904 and 1963, either from original station bulletins in the ISC archive or by digitizing the scanned images of the ISS bulletin (Villaseñor and Engdahl, 2005; 2007). Although no substantial amount of new phase data were acquired for the modern period (1964-2009), the number of phases used in the location has still increased by 3 million, owing to fact that both the EHB and ISC locators use all *ak135* (Kennett et al., 1995) phases in the location.

With regard to magnitude, some 300,000 amplitude observations were manually entered into the ISC database from a selection of original station bulletins for the period between 1904 and 1970. The unprecedented amount of body and surface wave event magnitudes, obtained by using uniform procedures, allowed us to derive new, nonlinear regression relations between GCMT (Dziewonski et al., 1981; Ekström et al., 2012) Mw and Ms, as well as mb. The regression relations were validated against a set not used in performing the regression. For events that do not have direct Mw estimates, we used the regression relations to obtain an approximate Mw estimate. Thus, each earthquake in the ISC-GEM catalogue is characterized by either a direct (64%) or an indirect (36%) estimate of Mw. The ISC-GEM catalogue is globally complete to the lowest magnitude allowed by the availability of instrumental data, as well as the available resources for the project. The magnitude threshold is M=7.5 for earthquakes occurring before 1918; M=6.25 between 1918 and 1963; and M=5.5 from 1964 onwards.

The ISC-GEM Global Instrumental Earthquake Catalogue represents the final product of one of the ten global components in the GEM program, and will be made available to researchers at the ISC (www.isc.ac.uk) website.

Stress field reconstruction from incomplete discrete data on stress measurements

A.N.Galybin[1], Sh.A.Mukhamediev[1], J.Irsa[2] and P.Haderka[3]

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This paper presents an overview of the stress reconstruction methods recently developed by the authors. The methods deal with both elastic and plastic models of the lithosphere and use discrete data on the orientations of principal stresses as input. The latter allows one to avoid consideration of inverse problems and, hence, treat the problem as the direct one. Despite this advantage, due to limited and incomplete input data, the stress reconstruction problems are still challenging ones mainly because they do not possess unique solutions, therefore, the standard numerical methods cannot be applied directly and require serious modifications.

Data. Although data on stress magnitudes can, in principle, be acquired from in-situ stress measurements (such as overcoring or hydro-fracturing), it is recognised that such information is not reliable (for different reasons, e.g. due to the scale effect) and related to shallow depth only. Therefore, we rely on the principal stresses orientations data available from the WSM open-access database. Most of these orientations are obtained from seismic data based on the analysis on earthquakes focal mechanisms. The data are highly inhomogeneous and therefore no standard methods of interpolation can be applied to build up the continuous stress field of stress trajectories.

Elasticity. For elastic models of the lithosphere we have developed two essentially different approaches for the stress field reconstruction. The first approach is based on solving a non-classical boundary value problem of elasticity where the boundary conditions are formulated in terms of principal directions. As the result of incomplete formulation the solution is non-unique but depends on a finite number of free parameters. The second approach is developed for the case when the data are given not on the boundary but inside the region as well. In this case the problem is reduced to an optimisation problem of a certain functional that provides the best fit of the predicted and given data. The solution of the problem assumes application of the Trefftz type method for the complex potentials. In the first variant, the complex potentials are approximated over the whole region as linear combinations of the holomorphic functions with unknown coefficients. In the second variant the region is subdivided into finite elements, thus, the solution is sought as a piecewise holomorphic functions with unknown coefficients within every element. In both these variants the coefficients are found after optimisation.

Plasticity. The approach for plastic regions is developed for the classical limiting equilibrium models such as Tresca, Mohr-Coulomb and some other but for the boundary data posed in terms of principal directions. We use the finite difference method to build the network of stress trajectories (ST), which is different from the conventional method that works with the slip lines (SL). As an advantage, the reconstruction can be performed outside the domain of dependence, which is impossible in the SL method. Furthermore, the alternation of the SL and ST methods allows one to expand considerably the domain where the plastic stress field reconstruction is performed.

Applications. The methods above have been applied for studying the stress fields in different regions of the earth's crust with the particular interest for identification of tsunamigenic regions. It is important that the stress trajectories field is reconstructed uniquely in both elastic and plastic cases, while the full stress tensor contains a few free parameters. The latter can, in principle, be found by employing in-situ stress measurements.

This work is partly supported by the RFBR (Grant 11-05-00970).

Seismic LAB beneath the Baltic Shield – or rigid Lithosphere?

M. Grad[1], T. Tiira[2], S. Olsson[3] and K. Komminaho[2]

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The problem of the asthenosphere for old Precambrian cratons, including East European Craton and its part – the Baltic Shield, is still discussed. To study the seismic lithosphere-asthenosphere boundary (LAB) beneath the Baltic Shield we used records of 9 local events with magnitudes in the range 2.7-5.9. The relatively big number of seismic stations in the Baltic Shield with a station spacing of 30-100 km permits for relatively dense recordings, and is sufficient in lithospheric scale.

For modeling of the lower lithosphere and asthenosphere, the original data were corrected for topography and the Moho depth for each event and each station location, using a reference model with a 46 km thick crust. Observed P and S arrivals are significantly earlier than those predicted by the *iasp91* model, which clearly indicates that lithospheric P and S velocities beneath the Baltic Shield are higher than in the global *iasp91* model. For two northern events at Spitsbergen and Novaya Zemlya we observe a low velocity layer, 60-70 km thick asthenosphere, and the LAB beneath Barents Sea was found at depth of about 200 km.

Sections for other events show continuous first arrivals of P waves with no evidence for "shadow zone" in the whole range of registration, which could be interpreted as absence of asthenosphere beneath the central part of the Baltic Shield, or that LAB in this area occurs deeper (>200 km). The relatively thin low velocity layer found beneath southern Sweden, 15 km below the Moho, could be interpreted as small scale lithospheric inhomogeneities, rather than asthenosphere.

Differentiation of the lid velocity beneath the Baltic Shield could be interpreted as regional inhomogeneity. It could also be interpreted as anisotropy of the Baltic Shield lithosphere, with fast velocity close to the east-west direction, and slow velocity close to the south-north direction.

