# Veðurstofa Íslands
# Report

Barði Þorkelsson
(editor)

# The second EU-Japan workshop on seismic risk

## Destructive earthquakes: Understanding crustal processes leading to destructive earthquakes

**Reykjavík, Iceland, June 23-27, 1999**

VÍ-G99012-JA04
Reykjavík
June 1999

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# THE SECOND EU-JAPAN WORKSHOP ON SEISMIC RISK

# DESTRUCTIVE EARTHQUAKES:

## Understanding Crustal Processes Leading to Destructive Earthquakes

Reykjavík, Iceland, June 23-27, 1999

Supported by: European Commission DG XII

Organized by: Icelandic Meteorological Office

Programme
Abstracts
List of participants

## Organizing committee:

Dr. R. Stefánsson (Icelandic Meteorological Office), chairman
Mr. B. Þorkelsson (Icelandic Meteorological Office)
Prof. P. Einarsson (University of Iceland)

## Scientific and technical advisory committee:

Dr. R. Stefánsson (Icelandic Meteorological Office)
Dr. A. Ghazi (Europan Commission DG XII)
Dr. N. Kamaya (Japanese Science and Technology Agency)
Mr. R. Burmanjer (European Commission DG XII)
Mrs. M. Yeroyanni (European Commission DG XII)

## Objectives of the workshop

The **scientific** objectives **aim** to reinforce EU-Japan cooperation in earthquake research. The main contribution of the earth sciences to mitigate seismic risks is to provide better understanding of where, how and when destructive earthquakes will strike. The better the scientists can answer such questions the better will be the basis for mitigating risks. It concerns actions taken by society, engineers, city planners and rescue teams. Multidisciplinary approach is necessary to answer the questions above, involving seismologists, geophysicists and geologists. Multinational approach is necessary for integration of experience and knowhow.

# PROGRAMME

**Wednesday, June 23**

**19:30 Icebreaker reception hosted by the Ministry for the Environment**

**Thursday, June 24**

**09:30-09:35 Opening address by the Minister for the Environment, Mrs. Siv Friðleifsdóttir**

**09:35-09:50 Presentation: Dr. A. Ghazi, Head of Unit, Biodiversity and Global Change, Natural and Technological Hazards, Directorate XII for Science, Research and Development, European Commission, Brussels, Belgium**

**09:50-10:05 Introduction by the leader of the Japanese delegation, Mr. Y. Kumaki, Director for Planning of Earthquake Research, Earthquake Research Division, Research and Development Bureau, Science and Technology Agency, Tokyo, Japan**

**10:05-10:20 Introduction by the chairman of the organizing committee, Dr. R. Stefánsson, Head of Department of Geophysics, Icelandic Meteorological Office, Reykjavík, Iceland**

*10:20-10:40 Coffee break*

**10:40-12:15 Morning session**
**Chairman: Prof. B.C. Papazachos**
**Rapporteur: Dr. P. Santanach**

10:40 *Nucleation process, preliminary rupture and earthquake bright spot*
Dr. Y. Umeda

11:00 *The PRENLAB-2 project, premonitory activity and earthquake nucleation in Iceland*
Dr. R. Stefánsson

11:20 *Space-time patterns of seismicity prior to large earthquakes*
Prof. J. Zschau

11:40 *Studies in the close vicinity of seismogenic zone in Ohtaki region*
Dr. H. Ito, Y. Kuwahara & S. Ito

12:00 Discussion

*12:15-14:00 Lunch break*

**14:00-15:35 Afternoon session I**
**Chairman: Dr. Y. Umeda**
**Rapporteur: Dr. Þ. Árnadóttir**

14:00 *A European test site for earthquake precursors and crustal activity: the Gulf of Corinth, Greece*
Dr. P. Bernard, J. Vandemeulebrouck, J.-C. Gariel, S. Abbad, Prof. K. Makropoulos, G. Veis, S. Stavrakakis, Prof. F. Scherbaum, B. Ducarme & M. VanRuymbeke

14:20 *Slip distributions for the 1944 Tonankai and 1946 Nankaido earthquakes evaluated using teleseismic waveform modelling*
Dr. P.R. Cummins & H. Kanamori

14:40 *Methodologies for tsunami warning using bottom observation devices — state-of-the-art*
L.A. Mendes Victor & Prof. L.M. Marques Matias

15:00 *Seismotectonic characteristics of the potential sites for the final disposal of the spent nuclear fuel in Finland*
Dr. J. Saari

15:20 Discussion

*15:35-15:55 Coffee break*

**15:55-17:50 Afternoon session II**
**Chairman: Prof. P. Einarsson**
**Rapporteur: Prof. J. Zschau**

15:55 *Distribution of stress drop from high sampling waveform data of microearthquakes detected by the Ootaki array, Nagano Prefecture*
Dr. S. Horiuchi & Y. Iio

16:15 *Monitoring sites for routine stress-forecasting of the times and magnitudes of future earthquakes*
Prof. S. Crampin

16:35 *Paleoseismicity in a moderate to low seismicity area: the case of Spain*
Dr. P. Santanach

16:55 *GEONET (GPS Earth Observing Network) monitoring crustal deformation of Japan*
Mr. T. Imakiire

17:15 Discussion

**17:50 End of first day of the workshop**

**20:00 Conference dinner**

## Friday, June 25

**08:30-10:05 Morning session I**
**Chairman: Mr. T. Imakiire**
**Rapporteur: Dr. B. Feignier**

08:30 *A tsunami research in Europe and perspectives of cooperation with Japan*
Prof. S. Tinti

*08:50 Shallow seismicity and deformation process of the crust in the northeastern Japan arc*
Dr. A. Hasegawa

09:10 *Earthquake soil-structure interaction analysis by time domain BEM and FEM*
Prof. C.P. Providakis & D.E. Beskos

09:30 Ocean bottom seismographic survey in Icelandic Sea conducted by a cooperation by Japan and Iceland
Prof. H. Shimamura

09:50 Discussion

*10:05-10:25 Coffee break*

**10:25-12:00 Morning session II**
**Chairman: Prof. K. Makropoulos**
**Rapporteur: Prof. P. Cross**

10:25 *Evaluation of seismic activity by the Earthquake Research Committee of Japan*
Mr. Y. Kumaki

10:45 *Rapid seismic data exchange for accurate determination of earthquake parameters*
Dr. B. Feignier

11:05 *A procedure for reliable seismic hazard assessment in the South Balkan region*
Prof. B.C. Papazachos

11:25 *Active faulting, earthquakes and deformation-stress fields — from the Mid-Atlantic Ridge (Iceland) to a collision boundary of Southeast Asia (Taiwan)*
Dr. J. Angelier, Dr. F. Bergerat, H.-T. Chu, Á. Guðmundsson, C. Homberg, J.-C. Hu, H. Kao, J.-C. Lee & S.Th. Rögnvaldsson

11:45 Discussion

*12:00-14:00 Lunch break*

**14:00-15:00 Round table discussion**
**Chairman: Dr. A. Ghazi**
**Rapporteur: Mrs. M. Yeroyanni**

**15:00-16:40 Afternoon session I**
**Chairman: Prof. F. Scherbaum**
**Rapporteur: Prof. S. Crampin**

15:00 *Geochemical Seismic Zonation programme (GSZ). An introduction of geochemical methods for the recognition of active faults. Results after two years research*
Prof. S. Lombardi

15:20 *SEISFAULTGREECE: An EU project on active faulting and crustal and upper mantle structure in Greece*
D. Hatzfeld, H. Lion-Caen, Prof. B.C. Papazachos, Prof. K. Makropoulos, G. Veis & K. Priestley

15:40 *An interdisciplinary approach to seismic hazard assessment in Greece*
Prof. P. Cross

16:00 *Evaluation of the potential for large earthquakes in regions of present day low seismic activity in Europe*
*Dr. T. Camelbeeck*

16:20 Discussion

*16:40-17:00 Coffee break*

**17:00-18:30 Afternoon session II**
**Chairman: Dr. A. Hasegawa**
**Rapporteur: Prof. S. Lombardi**

17:00 *Permeability structure of the Nojima Fault, Japan, from borehole and core measurements in GSJ borehole crossing*
Dr. H. Ito, Y. Kuwahara, T. Kiguchi, F. Fujimoto, T. Ohtani, D. Lockner, H. Naka & H. Tanaka

17:20 *The deep seismological lab in the KTB borehole*
Prof. F. Scherbaum, M. Weber & G. Borm

17:40 *Real-time analysis of microearthquakes in the SIL system — at present and ongoing development*
Mr. R. Böðvarsson

18:00 *Policy for earthquake research promotion in Japan*
Dr. N. Kamaya

18:20 Discussion

**18:30 Concluding remarks by Dr. R. Stefánsson**

**18:40 End of second day of the workshop**

## Saturday, June 26

**09:00-19:00 An excursion to seismically active areas in southern Iceland**
Trip leader: Prof. P. Einarsson

# ABSTRACTS

# NUCLEATION PROCESS, PRELIMINARY RUPTURE AND EARTHQUAKE BRIGHT SPOT

*Y. Umeda, Disaster Prevention Research Institute, Kyoto University, Gokasho Uji, Kyoto, 611-0011, Japan; e-mail: umeda@rcep.dpri.kyoto-u.ac.jp*

On the stick-slip rock experiment, a nucleation process, unstable slow rupture growth and high-speed rupture propagation is observed. All rupture processes in the experiment take place on a pre-cutting fault plane. On the contrary, the small preliminary rupture phases preceding onset of the high-frequency high-amplitude seismic waves are observed on the seismograms recorded at near source of large crustal earthquake.