Magnitudes and felt areas for earthquakes in Fennoscandia and Baltikum

S. Gregersen[1], E. S. Husebye[2] and and P. Mäntyniemi[3]

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Magnitudes of historical, pre-instrumental earthquakes are estimated from observed intensities and felt areas. As a basis for this we have calibrated the macro-magnitude scale using more recent earthquakes for which relaible ML-estimates are available. Generally, it is claimed that shields like the Fennoscandian have exceptional effective wave propagation so earthquakes are felt over correspondingly large areas. This hypothesis was confirmed from analysis of small and large earthquakes in Scandinavia proper and in the Kaliningrad area of the East European Platform. The correlations between digital record magnitudes and felt areas for various intensities is described well through a log-linear model. Since most earthquakes in this region are of moderate sizes intensity relations were established for macro-levels 3 and 4. The outcome as expected was that macroseismic felt areas are larger than those for non-shield areas like the west coast of Norway and Denmark. Reported earthquake magnitudes in the past are likely to be positive biased, unless they are properly corrected for this propagation effect.

We have extended our analysis to relatively large earthquakes of ML-magnitudes 5.0 and above. An instructive data set here stems from the recent, large Kaliningrad earthquakes of SEP 2004 (Gregersen et al., 2007 Tectonophysics). Their magnitudes are a little above 5. Felt area of the largest earthquake is slightly less than the 1904 Oslofjord earthquake for which the most recent magnitude estimate by Bungum et al. (2009 BSSA) is 5.4. This kind of research may have an important bearing on seismic hazard analyses as the larger magnitude earthquakes contribute the most to estimated risk levels.

Seismicity at Húsmúli, Iceland, due to water discharge from a geothermal power plant

G.B. Gudmundsson and S.S. Jakobsdóttir

Icelandic Meteorological Office, Reykjavík, Iceland

The Húsmúli area is located near the Hengill volcanic system in SW-Iceland about 20 km southeast of Reykjavík. The area is west of the main production wells of the Hellisheidi geothermal power plant. The power plant started production in 2006 and the operation license requires that the disposal water must be injected back into the geothermal system. Until last year all disposal water was reinjected in the Gráuhnúkar area south of the power plant. During that time a few microearthquakes were recorded, the largest one reaching magnitude 2. The Gráuhnúkar reinjection zone turned out to have high temperature reservoirs and was therefore much more promising for production. So a new reinjection zone was developed in the Húsmúli area to the west of the power plant.

The first reinjection well in the Húsmúli area was drilled in February 2008 and five more injection wells were drilled in the area. During the pumping tests in some of these wells, microseismicity was detected on north-south trending faults nearby. In September 2011 the new water disposal wells in the Húsmúli area were taken into use. Immediately following the start of the injection the SIL seismic network detected microearthquakes in the area and during the first month almost 1500 earthquakes were recorded. Only a few of them reached magnitude 2 and the largest one was of magnitude 3. Several of them were felt in a nearby town. Most of the earthquakes were found to occur on two parallel north-south trending faults striking N10°-15°E, the westernmost dipping westward ~70° and the other almost vertical. On 15 October 2011 two widely felt magnitude 4 earthquakes occurred, following a disturbance in the power production and the water injection into the wells. These earthquakes elongated the westernmost fault to the north and some seismic activity was observed on faults further to the west. Since then at least 4-5 faults seem to be active.

No earthquakes have reached magnitude 3 since mid-October 2011. The seismic activity has decreased but microearthquakes still occur in the area. Shortly after the magnitude 4 earthquakes, Orkuveita Reykjavíkur, the owner of the geothermal power plant, formed a group of specialists to better understand the induced seismicity and suggest how to monitor it and to reduce the risk of a repeated occurrence of magnitude ~4 earthquakes.

Use of seismic reflection profiling for 3D-modeling of mineralized regions: A case study from Pyhäsalmi, Finland

S. Heinonen[1], D. Snyder[2], P. Heikkinen[1] and I. Kukkonen[3]

[1]University of Helsinki, Finland
[2]Geological Survey of Canada, Ottawa
[3]Geological Survey of Finland, Espoo

Structures of the upper crust can be best understood by using 3D visualization and modeling techniques. Often most of the geological data available for such studies are from the surface and geophysical methods are needed in order to create a subsurface geological model. The seismic reflection profiling, or 3D-seismic studies, provide an important tool for geophysical-geological modeling. We present the results of the on-going 3D-modeling from Pyhäsalmi, Finland.

The Pyhäsalmi volcanic hosted massive sulfide (VHMS) deposit (>50 Mt) is located in a Proterozoic volcanic belt in central Finland. Currently mine is ~1.5km deep. The existing infrastructure with depth enables the economic exploitation of new deep ore reserves giving motivation for the geological modeling. In this study, six seismic profiles acquired in the area during project HIRE (High Resolution Reflection Seismics for Ore Exploration, 2007-2010) are used to develop and constrain the geological 3D-model. These profiles show discontinuous reflectors and complicated reflectivity patterns due to the complex geology.

Drill hole logging indicates that the seismic imaging of contacts between mafic and felsic volcanic rocks is plausible. Furthermore, acoustic impedance of Pyhäsalmi ore (32×10^6 kg/m^{2}s) is distinct from the host rocks ($16–19 \times 10^6$ kg/m^{2}s) enabling its detection with seismic reflection methods. Contact zone between mafic and felsic volcanic stratigraphies has potential to host mineralizations and seismic method enables the mapping of the key horizon for mineral exploration over a wide area. Near the surface (>500m), known structures and lithological contacts are sub-vertical. Seismic profiles show that generally they turn to almost subhorizontal orientation with depth. Steep folding with approximately north-south oriented fold axis can explain the large-scale reflectivity patterns of the area. In this interpretation, the steep fold limbs are not imaged directly with seismic technique but fold hinges, where orientation is locally subhorizontal, cause clear reflection.

Experiences from studying microseismicity from drifting sea ice at the Gakkel Ridge

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During the Norwegian expedition with the hovercraft RH Sabvabaa in the summer season of 2012 three subsequent short-term deployments of a small seismic array were performed from the drifting sea ice at the Gakkel Ridge (85N, 10E) in the Arctic Ocean.