The preliminary rupture for large earthquake corresponds to the high-speed rupture propagation on the stick-slip rock experiment. This rupture differs from the nucleation process which is aseismic process observed on the rock experiment, but it is normal earthquake producing the seismic waves. If a large earthquake goes through the same process as in stick-slip experiment, we propose a new conception combined above two process. First stage is quasi-static nucleation process (1) with very slow slip (1cm/s). Second step is also nucleation process (2) with slow dynamic rupture growth (10m/s). The seismic waves are not radiated from the above two stages, which may be detected by only near source strain meters. Third stage is unstable slow rupture growth (3) which is called transition process or accelerating stage. A seismic wave with slow rise up initial phase may be radiated from this stage. High-speed rupture propagation (stage 4) in stick-slip experiment correspond to the preliminary rupture of crustal earthquake. Preliminary rupture with high-speed rupture velocity induces the complex rupture called "an earthquake bright spot" (stage 5). A rupture passed through the bright spot propagates again with high-speed and forms a final fault (stage 6). The duration time (T sec) of the preliminary rupture proportion to the earthquake moment (M0: N*m ). We get the relationship of $\mathrm{Log}M0 = 3\mathrm{Log}T + 18.1$, which shows that the longer duration time of the preliminary rupture induces the larger earthquake. The high-amplitude seismic waves may be radiated from the dynamic interaction of a lot of pre-existent cracks distributed widely in the crust. On the surface of the earthquake bright spot, almost of boulders are dislodged by severe shaking.

Sometimes an initial faulting steps over to another faulting accompanying with a lot of cracks. Aftershock gap is also found in this spot. A set of the preliminary rupture and earthquake bright spot found only on the large earthquakes or the main shocks. Almost of the earthquake swarms, aftershocks and microearthquakes have not the preliminary rupture process. The earthquake having the clear preliminary rupture phase is found only 9 percent in the earthquake, swarm ($2.5 \leq M \leq 4.7$) in the east of Izu peninsula, Japan. They distribute a little apart from the earthquake swarm area.

# THE PRENLAB-2 PROJECT, PREMONITORY ACTIVITY AND EARTHQUAKE NUCLEATION IN ICELAND

*Ragnar Stefánsson, Icelandic Meteorological Office, Reykjavík, Iceland*

The PRENLAB-2 project is a multidisciplinary, multinational European seismic risk projects, supported by EU. The full name of the project is Earthquake-Prediction Research in a Natural Laboratory-Two, carried out 1998-2000. It is a continuation of the PRENLAB project, 1996-1998. Both projects aim at studying and understanding crustal processes in the seismic and rift zones of Iceland.

Various conditions prevailing in Iceland, ranging from well exposed geology to frequent short-term variations in strain rates as well as high level observations can be utilized to gain significant understanding of crustal processes leading to large earthquakes. In this way Iceland can be utilized as a large-scale natural laboratory.

Earthquake prediction research, as used here, means in general to increase our understanding on where, when and how a large earthquake motion will take place. Where means within a few kilometers, how means not only size but in general the severity and nature of earthquake motion in various sites, and when means everything from estimating in general what is the probability of a large earthquake in a certain region during tens to hundreds of years, towards being able to issue useful short-term warnings, i.e. of the order of hours to days. Approaching such an understanding is considered as a gradual process and it is not possible to claim which of these three objectives we approach fastest. Already now results and indications are emerging pointing towards a significant progress in approaching all the objectives.

A few papers presented during the workshop will describe some results of the PRENLAB projects. All the projects converge in applications for mitigating risks, and I will concentrate on describing how we apply the results of the projects, by a real example.

In short, I will describe our observations during a period of build-up of stress and the release of a magnitude 5 earthquake, at one site in our natural laboratory. This example touches all the questions above. Where will the next earthquake occur, how will the crust break, when will it occur. I will describe how we by observations and evaluations during a short lived earthquake cycle can possibly approach answers to such questions on basis of ongoing activity. We can call this real-time research.

Starting with an earthquake of magnitude 5.1 at the western end of the South Iceland seismic zone, June 4, 1998, we observed build-up of horizontal deviatoric stresses and change in stress direction up to a distance of 50 km from the epicenter around the E-W trending seismic zone. This was indicated by observing seismicity patterns, by shear-wave splitting time delays and by changes in mechanism of small earthquakes. The most likely epicenter of an impending earthquake was expected on a N-S fault, a southward continuation of the 5.1 earthquake of June 4. Question which was posed was, if the coming earthquake would be a 5.5 earthquake as has been for some time expected to occur in the region, based on historical and general tectonic considerations. Or would it be smaller because a part of the moment was already released. The earthquake occurred on November 13.

Premonitory activity at both ends of a 10 km long N-S fault line was observed a week before it, indicating change in stress directions revealed from fault plane solutions. Foreshocks which originated at 6 km depth within two days before the main shock started the nucleation of the main shock, just above the foreshocks. This 5.0 earthquake then triggered a swarm of small earthquakes along a 10-15 km long and 2 km wide E-W zone, probably indicating E-W left lateral shearing motion and extension of the zone. This zone had the role of a stress guide. 10 earthquakes larger than 3.6 occurred during the next 3 days along this E-W zone. The largest of these secondary earthquakes occurred 26 hours after the main shock 5 km to the east of it on a clearly N-S trending fault.

The E-W zone described here is a westward prolongation of the much wider and longer South Iceland seismic zone where magnitude 7 earthquakes occur on N-S faults. The features described here can be used as a large-scale laboratory test of what may happen in a sequence of much larger earthquakes in the South Iceland seismic zone and possibly also at other transform seismic zones at other places on the earth.

# SPACE-TIME PATTERNS OF SEISMICITY PRIOR TO LARGE EARTHQUAKES

*J. Zschau, GeoForschungsZentrum Potsdam, Potsdam, Germany; zschau@gfz-potsdam.de*

Space-time patterns of seismicity prior to large earthquakes in different areas of the world including Japan have been quantified by the algorithm SEISMOLAP. This algorithm quantifies variations of seismicity patterns by overlapping each microearthquake's surrounding space-time volume with the corresponding volume around the point of investigation, respectively. The surrounding space-time volume is determined by a certain space window and a certain time window. Besides the lower magnitude threshold, these belong to the three free parameters of the algorithm.

As main result, the algorithm's application suggests that large earthquakes are preceded by relative seismic quiescence starting years before the main event and terminating immediately before the event. This result, however, was only obtained by allowing the free parameters to be tuned to the investigated event, and in particular by increasing the time window with increasing magnitude of the events. The results were much less conclusive when the parameters of the algorithm were kept fixed. This situation, however, could be improved by including certain stabilising measures which can account for extremely small numbers of events in the moving window box. In addition, the algorithm had to be modified in order (1) to account for long term trends in seismicity, (2) to automatically identify the disturbing effect of aftershocks and (3) to take into account the observation that the duration (not the amplitude) of the quiescence anomaly is related to the main event's magnitude.

The modified SEISMOLAP algorithm was applied to large earthquakes in northern and central California. All three parameters of the algorithm were kept fixed and have not been tuned to specific earthquakes, respectively. As a result, all 9 earthquakes with magnitude 6.5 and above since 1970 were preceded by relative seismic quiescence. The spatial extent of the anomalies was much larger than the focal dimensions of the associated earthquakes, respectively. One pre-seismic quiescence anomaly is still going on. Only in 4 cases pronounced seismic quiescence was found without a following large earthquake. These anomalies were interpreted as post-seismic quiescence associated to the larger events.

## STUDIES IN THE CLOSE VICINITY OF SEISMOGENIC ZONE IN OHTAKI REGION

*Hisao Ito, Yasuto Kuwahara and Shinobu Ito*

The Ohtaki region is located in central Japan, close to Mt. Ontake volcano and the Atera active fault. In the Ohtaki region, the Naganoken-Seibu earthquake (M 6.8) occurred in 1984. Because of the high activity of shallow earthquakes in the Ohtaki region, it is one of the best areas in Japan to study earthquake source process through observations in the vicinity of the earthquake sources. We drilled an 800 m deep borehole which almost reaches the earthquake focal region, at the site where the largest slip was observed during the 1984 Naganoken-Seibu earthquake.

We cemented a multicomponent borehole instrument at the bottom of the borehole, and installed a water temperature sensor at the strainer depth and a water pressure sensor. The multicomponent borehole instrument is composed of a 3 component strainmeter, 3 component seismometer (2 Hz), 3 component accelerometer, and 2 component tiltmeter. The strainmeter, tilt meter, water pressure and water temperature data are digitized every 2 minutes. The seismometer data are digitized with 500 Hz by trigger mode and telemetered to GSJ in Tsukuba. The seismometer data are also recorded with an ultra high sampling rate of 10 kHz by trigger mode and by off-line recording.

At 09:06 on April 5, 1999, a M3.8 earthquake occurred near the borehole. Focal distance from borehole seismometer is at the range from 5 to 8 km. We tried to get source time function of this M3.8 events with empirical Green function determined from very small impulsive event by using only P-wave because mechanisms of most events can not be determined.

We detected the result that the M3.8 event has very complex slip that consisted of small one and large one, and moment of large one is about 10 times of small one.

## A EUROPEAN TEST SITE FOR EARTHQUAKE PRECURSORS AND CRUSTAL ACTIVITY: THE GULF OF CORINTH, GREECE

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*S. Abbad (INFOTERE, France)*
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*G. Stavrakakis (National Observatory of Athens; email: g.stavr@egelados.gein.noa.gr)*
*F. Scherbaum (University of Potsdam; email: fs@geo.uni-potsdam.de)*
*B. Ducarme, M. VanRuymbeke (all at Observatoire Royal de Belgique; email: vruymbek@mailserv.oma.be)*

The rift of Corinth is one of the most active continental structure of the Euro-Mediterranean region. Its opening rate is 1 to 1.5 cm/year, with an associated strain rate of $10^{-6}$/year, and 6 earthquakes with magnitude larger than 5.8 in the last 35 years. The European GAIA project (1996-1998) has allowed the installation of a multiparameter geophysical observatory continuously monitoring the activity of the rift, complementing the existing seismometer and accelerometer arrays, and adding shallow borehole tiltmeters, strainmeters and tiltmeters in a cave, gravimeters, radon probes in soil near fault zones and in karstic springs, and magneto-telluric and radio stations. Its aim is to detect and analyze short-term crustal instabilities within the long-term deformation context of the whole seismic cycle: coseismic and postseismic perturbations from large earthquakes, aseismic instabilities and clusters of small earthquakes, and possible precursory instabilities. The paper presents the recent achievements of the GAIA project, in terms of instruments, observations, and models.

# SLIP DISTRIBUTIONS FOR THE 1944 TONANKAI AND 1946 NANKAIDO EARTHQUAKES EVALUATED USING TELESEISMIC WAVEFORM MODELLING

*Phil R. Cummins, Frontier Research for Subduction Dynamics, Japan Marine Science & Technology Center, 2-15 Natsushima-cho, Yokosuka, Japan; email:cummins@jamstec.go.jp*

*Hiroo Kanamori, Division of Geological and Planetray Sciences, California Institute of Technology, Pasedena, California, USA*

The Nankai Trough in Southwestern Japan is the scene of large, destructive earthquakes which have occurred with some repeatability throughout recorded history. The most recent such events were the 1944 Tonankai and 1946 Nankaido earthquakes (Mw 8.1 and 8.3, respectively). Although few seismic waveforms were recorded in Japan at this time, some records were available globally which were used to constrain the size and source mechanisms of these earthquakes. Tsunami waveforms were recorded on Japanese tide gauges, and leveling surveys were made near the source region before and after the earthquakes occurred. These latter data sets have recently been used to obtain detailed slip distributions, which suggest that the earthquakes may have been larger than indicated by the earlier seismic waveform analysis. Also, the most recent results suggest that the 1946 Nankaido event may have been much larger than the 1944 Tonankai event, in contrast to the earlier seismic results suggesting that the earthquakes were of similar size.

In this talk we re-examine the teleseismic waveforms recorded at the time of these earthquakes to evaluate their consistency with the more recent slip distribution determinations. Synthetic seismograms are calculated using slip distributions obtained from recent studies, and the expected amplitudes and durations are compared with the observed waveforms to determine which slip distribution models are consistent with the seismic waveform data.

# METHODOLOGIES FOR TSUNAMI WARNING USING BOTTOM OBSERVATION DEVICES - STATE OF THE ART

*L.A. Mendes Victor, L.M. Marques Matias, CGUL - Centro de Geofísica da Universidade de Lisboa*

The site generation of earthquakes by earthquakes was considered an important target to improve the knowledge of this natural disaster and the call from the EC to stimulate research activity on the subject was accepted by the Iberian colleagues by the middle of the last decade. As a matter of fact the world known 1st November 1755 earthquake and tsunami motivated the first attempt to design a Destructive Earthquake and Tsunami Warning System (DETWS) funded by the European Community.

The historical research is teaching us about the probable structure responsible for this event located not far from the coast, but far enough to request special devices to survive the waves energetic field in the offshore and forcing the use of a satellite communication link. Thanks to the shallow bathymetry of the Gorringe Bank, considered the site of the 1755 event, it was decided to design the first prototype, consisting of a moored ocean buoy containing the electronic systems and providing power by solar panels and a wind mill to a set of sealed batteries. The seismic and pressure sensors are connected by cable and communications are maintained in near real-time (2 to 5 minutes delay) to the main Information Processing Centre using an INMARSAT-C satellite link. ready to be deployed by the early 90's, this system as suffered from successive delays due to lack of an adequate marine vessel. The main buoy weights 3 tons and its height (including mast and stabiliser) is over 10 m. Another trial will be done this summer.

Adequate to areas where water depth is under 100 m, this approach is not adequate to a general application. In fact, the development and deployment of deep sea observatories for long periods (exceeding 6 months) is still a very hard technological problem, not only for tsunami warning, but also for other scientific applications. From the great interest provided by INSU and IPG-Paris, a new concept has been developing for the last years, allowing for a quasi-permanent deployment of geophysical devices on the deep sea-floor. In this approach, power is deployed together with the control, processing and archiving units in the seafloor. To have data available at near real-time, a large buoy is moored at 200 m to avoid the worst wave energy and connection to a light surface buoy with an omnidirectional satellite antenna in made by a cable. This buoy assures the communications and can allow also the powering of batteries by means of a service ship. The question to be answered are still the assurance of a 3 year autonomy, the safe period needed for instruments to be deployed in remote areas were ship cruises are very rare and servicing is difficult.

In deep areas at a few hundreds km from the coast, the Japanese experience using cable technology solves most of the technological questions. This is still a very expensive solution for scientific research and current efforts follow the trial use of research vessels to deploy cables.

Thanks to the support of the EC another attempt to define a tsunami warning system, useful for medium distances generation - TREMORS System (GITEC and GITEC TWO). The method is based upon the interpretation of high dynamics seismic records obtained from adequate sites surrounding the tsunamigenic areas. The transmission of signals towards central stations is assured by satellite link. An automatic data processing received from selected seismic stations allows the fast warning of tsunami generation in the area determined by the processing system.

# SEISMOTECTONIC CHARACTERISTICS OF THE POTENTIAL SITES FOR THE FINAL DISPOSAL OF THE SPENT NUCLEAR FUEL IN FINLAND

*Jouni Saari, Fortum Engineering Ltd., Vantaa, Finland*

In accordance with the decision in principle by the Council of State in 1983 the Finnish bedrock is studied for the final disposal of spent nuclear fuel. Four sites, Hästholmen, Olkiluoto, Kivetty and Romuvaara, have been studied in detail. The seismotectonic investigations carried out at these sites are presented.

The same basic approach has been applied to each of the potential waste repository sites. The seismic characteristics of Finland suggest that an area within a distance of 500 km from the disposal site is considered large enough to include all significant seismic events. Belts of seismic activity have been identified within the study area. Kivetty lies in the middle of the relatively active Southern Bothnian Bay-Ladoga Seismic Zone.

The focus of the seismotectonic interpretation is within a distance of 100 km from the site. However, knowledge of the surrounding structures is essential when the possible seismotectonic connections between regional earthquakes and the potential repository site are investigated. Therefore, a thorough mapping of the fracture zones within a radius of 200 km from the site is performed.

In Finland, as usual in intraplate areas, the principal knowledge of larger earthquakes generally relies on macroseismic observations, whereas instrumentally located earthquakes are mainly smaller. In both cases the location error is likely to be too large in comparison to the dimensions and separation of faults. In addition, the faults, where intraplate earthquakes occur are not easily recognisable at the surface. This is because the faulting is usually several kilometres deep, and little cumulative offset occurs because of the long recurrence intervals.

Owing to the long recurrence interval, the reliability of seismotectonic interpretation of the sites will be improved rather slowly, if conventional methods are used. However, it is possible, in a relatively short term, to get regionally and statistically representative information about the regional and local seismotectonics. The study carried out in the Hästholmen site shows, that microearthquakes can be used quite reliably in studies of stress field and slip pattern as well as in the identification of active faults and the estimation of their geometry.

# DISTRIBUTION OF STRESS DROP FROM HIGH SAMPLING WAVEFORM DATA OF MICROEARTHQUAKES DETECTED BY THE OOTAKI ARRAY, NAGANO PREFECTURE

*Shigeki Horiuchi, Yoshihisa Iio, Solid Earth Science Division, National Research Institute for Earth Science and Disaster Prevention*

The Ootaki seismic array in Nagano Prefecture consists of 38 stations with a sampling frequency of 10 KHz, which is higher by about 100 times than ordinary seismic recordings. Since 1995, May, small earthquakes (Mag. 0.5-4.0) have occurred in the array area of about 15 km x 15 km. We determined values of station corrections for P and S wave arrival times and located hypocenters for 8,000 events. RMS residuals of P waves for 80% of events are less than 0.01 sec.