The prototype array consisted of three buoys specifically designed for the purpose. They were placed in a triangle with side lengths of about 5.5 km on the 1-3 m thick sea ice. Each buoy is connected to a hydrophone let through a hole in the ice, and leveled just below the ice, with a digitizer recording continuously.

A wireless network connects all nodes of the array with a central logging point at the hovercraft where status, position and data was monitored during the experiment. Each station has a GPS which provides accurate position and timing.

The array was deployed upstream the rift valley of the anticipated ice drift. Depending on the wind it would drift southwards over the valley before it eventually would be too far off the axis to register the generally small events or could give any hope of reliably locating the events. A total of 25 days of recording were achieved, with about 10 events on average each day.

We will present the experiment and its approach, with the challenges that were experienced in recording microseismicity in a very remote environment, covered with an all-year and continuously moving ice sheet. Examples of the collected events and data will be presented as well as some preliminary processing results.

Focal depth estimation using Pn coda phases - like pP, sP and PmP

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We address a classic problem in observational seismology, namely that of accurately estimating the focal depth of small to moderate earthquakes. The data at hand are 3 component records including Pn onsets and its coda. Our rational is the belief that the Pn coda contains P type phases which originate in the source area and lag behind the Pn arrival due to longer travel paths. Only exceptionally are phases like pP and sP included in seismic bulletins and even cepstrum and array f-k techniques have not proved successful in extracting such arrivals. We use recent developments in polarization analyses (Fedorenko et al.,2008; Roberts and Christoffersson, 1990) and corresponding software tools for extracting secondary P phases in local and regional records of 5 earthquakes.

Phase characteristics are typically slowness and lag time relative to the preceding Pn phase. However, information is incomplete for deciding confidently whether an arriving wavelet should be classed as pP, sP or something else. This validation problem is resolved by picking several coda arrivals which can uniquely be fitted to travel time curves for suite of Pn coda waves. Focal depth estimates,even for so-called Ground Truth 05 events, are seldom accurate to 5 km so we compared our results to those obtained by moment tensor analysis. Differences in depth estimates were less than 5 km, and interestingly, for H < 15km the first secondary Pn arrival appears to be sPn. The Dt(Pn-pPn) lag time for such relativelyshallow events is 2.0 sec or less and hence difficult to detect in the coda. Most techniques for focal depth estimates are not user friendly. In contrast, the polarization schemes tested in this study are easy to use and depth estimates are more accurate than those stemming from ground truth studies based exclusively on P arrivals.

Recent Developments and Results of Local Seismicity Studies in Lithuania and Adjacent Areas

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Lithuanian Geological Survey

Lithuania and adjacent areas have always been considered as territory of low seismic activity. There are known some historical and instrumentally recorded earthquakes in the region, but there is no reliable data about any natural seismic activity in the territory of Lithuania. No natural seismic events have been detected since the beginning of seismological monitoring in Lithuania. Since 1999 we have registered several hundreds both natural and artificial local seismic events in Lithuania and neighbouring countries. Most of the seismic events were explosions in the quarries and in the Baltic Sea. The strongest registered earthquake in the region took place in the Kaliningrad District in 2004.

Large amount of seismological data was achieved during the Passive Seismic Experiment PASSEQ 2006-2008 (Wilde-Piórko et al., 2008). During the project 26 temporary seismic stations were installed in the territory of Lithuania. The data was analysed in order to find any local natural seismic activity. The studies revealed some previously unreported explosions in the quarries, and some natural seismic activity in the water area of the Kaliningrad District (Janutyte et al., 2012). Also, combining PASSEQ data with the data of some deep seismic sounding projects there are made efforts to make a precise crustal model for the territory of Lithuania (Budraitis et al., 2009).

The historical information, seismological monitoring and other data was used for seismic hazard evaluation in the territory of Lithuania. The calculated possible maximum PGA value for return period of 475 years is 32.6 cm/s^2 in Eastern Lithuania, up to 25 – 30 cm/s^2 in Northern Lithuania, and 10 – 20 cm/s^2 in the rest part of Lithuania (Pačėsa et al., 2011).

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First results of the seismic station "Franz Josef Land"

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In early September 2011 the northernmost seismic station of Russia - Franz Josef Land (ZFI) was installed. The two sets of equipments has been installed there - broadband and shortperiod stations of the firm by Guralp (CMG-6TD and CMG-40T with the registrar GSR-24). The distance between stations is about 250 m. The seismic information arrives to the Center with delay about one month on memory sticks. Interactive seismological bulletin is also created on the base of ZFI seismic station. Due to this new station the efficiency of Arkhangelsk Seismic Network (ASN) was improved significantly. Additionally a large number of small and middle earthquakes (M<3.5) in the vicinity of the ZFI were recorded. Epicentral distances for these seismic events are from 300 to 900 km. We compared the data of our ZFI bulletin with bulletins of the Norwegian National Data Centre (NDC NORSAR). The most of regional seismic events recorded by ZFI are the earthquakes near Svalbard and the ridges of Arctic Ocean. The information about other events we could not find in any other catalogs of known seismic services, but, presumably, they are also related to geodynamic activity of Gakkel Ridge and Svalbard.

The seismic station ZFI registered the large number of very weak events with epicentral distances from 15 to 25 km which were not possible to detect without filtration. We suppose that these events are connected with glacial processes. Such processes are well known and have been observed earlier during the expedition to Alexandra island of Franz Josef Land in 1968.

Analysis of the power spectrum of microseismic field on the Franz Josef Land shows the almost complete absence of technogenic interference that makes this area a unique testing ground for studying the dynamics of processes in the Earth's crust and in ice. The level of natural microseisms in the bandpass filter from 0.2 to 0.8 Hz is high and connected with an influence of the northern seas and the Arctic Ocean.

Our short experience (5 months only) shows that ZFI seismic station is high-efficient both teleseismic and regional monitoring. Using data of ZFI is allowed us to increase location accuracy and identification reliability of different nature seismic events.

Seismic station ZFI opens new possibilities in the seismological monitoring and research in the Arctic.