We plot accelerograms for many events observed at two nearby borehole stations located 3 km apart. It was found from the comparison of same event seismograms that initial parts of P waves of about 0.03 sec are similar to each other. However, there is a large difference among initial parts of P waves of different events, even though these events are located closely.

This result suggests that the source process of microearthquakes is complex and the borehole seismometers can detect this complexity. We also made comparison among P waves for many events recorded by surface stations.

It was found in this case that stations, which are not located in very hard rock, could not detect the complexity of the source process because almost all the P waves for events located closely look similar.

Since this comparison strongly suggests that we can investigate the source process of small earthquakes from waveform data observed by the borehole seismometers, we determined source parameters for 1,000 events using P wave spectrum. Assuming that the site response of the borehole station for all events is constant and can be approximated by a function of frequency, we determined values of the corner frequency and stress drop for all events, and the site response function. The following results were obtained: (1) Values of stress drop are large for earthquakes in regions with very high seismic activity. (2) Average stress drop for events at depths deeper than 3 or 4 km is larger by several times than those for shallow events. (3) There are large spatial variations in values of the stress drop for microearthquakes. (4) Stress drop for small events less than about M3 increase with magnitude.

# MONITORING SITES FOR ROUTINE STRESS-FORECASTING OF THE TIMES AND MAGNITUDES OF FUTURE EARTHQUAKES

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Variations in seismic shear-wave splitting imaging the build-up of stress before earthquakes and the release at the time of (or in one case shortly before) the earthquake have been identified with hindsight before three earthquakes in USA, one in China, and now routinely before four earthquakes in SW Iceland. One earthquake (as of 17th March, 1999) has been successfully stress forecast in real-time giving the time and magnitude of a M=5 earthquake in SW Iceland. The time-magnitude window (necessary because of errors in estimates) on 10th November, 1998 was a M>=5 soon or, if stress continued to increase, a M>=6 before the end of February 1999. Three days later (13th November, 1999), there was a M=5 earthquake within 2 km of the centre of the three stations where changes in shear-wave splitting were observed. We claim this is a successful real-time stress-forecast, as anticipated from those observed with hindsight elsewhere. Note that shear-wave splitting does not indicate potential earthquake locations, but analysis of local anomalies by IMO correctly predicted the small fault on which the stress-forecast earthquake occurred.

Such stress-forecasting was possible in SW Iceland only because of the unique seismicity of the onshore transform-zone of the Mid-Atlantic Ridge, where nearly-continuous swarm activity provided adequate source signals to illuminate the rockmass. Routine stress-forecasting elsewhere, without such swarm activity, would require controlled-source cross-well seismology between neighbouring wells. These wells would need to be comparative deep to escape near-surface attenuation and scattering.

A group of wells near Húsavík in Northern Iceland provide (approximately) suitable geometry for a such stress-monitoring site. An EU grant application has been made to test routine stress-forecasting at this site. The location is also a seismic gap on the Flatey-Húsavík Fault in the Tjörnes Fracture Zone were a M=7 earthquake is expected.

If successful (we have some confidence in its success as there are tens of thousands of individual observations and theoretical (APE) modelling consistent with the interpretation), such build-up could be monitored almost anywhere. Such stress-monitoring sites would be comparatively cheap to establish elsewhere (near the thousands of cities vulnerable to earthquakes, for example), if existing wells could be used, as near Húsavík.

# PALEOSEISMICITY IN A MODERATE TO LOW SEISMICITY AREA: THE CASE OF SPAIN

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Spain is affected by a shallow, low to moderate seismic activity. Most of the earthquakes occur above a depth of 15 km. The slip rates of the active faults range from 0.1 mm/y to 0.01 mm/y. So, the expected recurrence intervals of the large earthquakes are expected to be between 104 and 106 years. The historical catalog reaches back to 1400 with a reasonable completeness. It records 32 destructive earthquakes that caused a noticeable number of casualties (two earthquakes I=X, thirteen I=IX, and seventeen I=VIII). However, the time span covered is only an extremely short sample of the duration of the expected seismic cycles.

Therefore, the maximum earthquakes of many of the faults capable to produce large earthquakes are not registered in the catalog. One important goal in Spain is to identify and characterize the active faults capable to produce large earthquakes, either if they produced large earthquakes in historical times or not. Active faults located close or in urban and industrial areas may not have a significant historical record. Nevertheless, these faults have to be considered in hazard analysis because of the vulnerability of the nearby areas. Geological and geomorphologic techniques are clue tools in order to identify and characterize the active faults. If possible, paleoseismological analysis should also be carried out.

The Neotectonic map of Spain produced by ITGE and ENRESA in a cooperative work with different academic groups is a good starting tool. Among the academic groups working on active faults in Spain, the University of Barcelona group is involved in FAUST EU-project and subcontracted in PALEOSIS EU-project, as well as in national projects regarding this subject.

The following table summarizes the different cases to be considered in Spain:

| | Quaternary active faults | No associated faults |
|---|---|---|
| Large historical earthquakes | Yes<br>(Ex. 1884, 1829, 1427/28) | Yes<br>(Ex. 1373) |
| Small earthquakes | Yes | Yes |
| No historical seismicity,<br>but paleoseismicity present | Yes<br>(Ex. El Camp fault) | |
| No seismicity | Yes | |

Different examples will be shown in order to illustrate the methodological problems and the results obtained.

## GEONET (GPS EARTH OBSERVING NETWORK) MONITORING CRUSTAL DEFORMATION OF JAPAN

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GSI (Geographical Survey Institute) has been constructing a GPS control points network covering all over Japan since 1993. This network, GEONET, consists from about one thousand GPS observation sites with average distance between two neighboring points being 25-30 km. Data observed by the receivers at those sites are sent to data processing center in GSI (at Tsukuba) and analyzed once per day.

This network has detected a number of coseismic crustal deformation, for example that of Kobe earthquake (1995). As well as such coseismic deformation, the accumulation of observation results shows the continuous crustal movement regularly occurring on Japanese islands. Some typical patterns of crustal movements can be seen on the horizontal crustal movement vectors. The sites on the eastern and southern coast of northeast Japan seem to move toward west and northwest according to the subduction of the Pacific plate and the Philippine Sea plate. On the other hand, the northern part of southwest Japan moves toward east, according to the eastward movement of the Amurian plate. These patterns of crustal movements coincide the model constructed from the result of geodetic surveys for one hundred years. But GEONET made it clear within a few years. These results gave a large impact to the study of tectonics around the Japanese islands.

GEONET is also used for the monitoring the crustal deformation relating to the volcanic activity. Crustal deformation at east Izu Peninsula caused by earthquake swarm activities relating to East Izu Volcano was detected and showed that the amount of deformation was closely related to the seismic activity.

GEONET will be utilized as the geodetic control frame of Japan. The geodetic systems of Japan will be changed to a geocentric system in 2000.

The GPS based control points network consists the most important part connected to VLBI stations. GSI is also planning to supply observation data of GEONET for surveying and navigation through the internet and telephone line in near future.

# A TSUNAMI RESEARCH IN EUROPE AND PERSPECTIVES OF COOPERATION WITH JAPAN

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Tsunamis affecting Europe are mainly generated in the Mediterranean Sea by submarine earthquakes, but important tsunamigenic areas may be even found in the Atlantic coast facing the Hyberian peninsula. In the northern part of Europe tsunamis are mostly due to slides. Rockslides and rockfalls are the primary cause of tsunamis in Norwegian fjords, where very high and locally damaging water waves have been observed several times. In recent times, research on tsunamis in Europe has done very remarkable progresses, especially thanks to the increasing recognition among scientists and administrators that tsunamis constitute a serious hazard for European coasts and that they deserve very special attention and consideration in any policy of natural hazard mitigation and protection. The financial contribution of the European Communities has been essential to launch multidisciplinary and international projects (such as GITEC and GITEC-TWO) on tsunamis involving many European countries and made it possible to begin filling the gap that until late '80 existed between Europe and the countries on the Pacific coasts, such as USA, Russia and Japan, where a long tradition of theoretical and applied research had permitted to reach important results.

The main issues on which research was focused in Europe concern 1) collection and interpretation of data, mostly of qualitative nature, on historical tsunamis, 2) development and application of geological means to investigate tsunami deposits in order extend tsunami records back to pre-historical times, 3) development of numerical techniques to model tsunami generation and propagation, 4) studies and experimental establishment of pilot tsunami warning systems. A catalogue of tsunamis that occurred in Europe has been assembled as the results of cooperative efforts of several European groups in the form of a digital data base that can be easily used by non-expert users. The first event included in the catalogue is a paleotsunami whose occurrence was ascertained by geological analyses on tsunami deposits in Scotland an Norway. It was due to a huge submarine slide (the Storegga second slide about 6000 years BP) and affected the Norwegian and the North sea. One of the most catastrophic events is the November 1st, 1775 Lisbon tsunami, produced by a large earthquake whose source region is still not fully identified. Greece and Italy are the Mediterranean countries most affected by tsunamis. The last disastrous event that took place in Europe occurred on December 28th, 1908 in the Messina Straits and hit many important coastal Italian towns (Messina, Reggio Calabria, Catania) causing thousands of victims. Numerical simulations of several important cases have been carried out (the aforementioned Storegga, Lisbon and Messina tsunamis, as well as several others, such as the 1627 Gargano-, the 1693 Augusta-, and the 1887 Ligurian Sea-tsunami, Italy, and the 365 Cretan large tsunami, the 1961 Nice event, etc.), with the main purpose of better understanding the source mechanism and the propagation of the wave fronts approaching the coast and the coastal settlements.