Structure of the upper mantle in the northern Fennoscandia revealed by joint inversion of P-and S-receiver functions

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In order to understand structure of the crust and sub-continenlal lithospheric mantle (SCLM) beneath the northern Fennoscandian Schield, we used joint inversion of P- and S- receiver functions (PRF and SRF, respectively) estimated from data of the POLENET/LAPNET seismic array experiment in northern Fennoscandia during the International Polar Year (IPY) 2007-2009. The array consisted of 37 temporary stations deployed in northern Finland, Norway and Russia and of 21 permanent broadband stations operated by several research institutions in northern Fennoscandia. Most of the stations of the array were equipped by the broadband instruments. The array registered teleseismic, regional and local events during May 2007 – September 2009.

The P- and S-receiver functions were estimated at broadband stations of the array using recordings of teleseismic events. The filtered PRF and SRF from individual events were then stacked and resulting waveforms were inverted using the global optimization procedure based on the Simulated Annealing (SA) algorithm. The obtained models were also constrained by the travel time residuals of Ps conversions from 410 km and 660 km discontinuities. The main results obtained in our study can be formulated as follows:
1) The Moho depth estimated by joint inversion of PRF and SRF is in good agreement with the Moho obtained by controlled-source experiments in the areas with the flat Moho.
2) The deepest Moho (about 60 km) was found in the southeastern part of our study area.
3) Joint interpretation of PRF and SRF revealed heterogeneous structure of the upper mantle beneath the eastern part of the POLENET/LAPNET array down to 200-250km;
4) S-wave velocities beneath 200-230 km are close to the S-wave velocities in the IASP91 model;
5) Mantle with Vs>Vs(iasp91) from the Moho down to 200-230 km has been revealed in the southern part of the study area corresponding to the non-revorked part of the Karelian Craton;
6) Mantle with heterogeneous layer from the Moho down to 90-120 km has been revealed in the northern part of the array (Kola Craton and Belomorian Belt and revorked part of the Karelian craton);
7) No low S-wave velocity layer corresponding to the asthenosphere has been revealed;
8) A boundary with positive contrast of P-wave velocities at 200-230 km has been found beneath the whole study area;P-wave velocities beneath this boundary are higher than the velocities in the IASP91 model.
The future work will be comparison of our results with the results of surface wave studies and teleseismic body wave tomography.

Data Processing of Large Earthquake Aftershock Sequences

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Waveform pattern detectors (e.g., correlation, subspace, and matched field detectors) merge the signal detection and source identification processes into a single operation. The organization of repeating waveforms for efficient analyst interpretation may result in significant gains in productivity when analyzing extensive aftershock sequences and explosions from repeating sources.

We have developed a prototype detection framework for investigating procedures related to automatic data processing, including conventional beamforming, STA/LTA detectors and pattern detectors. Using data from arrays in Kazakhstan, the system is being tested on two aftershock sequences: that for the 8 October 2005, M=7.6, Kashmir earthquake and that for the 23 October 2011, M=7.1, Eastern Turkey event. Both cases are representative of challenging aftershock sequences given the vast numbers of events and relatively large source regions.

Encouraging results are found from processing of the Kashmir sequence individually at the 9-element Kazakhstan arrays KKAR and ABKAR. We also show results from multi-array correlation-type processing across these two arrays, where the system was able to automatically detect and associate more than 500 aftershocks during a 10-day period.

The SHARE project;
Harmonization of Seismic Hazard Assessment for the European region

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NORSAR

The EU project SHARE started in 2009 and is closing by the end of 2012. The results, the harmonized earthquake hazard maps and related products, will be made public. These results will have the potentials to eventually impact European and national building regulations, Eurocode 8 and the national application documents. Even if all countries covered in the study could not be represented in the project there were still 18 partners from Norway in the north to Greece in the south, from Portugal in the west to Romania in the east. The project was directed from ETH, Switzerland.

The background for SHARE was the inhomogeneity of seismic hazard at borders and the diversity of methodologies used, caused by national groups focused only on national territories and using their favorite methods. SHARE aimed at using the advanced logic-tree based PSHA software (OpenQuake) combined with updated catalogues, unified processing methods (Completeness analysis; Removal of dependent events; Penalized orthogonal regression analysis) on a uniform all-European earthquake catalogue (SHEEC) and updated ground-motion prediction equations. The source characterization includes a large number of slip-rate assessed active faults in southern Europe, which was developed in parallel with a classical area zonation model. The earthquake recurrence model is now in its final phase of completion and a unified all-European hazard model is expected to be finished before the end of 2012. Only on-shore regions will be included initially even if the zonation also covered offshore regions.

Scandinavia and the Baltic countries have been represented only by NORSAR, aided by BGS and two Swedish scientists working at GFZ. Experiences from such a large scale cooperation will be presented.

Historical seismicity in the Gulf of Bothnia area: issues of completeness

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This study focuses on the northern half of the Gulf of Bothnia that is today bordered by Finland to the east and Sweden to the west.

The available seismicity record spans three centuries, about 250 years of which rely on non-instrumental historical data. An understanding of the level of completeness of the non-instrumental record is a prerequisite for assessing site-specific seismic hazard and seismic potential of the area. It involves putting the data on individual historical earthquakes to their context and analysing the perception level of documentary sources.

Seismic histories are presented for two coastal towns, Vaasa (*Vasa*) and Tornio (*Torneå*), from 1730 to 1920. The earthquake effects recorded in writing in Vaasa are attributed to earthquakes in the Gulf of Bothnia and west of it. The maximum effects were estimated at macroseismic intensity I = 4–5 (EMS). The effects experienced in Tornio are attributed to local earthquakes at the bottom of the Gulf of Bothnia, except for the 1819 Lurøy earthquake in Norway. The maximum intensity recorded in Tornio was estimated at I = 6–7 (EMS). No historical earthquake was reportedly felt in both towns.

The seismic history of Vaasa shows an absence of earthquake effects between 1787 and 1883. No earthquakes felt in the vicinity of the town, or on both sides of the Gulf of Bothnia, are known from that time. The gap may follow from a combination of missing reports and an absence of earthquakes. Earthquakes felt simultaneously on both the eastern and western coast appear to be relatively rare in the record and somewhat synonymous to largish events (as a rule of thumb M around 3.5 or higher). There may have been a seismic quiescence spanning several decades. When the seismicity level increased from 1882 onward, earthquakes surprised observers and no recollections of previous occurrences emerged. The seismic history of Tornio is less intermittent.

The notion that Swedish science blossomed in the 1700s is supported by the earthquake reports available. A network of learned persons made contributions to a diverse range of natural scientific topics, including seismological observations, and improved the quantity and quality of reporting. The war of 1808–1809 and the consequent splitting of the Gulf of Bothnia in two changed the situation. During the Crimean war in 1853–1856 English-French troops attacked many towns along the coasts of the Gulf of Bothnia. Further impairment was caused by economic decline along the eastern coast in the latter part the 1800s. It is possible that the worsened conditions heightened the threshold for complete reporting in the 1800s from that in the latter half of the 1700s. A tentative conclusion is that no intensity data point of I = 5 or higher is missing from the historical record of the northern Gulf of Bothnia since the 1730s, but the threshold for complete reporting was lower at some specific places during shorter time intervals.

Earthquakes and seismotectonics of the Gulf of Finland area: contemporary examination

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The Gulf of Finland, as well as all southern Fennoscandia and south-eastern Baltic, for centuries were believed to be the region of very low seismic activity in framework of IV-V points of macroseismic scale and M=3-4. This calm position was disturbed by the quite unexpected Osmussaar earthquake, 25 X 1976, M=4.7. Thereafter more detailed and comprehensive investigations started by Russian and Estonian researches. The author being involved in this work rather actively for decades is in position now to perform some updated results. Modern results have been published partly in periodicals and presented orally to the scientific session of the Tallinn University on January 20, 2012.

A special attention was paid by the author to discrimination of non-tectonic quakes such as being produced by earth's collapse and sinking down and frost phenomena. In the current year the improved version of the catalogue of tectonic namely earthquakes was compiled. Epicenter maps of all felt earthquakes in East and South-East Baltic are presented. Most important seismic events of 1877, 1881, 1976 are considered according to recollected and newly processed macroseismic data. Some observations of arhaeoseismic and paleoseismological sense bring in light on stronger, I_0 =VII-VIII, prehistoric earthquakes in period of some thousand years. Present seismotectonic approach using updated catalogue of tectonic felt earthquakes for centuries, data on some prehistoric earthquakes, seismodeformations of different types, and distribution and characteristics of relatively active faults gives a new version of seismic zoning for the area under study.

Within the region it's possible to distinguish and confine some seismogenic traces (zones, crest spots) seismic activity in long-term respect. Within each of delineated newly zones moderate and severe earthquakes can occurred with intensity VI once per 100–200 years and intensity VII–VIII once per 500–1000 years. Generally speaking seismic hazard of the area is essentially higher in long-time aspect then it's believed till nowadays. So the task to provide more thoroughly modern research on a special program seems to be quite actual one.

Experience in the peak ground velocities evaluation by the study of paleoseismic local rock disturbances (Eastern Fennoscandian shield as example)

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The new approach to paleoearthquake parametrization based upon the examination of displacements of separated rock blocks is presented. Natural cases under review include displacements that occurred due to large earthquakes within the North Eurasia in the 20th century and paleoseismic dislocations thoroughly studied by the authors on key-sections in the crustal rocks in the eastern (Russian) part of the Fennoscandian shield. Two independent options were used: (1) estimation with reference to similar cases in the instrumental measurements period and to the currently applied scaling systems, and (2) introduction of physical characteristics of disturbances of particular types and habitus and fixed values of displacements of the rock blocks. In terms of the second approach 6 simple mechanical models for evaluation of peak ground velocity to interpret the revealed and measured paleoseismic dislocations and block displacements were singled out. These models correspond to a pushing out and droping of stone off the maternal wall (model 1), block schifting along horizontal surface (2), displacement of block(s) not in the direction of the slope maximal inclination (3), knocking out of block from the base and throwing up the boarding edge (4), turning of block around horizontal axis (5), displacement of large rock unit from the rock wall (6).

Macroseismic scales of some generations up to novel one, strong motion data, and explosion data were used to construct a nomogram that gives possibility to evaluate the parameters of studied past earthquakes (pairs of values of magnitude and source distance) for the given characteristic peak ground velocity value. Values of mass velocities of seismic impacts (peak ground velocities, PGV), which were needed for initiation of the revealed dislocations, were estimated. In many cases, PGV values were above 1 m/sec, i.e. considerably higher than values conventionally accepted (for ground conditions) and fixed in Fennoscandia during some last centuries. For clarifications, data on strong movements and explosions were used, and the whole set of data was found reasonably consistent. It was concluded that the cases with PGV>1 m/sec corresponded to focal areas of earthquakes with M>6 (mainly in the period of deglaciation).

A graphical chart is proposed for estimation of magnitudes and hypocentral distances of initiating earthquakes in case of maximum PGV within a range from 0.01 to 5.00 m/sec. Based on the graphical chart, parameters are estimated for earthquakes that might have caused the dislocations observed on the main sites of the region under study.

An artificial seismicity in the East Baltic region

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Seismic activity of the East Baltic region at the western part of the East European platform is due mainly to the presence of artificial sources of explosions for getting of mineral resources for the construction industry (dolostone, limestone, gypsum) and energy (oil shale). In the Baltic region (Lat = 53.9°N - 59.7°N Lon = 19.4°E - 29.6°E) is located more than 40 artificial seismic sources: in Latvia - 11, Lithuania - 5 and Estonia - 27.

Development of energy, especially nuclear energy, in the East Baltic region (Leningrad NPP, Baltic NPP – in the stage of building), an ecological dangerous system of pipelines (*North Stream*) requires more attention to the estimation of the seismic conditions and to implementation of the seismic monitoring. In the East Baltic region occurred not only historical but also modern perceived earthquakes on Saaremaa in Estonia, October 25, 1976 (magnitude 4.7) and in the Kaliningrad district of Russia September 21, 2004 (magnitude 5.2).