The main problem that research on European tsunamis has to face is the lack of quantitative data on tsunami waves and the lack of operative experience in tsunami detection and warning. In the last decades no large events affected Europe. The last large tsunami dates back to 1956 and stroke the Aegean Sea. Cooperation with Japan would be extremely beneficial since frequency of severe tsunamis there is higher than in Europe. The last big case is the July 12th, 1993 Okushiri tsunami that produced coastal run-ups exceeding 20 meters on the coasts of Okushiri Island in the Japan Sea. Japan gained a lot of experience in studying this and other cases, for which instrumental data and after-event field survey data are available. The reconstruction of the villages completely destroyed or severely damaged by water waves posed the importance of establishing a policy of disaster prevention, mitigation and recover, whose definition and planning involved scientists, engineers, technicians, political authorities, administration responsibles and civil population. This issue is vital and Europe has a lot to learn from Japan.

# SHALLOW SEISMICITY AND DEFORMATION PROCESS OF THE CRUST IN THE NORTHEASTERN JAPAN ARC

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NE Japan is located at a typical subduction zone, and many earthquakes occur along the plate boundary beneath the Pacific Ocean. Shallow events also occur in the crust of the overriding continental plate beneath the land. Precise hypocenter locations show that shallow intraplate seismicity is confined to the upper ~15km of the crust. The cut-off depth for shallow seismicity can be interpreted as the zone of the brittle to ductile transition or stick-slip to stable-sliding transition due to increasing temperature with depth.

The cut-off depth has a large lateral variation with undulations amounting to ~5km. Tomographic imagings of seismic velocity structure give important information on the cause for this lateral variation. The brittle seismogenic zone, the upper portion of the crust, becomes locally thin in P-wave low-V areas. Exceptionally deep, low-frequency microearthquakes occur in and around low-V zones of the lowermost crust and the uppermost mantle, which are perhaps generated by deep magmatic activity. Actually, the number of low-frequency events beneath Iwate volcano has significantly increased following its volcanic activity which started last year. Distinct S-wave reflectors (bright spots) distribute in the midcrust below the brittle seismogenic zone in low-V areas. Anomalously large reflection coefficients for S-waves require that the interior of reflector bodies is filled with fluid such as magma or water in a state of super-critical fluid. Concentration of shallow microearthquakes, high topography and relatively large contractile deformation of the crust are also observed in those low-V areas. Active faults or fault planes of relatively large earthquakes are not distributed in low-V areas with a locally thin brittle seismogenic zone, but lie just along the edge or outside of them. In many cases, active faults are cut by low-V areas, or the fault lengths correspond to the areal extent of their adjacent low-V area.

These observations suggest that earthquake occurrence and deformation within the crust is governed, to a considerable degree, by the thermal regime of this volcanic arc and/or by a horizontally inhomogeneous distribution of fluid.

# EARTHQUAKE SOIL-STRUCTURE INTERACTION ANALYSIS BY TIME DOMAIN BEM AND FEM

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In the last twenty years one of the most important advances in the development of efficient procedures enabling a better understanding and evaluation of the dynamic behavior of structure-soil systems is undoubtedly the appearance and evolution of the Boundary Element Method (BEM). In this paper the application of the BEM to the earthquake analysis of foundations is addressed. The time domain formulations of BEM are reviewed on the basis of the available literature and an attempt is made to present the subject under consideration in a systematic manner. Therefore, only the major points of the BEM formulation of the SSI (Soil-Structure Interaction) problem are discussed along with some selected examples that serve the dual purpose of (i) illustrating the applicability and the effectiveness of the method. Furthermore, possible directions for future research are also identified.

The popularity that the BEM enjoys lately among the researchers and practitioners in the general SSI area comes as a result of some advantages that this method presents over its main competitors, the Finite Difference Method (FDM) and, in particular, the Finite Element Method (FEM). Since in common foundation problems one is interested in finding the displacements and the stresses at the contact surface between the soil and the foundation only, use of the BEM, along with the appropriate fundamental solutions, requires a discretization of this contact surface only. As a result, the dimensions of the problem are reduced by one, a minimum amount of surface discretization is used, true three-dimensional (3D) analysis becomes feasible, and most importantly, the radiation condition is effortlessly taken into account since it is automatically contained in the fundamental solutions. These are distinct advantages over the FEM and FDM which require a discretization of not only the boundary but of the interior of the domain of interest as well. Moreover, in order to represent the semi-infinite soil medium with a finite size model both the FEM and the FDM introduce artificial wave-reflecting boundaries and, thus, resort must be made to either extensive volume discretization of the soil medium underneath the foundation, or to special devices, e.g. non-reflecting boundaries, infinite elements, etc., in an effort to account for the radiation condition. None of these improvements succeeds in completely eliminating the problem, and in fact they complicate the application of the FEM and the FDM and make them rather uneconomical.

The present article concentrates, in the context of a substructure formulation, on the theoretical formulation and the numerical implementation. of the BEM in simulating a 3D linear elastic, homogeneous and isotropic half-space. Reference will also be made to the formulation of the analogous 2D SSI problem. The representation of the foundation substructure is undertaken and both surface and embedded foundations, rigid or flexible, are studied. The discussion of the coupling of the two substructures, i.e. the soil and the foundation, is undertaken and two possible cases of dynamic excitation, i.e. external loads and seismic waves, are examined. Numerical results for selected foundation problems in the time domain are presented. Reference to some topics of special interest is made in and the subjects of viscoelastic, anisotropic and layered half-spaces are discussed.

# OCEAN BOTTOM SEISMOGRAPHIC SURVEY IN ICELANDIC SEA CONDUCTED BY A COOPERATION BY JAPAN AND ICELAND

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Iceland is located on one of mid ocean ridges. Also Iceland is immediately above a hot spot. Because of this situation lots of earthquakes and volcanic eruptions have been taking place in and around Iceland. However, it is scientifically not enough to study earthquake and volcanic eruptions only in Iceland. Because Iceland is only a small island on a mid ocean ridge plunging above sea level, it is important to study sea bottom around Iceland in addition to study on Iceland. Hence scientific studies in Icelandic Sea are needed to clarify whole geophysical process which is going on in and around Iceland, which is unquestionably indispensable to mitigate seismic risks in Iceland.

As a cooperation with Icelandic scientists, who belong to Icelandic Meteorological Office, Iceland University and Icelandic Energy Authority, we Japanese have five times made dense OBS (Ocean Bottom Seismograph) array observations of microearthquakes, and controlled source seismology experiments (to study crust and upper mantle structure) in the vicinity of Iceland in 1990, 1991, 1994, 1995, 1996 and 1997. Most of the OBS experiments were made together with temporal land-based seismographs ran by Icelandic scientists. In these experiments we brought 15-30 OBS from Hokkaido University and Icelanders offered ships to deploy/recover OBS. The OBS are small, inexpensive and dependable instruments which have been developed in Hokkaido University. Also we are planning to make another dense OBS experiment in 2000. Some of the OBS experiments were also cooperations with scientists from Cambridge University, UK, and University of Bergen, Norway.

Aside from Icelandic Sea, we have made similar dense OBS experiments in Azores islands region, Bay of Biscay, Norwegian Sea, Barents Sea and Arctic Ocean in 1987, 1988, 1989, 1992, 1993, 1995, 1998 and 1999. These OBS experiments are cooperations with University of Lisbon (Portugal), University of Paris (France), University of Hamburg (Germany) and University of Bergen (Norway), Cambridge University (UK) Geophysical Institute of Polish Academy of Sciences (Poland) and Alfred Wegener Institute (Germany). The number of OBS put in an experiment was 18 - 93.

In these OBS studies, variability of seismic activities, crust and upper mantle structures of Mid Ocean Ridges, history of opening of Atlantic Ocean (after its birth of ca. 60 Ma ago), weakening history of Icelandic hot spot, tectonics of triple junctions, etc. have been tackled.

Reference: Shimamura, H., Stefánsson, R., Mochizuki, M., Watanabe, T., Shiobara, H., Gudmundsson, G., Einarsson, P., 1996. Northern Reykjanes Ridge microseismicity revealed by dense OBS arrays. In: Seismology in Europe, edited and published by European Seismological Commission, 701 pp., 491-497.

# EVALUATION OF SEISMIC ACTIVITY BY THE EARTHQUAKE RESEARCH COMMITTEE OF JAPAN

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The Earthquake Research Committee (ERC) was established as a part of Headquarters of Earthquake Research Promotion after the Hyogo-ken Nanbu Earthquake of 1995. It holds monthly regular meetings and extra meeting in case of need for evaluating the current state of seismic activity in Japan. The results of the evaluation are made public through press conference and home page immediately after the meeting.

When an earthquake of high intensity occurs, information of probable aftershocks is very important to prevent damage expansion and to reduce people's anxiety. From this viewpoint ERC proposed an evaluation method of aftershock probability in April, 1998, and the aftershock probability based on the method is to be announced by ERC and/or Japan Meteorological Agency since then.