Since 2008 operates BAVSEN virtual seismic network in the East Baltic region. BAVSEN is based as the part of network GEOFON of regional seismic stations, available on the server GFZ Potsdam. Although the network has 10 seismic stations to locate of seismic events in the East Baltic region, but mainly only five seismic stations are used: MEF, MTSE, RAF, VSU, SLIT. Additional stations PBUR, PABE in Lithuania did not allow to improve the quality of location of seismic events in the East Baltic region.

On January 1, 2008 to September 14, 2012 BAVSEN recorded about 2750 seismic events in the East Baltic area. An artificial seismicity dominates in the East Baltic region. 96% of seismic events are occurred in the daytime and working time. Minimum local magnitude of seismic events in the East Baltic region, which can be available to detection BAVSEN is 1.0 - 1.5.

For location of seismic events in Latvia are used the regional travel times on basis of *Baltic07* velocity model. Error of location 11 calibrated explosions in accordance with BAVSEN does not exceed 17 km. Error location 8 calibrated explosions in accordance with NORSAR GBF is in a range from 22 up to 115 km. The travel times on basis of Fennoscandia and ISHU velocity models for location of seismic events in Estonia also are used.

Spectral-temporal analysis (STAN) and analysis of the spectral relations P/S are used for identification of genesis of seismic events. Lack of regional tectonic earthquakes in the East Baltic region complicates estimation of effectiveness of these methods to identify the genesis of seismic events.

Earthquakes in Greenland: Achievements during the last 43 years

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Geological Survey of Denmark and Greenland – GEUS

Results from the earthquake monitoring in Greenland during the last 43 years are presented, and these results show; a large increase of the number of detected earthquakes, an improved detection threshold, new areas of high seismicity, several earthquake clusters and seismicity below the ice cap. Despite the improved monitoring, detection of local events is still performed manually, by analyzing all of the real time data. With a station separation of around 400km many earthquakes are only detected on one or two stations which make automatic detection very difficult. But improved instrumentation has enabled the use of single station location technique. Results from and challenges using this method are presented. The development of the seismic monitoring have gone from having only three seismic stations placed in Greenland in the 1960'ties, till today where there are18 permanent stations placed in Greenland. All equipped with broadband sensors, of which 13 has Internet connection and transmit 100sps data in real time, and 5 used the Iridium satellite system and transmit 1sps data with a delay. The resent major improvement of the seismic monitoring is performed by the Greenland ice sheet monitoring network (GLISN, http://glisn.info).

Mine blasts in Estonia – a multidiciplinary study using seismology and mining engineering

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Seismic events in Estonia are monitored by the Geological Survey of Estonia, in co-operation with the Institute of Seismology at Helsinki University. Around 1000 local events are detected yearly, and are almost exclusively identified as man-made events. In the sea areas they are principally caused by elimination of war-time sea mines. In the land areas most events are blasts in open cast oil shale mines or in limestone quarries.

The detected seismic events can be used for research on parameters and circumstances in conducting mine blasts. For instance, estimated magnitudes do not correlate clearly with the amount of explosives used. Several factors have an effect on the size of the actual blast: amount of explosives (total and subtotal), delay time, blast geometry, geological conditions such as layering and ground fractures.

In this study, we use a detailed parameter database of blasts conducted in open cast oil shale mines and a limestone quarry in NE Estonia. These data are compared with the seismic catalogue in order to find relations between blast size and magnitude, constraints for location accuracy and detection threshold.

The results will be useful for several applications. From the mining point of view, economical factors are decisive, and cost-effective improvements verified with research can be applied. The public is concerned with safety and possible property damage by blasting, and confirmation for safe procedures can be gained by research. For seismology, this study provides material e.g. for improving event location accuracy and seismic velocity model.

The Seismic Station TROLL, Antarctica

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NORSAR

In the framework of the Norwegian Antarctic Research Expedition (NARE) NORSAR was granted a project to install a permanent seismic broadband station at the Norwegian research base TROLL in Dronning Maud Land. The seismic station consists of a Streckeisen STS2.5 broadband seismometer and a Quanterra 330HR digitizers. Both units have been tested for temperatures below -50 deg. The station was installed in the beginning of 2012 and it is providing continuous real-time data (100 Hz and four lower frequency taps) since 5 February 2012 to NORSAR and ORFEUS (see http://www.norsardata.no/NDC/heliplots/ for current records).

TROLL is one of the few seismic stations in Antarctica build on bedrock. This means stable conditions and less noise through reverberations in the ice shield. Except for occasional time periods with strong winds/storms the station has an excellent low ambient noise level.

TROLL has acquired a rich record of teleseismic events and of Antarctic seismicity at local and regional distances. In addition, many icequakes and iceberg-related signals could be identified.

Seismological studies related to the potential site of spent nuclear fuel in Finland

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ÅF-Consult Ltd.

Posiva Oy is an expert organisation responsible for the final disposal of spent nuclear fuel of the two currently operating Finnish nuclear power companies. Posiva is preparing to submit the construction license application for a spent fuel repository at Olkiluoto by end of the year 2012.

The plan is to dispose the spent nuclear fuel in a repository, to be constructed at a depth of about 400 m in the crystalline bedrock at Olkiluoto, Finland. Due to its long-term hazard, the spent fuel has to be isolated from the surface environment over a prolonged period of time. Safe disposal is achieved by long-term isolation and containment. The host rock shall provide stable and favourable conditions for final disposal facility.

This presentation introduces examples of Posiva's seismological studies and reports. The studies deal with excavation induced seismicity, current tectonic seismicity, and post glacial seismicity. The seismological studies include also modelling of the bedrock, modelling the stress evolution and fault stability during the Weichselian glacial cycle as well as modelling the end-glacial earthquakes.

Use of in situ stress estimates for earthquake warning - some examples

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QuakeLook's patented method for esimating the in situ stress tensor field from microearthquake analysis will be presented. It has so far been tested on large tectonic earthquakes (Iceland), induced seismicity in geothermal sites (Geyser, California), and to induced seismicity in a large underground mine. The results are promising and will be presented. An interesting aspect is that the use of stresses for earthquake warning is rather independant from the rate of seismic activity (the most common method for earthquake warnings in mines) which may give synergetic effects.

Shallow swarm-type earthquakes in south-eastern Finland

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The Vyborg rapakivi batholith comprises an area of more than 20 000 km^3 in south-eastern Finland and Russian Karelia. The 1.65-1.63 Ga old batholith intrudes Paleoproterozoic bedrock that was formed in the Svecofennian orogeny between 1.9 and 1.8 Ga. The batholiths area is known for shallow swarm type earthquake activity. The latest swarm has been occurring since December 1, 2011 in and around the town of Kouvola. More than 160 earthquakes, with magnitudes ranging from M_L 0.4-2.8, have been recorded so far by the Finnish permanent seismic network. The swarm has been widely felt and reports on explosion- or thunder-like sounds accompanied by shaking of the ground are common. The felt effects and a strong Rg phase recorded by the nearest stations, at epicentral distances of 60-70 km, constrain the earthquake foci within the uppermost few kilometres of the crust. The events are concentrated around a major sub-vertical fault and contact zone traversing the batholith in NE- SW direction.

Inspired by the ongoing activity, four off-line seismic stations were operating in the source area between December 19, 2011 and June 6, 2012. The central station was located close to the active fault segment, while the others were deployed within a radius of 9 km from it. The stations were equipped with three-component Trillium 120 PA broadband seismometers and the sampling rate was set to 250 Hz. The response to ground velocity was flat in the frequencyband of 0.01-100 Hz.

In this study, waveform data recorded by the off-line stations were used to improve the detection capability and hypocentre locations of the events. Focal depths were constrained by using synthetic waveform-modelling of depth sensitive phases, such as Rg and sP. The hypocentres were correlated with magnetic anomalies associated with tectonized lithological contacts within the batholiths. A composite fault plane solution was computed by using the three strongest events.

Preliminary results indicate that the swarm events are concentrated around a major sub-vertical fault and contact zone traversing the batholith in NE- SW direction. Injection of fluids into the zones of crustal weakness has been suggested as the governing process behind the shallow swarm-type earthquake activity. In the next phase, a high precision relative location method will be applied to further constrain the hypocenter distribution.

Seismic monitoring in Estonia

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In Estonia, seismic events are monitored by the Geological Survey of Estonia, in integrated co-operation with the Institute of Seismology at Helsinki University. Seismic analysis is based on data from the three Estonian seismic stations: Arbavere (ARBE), Matsalu (MTSE) and Vasula (VSU), as well as from several stations in the southern half of Finland and one in Latvia. Vasula is also a part of the international seismic network of the GEOFON data centre in Potsdam.

The focus of seismic monitoring is on the Estonian territory, waters and surrounding areas. Some 1000 local events are detected yearly, and are almost exclusively identified as man-made events. In the sea areas they are mainly caused by elimination of war-time sea mines. In the land areas most events are blasts in open cast oil shale mines or in limestone quarries.

The results of seismic analysis in Estonia are merged into the bulletins of the Institute of Seismology at Helsinki University (www.helsinki.fi/geo/seismo/english/bulletins/index.html).

Developments at the ISC: new Locator, GT, Bulletin Re-Build and the CTBTO-Link

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The International Seismological Centre (ISC) is a non-governmental non-profit making organization funded by 57 research and operational institutions around the world and charged with production of the ISC Bulletin – the definitive summary of the global seismicity based on reports from over 130 institutions worldwide. Jointly with NEIC, the ISC runs the International Seismic Station Registry (IR). The ISC provides a number of additional services including the depository of the IASPEI Reference Event list (GT), EHB and ISS data. The ISC assists to the IRIS DMC in providing waveform data for specific seismic events.

The ISC has a substantial development programme that ensures that the ISC data remain an important requirement for geophysical research. We modernized the ISC event location and magnitude computation procedures. We are working on the project of re-building the entire ISC Bulletin (1960-2010) by re-computing the hypocenters and magnitudes with the new location algorithm using ak135 velocity model, identifying and filling the gaps in data, correcting known errors and introducing essential additional bulletin data from temporary deployments. The ISC is also running the CTBTO-Link where the ISC Bulletin data are provided to the monitoring community as a historical perspective into current recordings by the IMS network as well as making a link to current data of non-IMS networks.

Postglacial paleoseismic deformations of the southeastern Fennoscandia and Estonia

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Studies of postglacial and recent bedrock movements in Russian Karelia were initiated by A. Lukashov around 1970 and during the 25 years, zones of localized paloseismic deformations were found and studied in different part of the Karelian region (Lukashov, 1995). Numerous small-scale seismic dislocations have been described in the surroundings of Lake Ladoga and its islands, on the Zaonezhje Peninsula of Lake Onega, from near Petrozavodsk and at Lake Segozero etc. The Kuusamo–Paanajärvi–Kandalaksha zone is seismically the most active in Karelia (Lukashov & Systra, 1998), each year seismic stations in Finland have recorded earthquakes from this zone with magnitudes of 0.6–2.4. Paleoseismic deformations are known from the Kuukaisjärvi syncline and the Nyhcha–Lehta zone, near the village of Kalevala.

The seismic-related deformations in SE Fennoscandia are seismo-gravitational, gravitational-seismotectonic and seismotectonic in origin. Seismo-gravitational dislocations form as a result of seismic vibrations activating unstable blocks, rock and soil masses and causing displacement of large rock masses. Collapse of crystalline rocks, slumps and debris flows are usually observed in unconsolidated Quaternary sediments, accompanied by deformation of layering in the basal sediments. Gravitational-seismotectonic deformations result from passive opening or movements on fault surfaces, and shocks and vibration caused by seismic event. Many areas of rugged relief are commonly caused by displacement-related rock-falls, rock slides, blocks displaced from ledges, or “rock feathers” and “rock pillars” on sloping surfaces. Seismotectonic deformations are directly related to fault movements expressed at the surface after strong earthquakes (M ≥ 6.5), resulting in seismotectonic depressions, fault scarps and terraces, fracturing and brecciation, opening of joints, and mass movements. More than 150 seismic deformations have been studied in the Putkozero Syncline in the Onega Synclinorium, including large (8 x 6 x 3 m) angular blocks and 30 m wide seismo-gravitational rock-falls. At one locality near the River Luashtangi the flat-lying, slightly schistose komatiitic basalt outcrop is located at the intersection of the two regional NW 295-300º and 335-340° fault zones. As a result of strong compressive forces a number of uplifted blocks up to 10 x 18 m in size and with uplift amplitudes from 1-160 cm were studied. Near Petrozavodsk, at Chertov Stul (Devil’s Chair) and on the top of Vottovaara the seismic activity produced displacements, tension joints, shatter zones, extensional clefts with rock-falls etc.