ERC also conduct the long-term evaluation of seismic and crustal activity. As the first step, the committee published a book "Seismic Activity in Japan - Regional Perspectives on the Characteristics of Destructive Earthquake" in 1997 (Abbreviated English version was published in 1998). In addition, faulting properties of approximately 100 major active fault zones in Japan are under examination for the evaluation of earthquake occurrence. Up to now the evaluation results on the Itoigawa-Shizuoka Tectonic Line fault system, Kannawa and Kozu-Matsuda fault zone and Fujikawa Kako fault zone, each of which is one of the largest and most active fault zones in Japan, has been publicized. However, evaluated time of the future faulting event is described only in vague expression such as "within several hundred years". On the other hand, in order to provide more useful information for administrators and engineers the Subcommittee for Long-term Evaluation has proposed a method for probabilistic estimate of an earthquake occurrence on the basis of recurrence time data in January, 1999.

One of the biggest contribution of earthquake research to mitigation of damage would be to show seismic hazard maps. The government of Japan formally established "Comprehensive and Basic Policy on Earthquake Research" in April, 1999, saying that the seismic hazard mapping by synthesizing the estimates of occurrence probability and of strong ground motion of anticipated earthquakes is one of the major goals. The ERC and relating organizations are in actions to realize it.

# RAPID SEISMIC DATA EXCHANGE FOR ACCURATE DETERMINATION OF EARTHQUAKE PARAMETERS

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In order to obtain, in a rapid manner, reliable technical information on earthquake location, depth and strength, it is indispensable to operate a real-time warning system. This paper is focused on the results of an EC-funded project intending to provide such information. The new operational system is based on the upgrade of an existing scheme currently in operation at the European-Mediterranean Seismological Centre (EMSC).

At the start of the project, the EMSC could rely on the contribution of 21 seismic networks providing their data rapidly after an event detection. Most of these detections where obtained through real-time processes leading to the automatic computation of hypocenter parameters. These were sent by electronic mail to the EMSC where they were automatically passed. Messages for seismic events with a magnitude greater than 5.5 would trigger an alert which is sent to the seismologist on duty. After merging all the information available and validating the result, the seismologist on duty would send this information to interested users (European authorities, national and regional seismological laboratories, individuals).

In the framework of the project, numerous improvements were brought to the system. By bringing more seismological observatories into the system, the coverage of the whole European-Mediterranean region has been much improved, in particular in areas of high seismic hazard such as North Africa, Strait of Gibraltar, Greece and Romania. Furthermore, this better coverage of the region allows the EMSC to lower the threshold of alert triggering down to 5.0 in some instances. By improving the location software used at the EMSC, both epicentral and depth coordinates can now be estimated with greater accuracy. Finally, this project has defined the basis for a reference magnitude estimation which can now be used when alerts are being triggered.

Specific to this project is the direct connection between the results obtained and an operational application of these. Indeed, all the deliverables from the project have now been included into the new system in use for continuous seismic monitoring at the EMSC. Events recorded in the recent months have clearly demonstrated the benefits of the new system. For example, the Romania event of April 28, 1999, was accurately located at 148 km depth in less than one hour. This was made possible thanks to all the data collected within 30 minutes of the quake's occurrence and to the new location software using local velocity models. All the data available at the EMSC are displayed on the Web page in real-time for public access. All the results from data processing at the EMSC is also available on the Web page.

In conclusion, the project was successfully completed. It provides Europe with a new and upgraded alert system for $M > 5$ earthquakes. The scheme used is a very decentralized one, favoring local data processing and concentration at the EMSC of pre-processed data. This scheme has proven to be very efficient over its 5 years of operation. It could easily be extended to Japanese agencies for the mutual benefit of both Europe and Japan.

# A PROCEDURE FOR RELIABLE SEISMIC HAZARD ASSESSMENT IN THE SOUTH BALKAN REGION

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A procedure has been developed and applied for time dependent and time independent seismic hazard assessment in South Balkan region (34° N – 43° N, 18° E – 30° E), which includes Greece, Albania, south F. Yugoslavia, south Bulgaria and western Turkey. In this procedure, there are taken into consideration seismicity parameters at seismogenic sources, anisotropic radiation at these sources, attenuation along the wave path and site effects. Seismogenic sources have been determined by the use of all available information on active tectonics of the area, while seismicity parameters in each source are calculated by the use of instrumental and historical data and the application of a time independent seismicity model (exponential distribution of magnitudes, Poissonian distribution of the recurrence time) and of a time dependent model (time predictable model, lognormal distribution of repeat times). Anisotropic radiation at the source based on rupture (fault) zones are defined by several kind of relative data (surface fault traces, fault plane solutions, macroseismic data, etc.). Attenuation relations and site effect estimations are determined by the use of a huge number of macroseismic observations (35000 macroseismic intensities) and a satisfactory sample of strong motion accelerometer records. This improved procedure has been applied for time independent and time dependent seismic hazard assessment in this region and making the calculations by a properly modified version of the EQRISK computer program.

An effort has been made to further improve our knowledge on the time dependent seismic hazard assessment. This has been made by the use of other seismicity models. It is shown that the critical earthquake concept, which suggests that the cumulative seismic strain increases with time according to a power law before a main shock, can be used as a base for an alternative methodology for time dependent seismic hazard assessment.

# ACTIVE FAULTING, EARTHQUAKES AND DEFORMATION-STRESS FIELDS — FROM THE MID-ATLANTIC RIDGE (ICELAND) TO A COLLISION BOUNDARY OF SOUTHEAST ASIA (TAIWAN)

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In this abstract, three problems related to seismotectonically active structures are addressed successively, based on comparative case studies from Iceland (rifting and transform motion) and Taiwan (collision and subduction):

- the temporal behaviour, discontinuous or not, of major fault zones (earthquakes vs creep);
- the effect of crustal-lithospheric discontinuities in the distribution of stress-strain fields;
- and the relation of these stress-strain fields to plate motion.

Fault zones where major earthquakes and quiet periods alternated are present in the South Iceland Seismic Zone, an E-W transform fracture zone that connects the rifts of eastern and southwestern Iceland. Normal and strike-slip faulting are represented, with a variety of trends, for both the recent fault traces and the focal mechanisms of earthquakes. Multiple stress regimes are represented by heterogeneous data sets, with normal and strike-slip faults consistent with a single direction of extension. Opposite stress regimes involve perpendicular directions of extensions, and even reversals in deformation. The stress states reconstructed from recent faulting and earthquake focal mechanisms are similar, but the larger amount of strike-slip in the latter case is consistent with an evolution of the tectonic regime from rift-type pure extension to left-lateral transform motion. That elastic behaviour plays a major role in the South Iceland Seismic Zone is illustrated by large amounts of deformation occurring during large earthquake crises. In contrast, continuous motion took place in the absence of large earthquakes for several tens of years along the active Chihshang Fault, a segment of the NNE-SSW Longitudinal Valley fault zone of eastern Taiwan, the present-day plate boundary between the Philippine Sea Plate and Eurasia. This is illustrated for 1996-1999 by accurate measurements of active deformation. Annual records of displacement revealed extreme concentration of shear on a single fault, with a rather constant velocity of 2.7 to 3.7 cm/yr including transverse shortening (1.8 cm/yr), left-lateral strike-slip (1.3 cm/yr) and relative uplift (1.5 to 3 cm/yr). These local results, consistent with geodetic and tectonic analyses, account for 27% of the N54°W total shortening between the Luzon Arc and South China. In terms of earthquake prediction, the Chihshang Fault case shows the importance of continuously surveying active faults where creep motion concentrates, in order to detect stress-strain accumulation before major earthquake crises. On the other hand, the example of the South Iceland Seismic Zone illustrates the importance of understanding how stress concentration zones move within a complex fracture zone undergoing a succession of major earthquakes.

The case of the active Tjörnes Fracture Zone of Iceland, a N120°E right-lateral transform zone that connects the rift of northeastern Iceland and the northern Mid-Atlantic Ridge, reveals the high variability of tectonic and seismotectonic regimes, despite the relative simplicity of the kinematic pattern. As for the South Iceland Seismic Zone, couples of opposite stress regimes are reconstructed, with major and minor directions of extension. More complexity results from the presence of two major groups of stress regimes, at different angles to the transform direction, indicating moderate mechanical coupling with E-W extension and very low mechanical coupling with NE-SW extension. Abrupt variations in mechanical coupling result in complex intricate stress patterns. In the case of the active collision zone of Taiwan, the mechanical modelling analysis carried out in terms of finite-element and distinct-element methods shows how far the presence of major weakness zones influences the regional distribution of tectonic stresses (as constrained by inversion of fault slips and earthquake focal mechanisms) and that of present-day deformation (as revealed by GPS positioning studies).

At a wider regional scale, the reconstruction of regional stress-strain patterns based on consideration of large data sets concerning recent-active fault slips, focal mechanisms of earthquakes or GPS-based velocity vectors reveals large variations related to the shape of the plate boundaries. This is the case for active collision in Taiwan, where a fan-shaped pattern of compressional stress trajectories around the NW-SE direction of plate convergence is consistently highlighted by (1) the inversion of brittle tectonic data, (2) the inversion of focal mechanisms of earthquakes, and (3) the analysis of GPS-based velocity vectors which furthermore reveals the importance of lateral escape at belt tips. Especially, consideration of relocated large earthquakes allows better definition of the seismogenic structures related to collision and subductions in and around Taiwan. This is also the case in the oceanic rift zones of Iceland, where the inversion of a total data set of about 50,000 double couple focal mechanisms of earthquakes reveals regional deviations as large a 40° in the direction of extension near the major transform zones (clockwise for the South Iceland Seismic Zone, counterclockwise for the Tjörnes Fracture Zone), relative to the N104°E trend of plate separation across the Mid-Atlantic Ridge.

This abstract is based on results of various studies principally supported by the France-Taiwan cooperation framework (IFT-NSC) for the active collision in Taiwan, and by the French Polar Institute (IFRTP) and Prenlab project (European Community) for the active rifting in Iceland. The senior author also thanks. the Institut Universitaire de France for providing support to his research.

# GEOCHEMICAL SEISMIC ZONATION PROGRAMME (GSZ). AN INTRODUCTION OF GEOCHEMICAL METHODS FOR THE RECOGNITION OF ACTIVE FAULTS. RESULTS AFTER TWO YEARS RESEARCH

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Recognising an "active fault" and distinguishing it from one which is "inactive" is one of the most important problems facing geology today, for fault activity dictates all safety and zoning issues for seismically active areas. The many criteria proposed in the past for defining active faults do not provide a universally accepted definition because these criteria are based on completely different approaches, because areas show different styles of seismicity and because interpretation can be subjective. The lack of an agreement on a single definition has caused confusion as well as geological, engineering, social and legal difficulties. Recent advances in the study of fluid geochemistry related to seismology have shown the potential of this method, for both fault activity and earthquake prediction. The importance of fluid geochemistry is rooted in the fact that the earth is an enormous open system and that fluid-releasing crustal phenomena are the major means for the exchange of matter and energy at different depths. As such, a fluid-releasing channel like an active fault is actually a "window" on subterranean physical and chemical variations in seismically active regions. This can result in sharp variations in the concentrations of some gaseous and /or aqueous species in soil-air and groundwaters due to the evolution of the local stress regime. Based on these variations a *geochemically active fault zone* has been defined as an areal belt characterised by anomalous fluid discharge (either in space or time) with respect to the surrounding geochemical "background". In this sense an *"active fault zone"*, defined in a strictly tectonic sense (i.e. by paleoseismology, neotectonics, etc.) may or may not correspond to a geochemically active fault zone. It must be remembered, however, that a strict link does exist between recent fault activity, the fluid bearing properties of the faults and the ascent of deep-seated fluids. In addition to the fact that these various geochemical species may be used as tools to better understand the subsurface stress-stain regime, enhanced upward fluid migration may also result in an increased environmental hazard, particularly in urban districts. In particular soil gas is well suited to different-scale studies (particularly in urban sites) because it is not restricted by the presence of water wells or springs. Groundwater surveys can, however, aid in the interpretation of soil gas data by outlining deep input along active faults (i.e. deep helium).

The integration of geochemical data with other geological and geophysical techniques is rarely undertaken and data interpretation usually involves only basic statistical treatment. The present study has endeavoured to address these deficiencies by applying a multidisciplinary approach to areas having diverse geological and tectonic environments, and then interpreting the results with state of the art geostatistical programs. The study has advanced the method, particularly in terms of interpretation, and provides a significant database on which future studies can be built.

# SEISFAULTGREECE: AN EU PROJECT ON ACTIVE FAULTING AND CRUSTAL AND UPPER MANTLE STRUCTURE IN GREECE

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The SEISFAULTGREECE project was a multidisciplinary effort towards a better understanding of (a) the active faulting and deformation process of the area around the Gulf of Evia island and (b) seismological observations for structural studies of the Aegean region. From the very first design phase of the project, it was realised that the key-issue of this ambitious effort was the collection of as many accurate and precise as possible relevant data. This is the only way to be able to identify and map active discontinuities that could generate earthquakes and to study the geodynamics responsible for the creation of these faults. The accomplishment of such an effort is directly related to the seismic hazard mitigation and risk reduction, which are of vital importance for an area with the highest seismicity in Europe, like Greece.

With these in mind and thanks to the EU approval and generosity, the targets of this project were to a satisfactory degree accomplished. Thus, in the area around the Gulf of Evia:

a. Detailed tectonic work was conducted by the I.P.G. Paris, Grenoble and NOA, including field reconnaissance, satellite imagery and geological map analysis. This work provided the tectonic frame for Evia. Faults and their kinematics were also mapped.
b. Geodetic work including installation of GPS network and re-survey of existing pillars that were installed 20 years ago was conducted by Grenoble, Paris and NTU Athens. This laborious work gave valuable information about the deformation of the Evia system.
c. Detailed seismological work by installing 60 seismological stations, most with 3-component seismometers, in 2 parallel profiles across the Gulf of Corinth and the Gulf of Evia for a period of 6 months was conducted by Paris and the Univ. of Athens, Thessaloniki and Grenoble. During this period more than 700 teleseismic events with M>5.0 were recorded. The inversion of P-travel times gave a 3D-velocity structure that shows a strong velocity anomaly beneath the Gulf of Corinth in contrast with the Gulf of Evia. The huge amount of good quality data is still under investigation subject of 2 PhD thesis.

The second target, that of studying the structure of the Aegean area, was tackled by installing 28 broadband seismological station on different islands of the Aegean and coastal areas of Greece for a period of 6 months, conducted by the Univ. of Athens, Thessaloniki, Grenoble and Cambridge. More than 105 teleseismic events with M>5.5 and hundreds of local events were recorded giving thus valuable data for surface wave and mantle anisotropy studies using SKS splitting techniques, subject of 2 PhD thesis, and several presentations at international meetings.

Detailed results from the project will be presented and discussed during the workshop.

# AN INTERDISCIPLINARY APPROACH TO SEISMIC HAZARD ASSESSMENT IN GREECE

*Professor Paul Cross, Department of Geomatic Engineering, University College London*

This talk describes and reviews the progress of a European Commission FP4 (Climate and Natural Hazards) funded project entitled GPS Seismic Hazard in Greece (SING), in which a major international interdisciplinary consortium is investigating and comparing strain derived using both geodetic and seismic methods. The SING project will run for three years and was started at the end of 1997. Seven main partners from five countries and the disciplines of geodesy, geology, seismology and geophysics are involved.

Greece lies within a region of intense intra-plate deformation with on average eight M5 earthquakes per year. The specific objectives of SING are; to assess the spatial and temporal accumulation of strain throughout Greece, to identify areas of high seismic hazard, to develop new and more efficient operational and computational methods for GPS, and to improve our understanding of the relationships between geodetic strain, the seismic catalogue and geological data.

New GPS networks have been installed and will be observed annually in regions of significant seismic hazard where there are little or no prior GPS studies; Chalkidiki, Patras, Saronic/Argolic Gulfs and the Southern Peloponnisos. Further measurements will be made at existing GPS networks where extra observations will add significantly to the strain picture. Approximately 300 monuments are observed annually with GPS by the project team. The project utilises a novel approach to GPS data collection whereby a few receivers occupy a large number of stations in a quasi-continuous fast, accurate and cost-effective manner.

To date, a primary result of SING is the integration of 33 historical geodetic data sets to provide a national strain map. Results from twelve different networks have been combined in a common reference frame. The results give the first full picture of geodetic strain throughout Greece and provided the basis for the setting up of the new geodetic networks. Processing of the first years' GPS observations is well under way using both the GIPSY and Bernese scientific GPS processing packages. The rates of crustal deformation in some specific seismotectonic zones have been estimated from the moment tensor mechanisms of earthquakes. These rates will be compared with the geodetic velocities once final values are determined.

# EVALUATION OF THE POTENTIAL FOR LARGE EARTHQUAKES IN REGIONS OF PRESENT DAY LOW SEISMIC ACTIVITY IN EUROPE

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In continental zones of Europe with low tectonic deformation, surface coseismic deformations or ruptures were up to very recently unknown and considered to be improbable. Active faults remain largely unidentified and the potential for large earthquakes totally unknown. Then the problems to solve are different from that encountered in active zones. To identify active faults is a difficult problem mainly because the morphological expression is often not clear due to the low level of deformations, the climatic regime and the strong anthropic activity. On the other hand, the interpretation of deformation and their dating are very complex due to the probable long duration of the seismic cycle which produce and intercorrelation between tectonic and climatic events. In this context, the PALEOSIS-project is the first real collaborative work in Europe dedicated to elaborate methodologies to evaluate the potential for large earthquakes in low tectonic deformation areas of Europe.

In the framework of the project, new approaches in paleoseismology were proposed. The first aspect was to combine detailed geomorphic and geologic informations to identify active faults and to have a first idea of its activity. The second aspect was to use geophysical methods to locate precisely the faults and obtain his image near the ground surface. Finally, to study trench exposures to analyse in detail the fault activity and the related paleoearthquakes.

This methodology seems appropriate in the Lower Rhine Embayment where active faults have been identified in Belgium (Bree fault scarp), in The Netherlands (Peel Boundary fault) and in Germany (Rurrand fault). At least for the Bree and Peel faults, post late-glacial activity is suggested or well-documented.