The northern and NW shoreline of Lake Ladoga Lake bus subject to intense fault activity during the formation of the Ladoga aulacogen in Mesoproterozoic time and underwent later reactivation during the postglacial period. The entire region is covered by a dense network of faults with deep valleys and high scarps. Seismic deformations, rock-falls, ruins, numerous rock “feathers” and rock “pillars” are common here. The northwestern Precambrian part of Karelian Istmus has also many fault zones with deep and wide valleys, such as that of the Vuoksa River. On the rapakivi granite ridges of the Vyborg massif large angular blocks occur along river rock-falls. An interesting site, namely the Inostrantsev cave, formed in granite by seismically induced displacement of large blocks, is located 5 km to the SE of the town of Kamennogorsk town a cave in the granite. This place was visited famous Russian geologist A.A. Inostrantsev (1843-1919) at the end of 19thcentury, after which the cave takes its name.

More than 30 seismic events have been recorded in historical times in Estonia. A strong earthquake occurred on 25.10.1976 near the island Osmusaar (M = 4.7-4.8) (Nikonov, 2002). In a old quarry near the town of Paldiski town, joints trending NW 305-310º can be traced for 100 m and show dilation of 2-3 cm, separating large blocks with vertical uplift of 1-3cm.

Estimation of paleoseismic intensity was initiated in the SW of Fennoscandia by A.D. Lukashov and B.Z. Belashev (2002). A group under A.A. Nikonov from the Schmidt Institute of Physics of the Earth RAS continues studying intensity and magnitude of paleodeformations in the Fennoscandia Shield and comparing them with modern earthquakes in Russia.

Norwegian fjords sang along – observations of seiches following the 2011 Tohoku, Japan, earthquake

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During the same hours as devastating tsunami waves inundated the shores of Japan following the Tohoku earthquake (11 March 2011), fjords in western Norway started to oscillate. The oscillations were triggered by the seismic waves. Several film clips from cell phone cameras, surveillance cameras and eyewitness reports are available from this seiche motion, which have been analyzed to derive information about wave periods and amplitudes. Maximum trough-to-peak amplitudes at the shores are of the order of 1-1.5 m and periods are in the range 1-2 minutes. The fjords continued to oscillate for at least two hours. The seiches are simulated with a numerical model with horizontal ground acceleration estimated from the earthquake recordings from the nearest broadband station as input. Preliminary results of the simulations show waves with periods comparable to observations, but the amplitudes are only about a tenth of the observed amplitudes. The simulated wave amplitudes are sensitive to the depth profile close to shore and a higher grid resolution may lead to higher local run-up. The thick accumulations of sediments in the fjord bottom may also amplify the earthquake accelerations. Using a soil amplification factor of 5-10 will lead to a better fit with observations. The seiches were initiated with the arrival of the horizontal S-wave.

The 30. August, 2012 M6.6 Jan Mayen earthquake

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Jan Mayen is an active volcanic island situated along the mid-Atlantic Ridge north of Iceland and hosts Norway's only active volcano. It is closely connected with the geodynamic processes associated with the interaction between the Jan Mayen Fracture Zone (JMFZ) and the slowly spreading Kolbeinsey and Mohns Ridges. Several large strike-slip earthquakes have been recorded along the JMFZ, most recently a M6.6 event on 30. August, 2012. The event was followed by a M5.3 aftershock after ca. 8 minutes. In this presentation, we will present preliminary results describing the source of the events and its aftershock sequence, based on data recorded by the Norwegian National Seismic Network. We will also discuss its relation to previous large events along the JMFZ.

Two aircraft accidents, two different interpretations

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We have studied two recent aircraft accidents in Finland and Sweden as their ground impacts were recorded at nearby seismic stations. Albeit such sources are not outstanding seismologically but they may be important in a search and rescue mission context. The first case is the crash of F-18 Hornet fighter of the Finnish airforce which we located to the nearest 4 km in Central Finland using the seismic impact records from 6 digital stations. From the event, magnitude estimate in combination with standard energy-magnitude conversion relations we also calculated the aircraft terminal velocity just before impact giving excellent agreement with the report of the investigation committee.

The other air crash was that of the Norwegian air force Hercules transport plane disappearing near the top of the Kebnekaise mountain NW of Kiruna. In this case the registrations of the nearest station Nikkaluokta 25 km away from the impact showed signals of the accident. Here the tentative terminal velocity is low at around 350 km/hour but flight recorder data have not yet been released.

In concluding remarks we summarise studies of air accidents and sea disasters from which recorded seismic signals have given additional and useful information on such accidents.

Obviously, record analyses if available may in certain circumstances contribute constructively to search and rescue missions.

NordQuake - Prospects and Results

P.H. Voss

Geological Survey of Denmark and Greenland – GEUS

The Nordic Earthquake Researcher Network – NordQuake, was established in 2011 with founding from NordForsk, an organisation under the Nordic Council of Ministers that provides funding for Nordic research cooperation as well as advice and input on Nordic research policy (http://www.nordforsk.org/).

NordQuake aims to strengthen and increase the quality of the earthquake research and research training in the Nordic and Baltic countries. NordQuake will e.g. organize and hold meetings and training courses for earthquake researchers and students at universities and other research institutions in the Nordic and Baltic countries and training courses for PhD students and young researchers. Researcher Network meetings are planned for 2012, 2013 and 2014 and training courses are planned for 2012 and 2013.

The 2012 training course was undertaken in June hosted by University of Bergen, Norway, with 11 participants. Outcome of the course is presented.

The status of NordQuake is given and a draft for the plan of future meetings and training courses is presented. http://nordquake.net

The 43rd Nordic Seismology Seminar, 24 – 26 October 2012

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