In the Upper Rhine Graben (France), the identification of active faults is complicated by the important deposition of loess during the two last glacial ages and the fact that it is not proved that at the present time extensive deformation plays a dominant role. In this region information was obtained on the average deformation rates since 400 to 450 ky along the Achenheim-Hangenbieten fault scarp, but up to now the identification of recent activity of the fault was not possible.

In the Pyrenees and the Eastern Alps (Italy), data related to active tectonics are generally difficult to find due to the strong exogenic remodelling of the landscape caused by the Late Pleistocene glacial activity and the subsequent fluvial regime. Moreover, such evidence may only be related to a short time interval which coincides with the last 10,000 - 18,000 years. The complexity of the geologic history, the differences in the present-day tectonic context compared to the Rhine Graben areas and the difficulties to identified scarplets in mountaneous areas give less easy the search for evidence. In this case, one of the basic idea applied in the eastern Alps (Italy) and in the Pyrenees (in Spain) is to start with different kind of informations like historical strong earthquakes and archaeology. For example, it has been shown in Italy at Egna site evidence of two dated coseismic ruptures, the most recent one having occurred around the middle of the 3rd century AD. The study of the Amer fault which is likely associated to the first strong earthquakes of the seismic sequence of 1427-1428 in Catalogna, is an other example of investigations based at the begining on a detailed knowledge of historical seismic activity.

In the framework of the project, a detailed investigation in Belgian caves has been undertaken to present scientific arguments that broken and (or) deformed speleothems can be used to retrieve strong earthquakes of the past. It is important to develop such a methodology because caves provide an environment of exceptional preservation of paleoenvironmental and paleoseismicity information with respect to the weathered landscape outside and in many regions of the world could be the unique source of information of past strong earthquakes.

# PERMEABILITY STRUCTURE OF THE NOJIMA FAULT, JAPAN, FROM BOREHOLE AND CORE MEASUREMENTS IN GSJ BOREHOLE CROSSING

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After the 1995 Hyogoken-nanbu (Kobe) earthquake, Geological Survey of Japan drilled a 746.7 m deep borehole to penetrate the Nojima fault. The drill site is 74.6 m apart from the trace of the surface break. The fault zone is characterized by altered and deformed granodiorite from 426.1 m to 746.7 m, with coaxial zone of fault gouge at 623.3 m to 625.1 m. Permeability distribution in the fault zone was evaluated from the tube wave analysis and Stoneley wave reflection, attenuation and slowness analysis. Stoneley wave analysis shows permeability increase in the fault zone. Both the hydrophone VSP data and the Stoneley wave analysis show several tube permeable zones at three gouges and cataclasite within the fault zone. The tube wave analysis at 624 m shows the permeability of the coaxial zone is estimated as a few darcies. We measured matrix permeability of core samples. We find a strong correlation between permeability and distance from the fault coaxial zone. The width of the high permeabile zone (approximately 20 to 40 m) is in good agreement with fault zone width inferred from trapped wave analysis and borehole results. The fault coaxial zone contains clays with permeability of approximately 0.1 to 1 microdarcy at 50 MPa confining pressure. Outside this zone, matrix permeability drops to sub-nanodarcy values. These permeability observations are consistent with fault zone model in which a highly localized permeable zone is surrounded by a damage zone of fractured rock. In this case, the damage zone will act as a high permeable conduit for vertical and horizontal flow in the plane of the fault. The clay gouge, however, will impede fluid flow across the fault.

## THE DEEP SEISMOLOGICAL LAB IN THE KTB BOREHOLE

*Frank Scherbaum, University of Potsdam*
*Michael Weber, GeoForschungsZentrum Potsdam*
*Guenter Borm, GeoForschungsZentrum Potsdam*

Supported by the Deutsche Forschungsgemeinschaft within the ICDP/KTB-Program and the GeoForschungsZentrum Potsdam, a 1 Hz three-component seismometer has been installed in the pilot hole of the KTB borehole. Primary goal of this joint project between the GFZ and the University of Potsdam is the continuous recording of local and teleseismic earthquakes simultaneously at a depth of 3827 m and at a surface station. In the second phase, an additional low frequency seismometer will be installed below 7500 m in the KTB Main Borehole.

Scientific intentions range from the investigation of propagation effects in the upper crust, the monitoring of crustal properties, the study of site effects to the investigation of source properties of local events and the study of the attenuation properties of the inner core.

Since the beginning of operation in November of 1997, numerous regional and teleseismic events as well as local and regional quarry blasts have been recorded simultaneously at depth and at the surface. The analysis is currently under way and first results will be presented at the workshop.

# REAL-TIME ANALYSIS OF MICROEARTHQUAKES IN THE SIL SYSTEM - AT PRESENT AND ONGOING DEVELOPMENT

*Reynir Bödvarsson, Uppsala University, Sweden*

The SIL seismic network has been in operation since 1990 and has been under continuous development during the operational period. Among the major achievements is the capability of the network to automatically determine source parameters of a large amount of earthquakes within few minutes from the origin time. Other important features of the SIL system are: high quality three component data, cost-effective operation and the cost effective off the shelf hardware technology used.

The major goals for the design of the system were to minimize the investment and operational cost of the system while retaining full detection capabilities and highest possible data quality. To achieve this, the system operation is highly automatic in order to minimize the analyst's workload and utilizes intelligent site stations to minimize data transmission cost.

The system has been further developed within the project Earthquake Prediction Research in a Natural Laboratory (PRENLAB and PRENLAB-TWO) supported by the European Union within the 4th framework of Environment and Climate. In this paper an attempt is made to give an overview of the present version of the data acquisition system and describe some of the enhancements currently being worked on. New features of the system include a geographically indexed database, stress tensor inversion software, interactive tools for fault movements analysis and the continuous ground motion monitoring software. Some of these concepts have been implemented while others are under development.

The focus in this research has been to achieve a data acquisition system that can cope with the large amount of earthquakes per time period providing instantaneous information about the ongoing deformation processes through the information carried by the microearthquakes. All progress in research on the microearthquakes should have the potential to be implemented in the automatic operation of the network. This is mainly due to the fact that the critical information regarding in timing of the large earthquakes is probably to be found in the large amount of microearthquake activity close in time to the main shock.

In this talk the main focus will be put on the questions regarding the data acquisition and its associated automatic and manual procedures. The knowledge gained from the manual operations involved in the network operation is gradually moved into the automatic procedures performed by the site computers and the computation facilities at the center. Extensive geophysical knowledge gained from the above research projects is used in the automatic procedures in the SIL data acquisition system. Attempt is made to utilize this knowledge to implement real-time procedures that can be of use as early warning system.

# POLICY FOR EARTHQUAKE RESEARCH PROMOTION IN JAPAN

*Noriko Kamaya, Earthquake Research Division, Research and Development Bureau, Science and Technology Agency*

In the light of the Great Hanshin-Awaji Earthquake Disaster, the Special Measure Law on Earthquake Disaster Prevention (implemented on July 18, 1995) was passed to protect the people's lives and properties from disasters caused by earthquakes. According to this law, the Headquarters for Earthquake Research Promotion was established under the Prime Minister's Office for unified promotion of earthquake research.

The Headquarters are conducting the following mandate concerning earthquake research.

1. Planning comprehensive and basic policies.
2. Coordinating administrative works such as budgets for relevant (administrative) bodies.
3. Formulating comprehensive survey and observation plans.
4. Collecting, arranging, analyzing and comprehensively evaluating the results of surveys by relevant administrative bodies, universities, etc.
5. Public relations based on the comprehensive evaluations.

Under the Headquarters, there are two subsidiary committees. They are Policy Committee and Earthquake Research Committee. Policy Committee is deliberating on mandate 1, 2, 3 and 5. On the other hand, Earthquake Research Committee is entrusted with mandate 4.

For mandate 1, Subcommittee for Comprehensive and Basic Policies established under the Policy Committee discussed and formulated "Comprehensive and Basic Policies for Earthquake Research Promotion".

This report made the aim of earthquake research clear to be prevention and/or mitigation of earthquake disaster. For this aim, this report stresses importance of promoting cooperation between earthquake research and earthquake disaster prevention. This is from our reflection which cooperation was not enough before Great Hanshin-Awaji Earthquake Disaster. In addition, this report also stresses that effort for earthquake prediction should be kept steadily. In Japan, especially after the Great Hanshin-Awaji Earthquake Disaster, pessimistic views on earthquake prediction have been prevailing even among seismologists. However, we recognize earthquake prediction could mitigate damage caused by earthquake, if it succeeded.

For approaches to the aim, following concrete earthquake research is promoted for a next decade.

1. Survey of active faults, Long-term evaluation for earthquake occurrence, and Estimation of strong motion. They should be connected to making of Estimation Map for Earthquake Strong Motion.
2. Real-time seismology.
3. Observation around Tokai region. The region is a central part of the Honshu (Main Island), which is considered to be the area where a devastating earthquake, the Tokai Earthquake, is imminent to occur.
4. Observation and Research for earthquake prediction.

On the basis of this report, Japanese earthquake research is promoted with the objective being disaster prevention/mitigation.

For further information is provided on www. The URL is http://www.jishin.go.jp/main/welcome-e.htm.

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